DAVID ROWAN

BORN 4TH DECEMBER 1822; DIED 30TH JULY 1898

TRANSACTIONS

OF THE

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IN SCOTLAND

(INCORPORATED).

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ADVERTISEMENT.

The responsibility of the statements and opinions given in the following Papers and Discussions rests with the individual authors; the Institution, as a body, merely places them on record.

ERRATA.

Page 79, line 21, *for* "soluble" *read* "insoluble."
Plate XV., fig. 10, *for* "Glas Loch" *read* "Geal Loch."
Plate XVI., fig. 13, *for* "flag staff *read* "top of ventilator."

INSTITUTION
OF
ENGINEERS AND SHIPBUILDERS
IN SCOTLAND.
(INCORPORATED.)

FORTY-FIRST SESSION, 1897-98.

PRESIDENTIAL ADDRESS.

By Mr George Russell.

Delivered 26th October, 1897.

Gentlemen,

Some few months ago, the completion of the sixtieth year of the reign of our most gracious sovereign, Queen Victoria, was celebrated with great honour throughout the whole civilised world. This present year sees also the completion of forty years of the history of this Institution, a period which is therefore exactly two-thirds of the Queen's reign. On this the opening meeting of the forty-first session, I purpose, very briefly, to review its history, and put on record some of the various changes which have occurred during this period. The lapse of forty years naturally suggests a retrospect. A great number of our members have joined the Institution recently, and to them it may be of some interest to hear of its earlier years.

The Institution was founded on 1st May, 1857, and its origin was due chiefly to a very successful summer meeting of the Institution of Mechanical Engineers, which had been held in Glasgow the previous year. The Institution of Mechanical Engineers was founded about ten years before, and at that time had its head-quarters in Birmingham, and this Glasgow visit was the first of the series of summer meetings which it has held.

Many of the leading engineers of Glasgow and neighbourhood attended this meeting; and it seemed to them that in such an important engineering centre there was an ample field for a Scottish society, and more particularly if it embraced all classes of engineers, as well as shipbuilders and founders.

Some preliminary meetings were held, and it was found that the proposal to establish a society was generally approved; and at the meeting on 1st May, 1857, a constitution was adopted, and office-bearers elected, and so "The Institution of Engineers in Scotland" came into existence.

Of the original members, at the present moment only seven remain on the roll; of the office-bearers of the first session, the only one still surviving is the secretary, Mr Edmund Hunt, who filled that office for the first seven sessions with conspicuous ability. The first president was Professor W. J. Macquorn Rankine, of whom it might almost be said that he founded the Institution, as the energy and enthusiasm which he brought to bear on its inauguration went far to establish it on its permanent basis. His opening address "On the nature and objects of the Institution," delivered on 28th October, 1857, is as applicable to us now, indicating the scope and nature of the papers to be read and discussed, as it was forty years ago.

There have been many eminent engineers associated with the City and University of Glasgow; but probably no one since James Watt has had such an extended reputation, or exerted more influence on other engineers, than Rankine. It is therefore much to be regretted that as yet, no statue or public memorial has been erected in this city to commemorate his work, although a quarter of a century has elapsed since his death.

The rules of the Institution as made by the original members remain, after all these years, almost identical to this day, and that so very few alterations have been found necessary, says much for the foresight of those who framed the rules.

In 1860 "The Scottish Shipbuilders' Association" was founded, and conducted for five years with great success. It was then amalgamated with our Institution, and the two societies met as a united body for the first time on 25th October, 1865. The title of the Institution was then changed to "The Institution of Engineers in Scotland, with which is incorporated the Scottish Shipbuilders' Association"—this name having been agreed to at a meeting held on 12th April, 1865. A joint-meeting of the two Societies was held in the Queen's Rooms, on 26th April, when the amalgamation was confirmed and office-bearers elected, Mr James Gray Lawrie being chosen president of the united Societies. In his introductory address Mr Lawrie said—"Both Societies have been conducted with singular success, and with great advantage to practical men; both have discussed and analysed practical questions of the greatest importance; both have issued volumes of transactions which suffer in no comparison that can be made with the transactions issued by any other similar bodies; and important fiscal changes in the laws relating more especially to ships, have resulted from the deliberations of these Associations."

At the meeting held on 7th July, 1870, the name of the Institution was changed to its present—"The Institution of Engineers and Shipbuilders in Scotland," and its first meeting as an incorporated body was held on 31st October, 1871. It may be noted in passing that at this meeting a memoir of Mr John Elder was read by Professor Rankine. Mr Elder was elected president for the 13th session, but died on 17th September, 1869, about a month before the opening of the session.

At the meeting on 23rd December, 1873, a considerable accession was made to the graduates' section, by the admission of the members of a society called "The Association of Engineers in Glasgow," thirty-six in number. This society originated in 1860, under the name of "The Association of Assistant Engineers in Glasgow," and only engineers in situations were eligible; but some years later, the word "assistant" was left out of the title to enable some of the members who had commenced business to continue their membership.

For the first eleven years our meetings were held in the Andersonian University, George Street; and for the following twelve years in the Corporation Galleries, Dalhousie Street. After many preliminary meetings and negotiations, a special meeting was held on 20th August, 1878, at which it was agreed to proceed to erect this building, jointly with the Philosophical Society of Glasgow; and the first meeting was held here on 2nd November, 1880.

It was announced at the meeting on 20th December, 1887, that the annual dinner in celebration of the birth of James Watt, which had formerly been held under the auspices of "The Association of Foremen Engineers," would in future, by a mutual arrangement, be held under the joint auspices of this Institution and the Philosophical Society. Accordingly the first celebration under this arrangement was held during January, 1888. The Institution and the Philosophical Society alternately made the arrangements till 1893; and subsequently, the celebrations have been managed entirely by the Institution. These annual re-unions have been highly successful. The attendance has always been numerous, affording a pleasant meeting of friends from all parts of the country. We may therefore recognise that the James Watt Dinner is permanently established as part of the proceedings of the Institution.

I have not been able to trace the origin of the Watt Dinner, or when and where the first was held. It appears to have originated with a small number of foremen engineers, who agreed to meet annually and have a supper on the Saturday nearest the birthday. Among those who had an active part in carrying it on, between forty and fifty years ago, were Mr Andrew Brown, Mr Archibald Gilchrist, Mr Thomas B. Seath (still members of the Institution), and the late Mr Benjamin Conner.

For many years before it was taken over by the Institution, the committee was composed of members of the Institution; and a large proportion of those attending were also members. Sir William

Arrol, Mr Seath, and many others attended for a long series of years without missing a single occasion.

Most institutions in this country, similar to our own, hold summer or autumn meetings in various localities or centres. These tend to increase the interest in the proceedings, and they afford opportunities to the members of seeing the progress made outside their own particular sphere. This Institution has not in the past displayed a migratory disposition. On only one occasion has it held a meeting outside of Glasgow. This was in July, 1872, when a number of our members went to Newcastle-on-Tyne and held a joint-meeting with "The North of England Institute of Mining and Mechanical Engineers." At this meeting the "Nicholas Wood Memorial Hall" was formally opened, and a statue of Nicholas Wood (who was one of our honorary members) was unveiled. Professor Rankine took a prominent part in this ceremony; it must have been one of his later public appearances, as he was then not in good health, and he died on the 24th December following. The Newcastle Institute had two years previously visited Glasgow, and held a joint meeting with our Institution in the Corporation Buildings, the proceedings of which occupy about one-half of our 14th volume of transactions. It has been proposed in the Council to hold a summer meeting soon, in some engineering centre; but the time and place are still open questions. I do not think we could hold such meetings oftener than at several years of interval, but twenty-five years having now passed another might be organised.

The progress of the Institution, with regard to membership and financial stability, has been satisfactory; although there is still ample scope for further improvement. At the close of the first session, the total number of members, associates, and graduates, was 127; at the close of the tenth session, 386; at the close of the twentieth session, 478; at the close of the thirtieth session, 636; and at the close of the fortieth session, 887. These figures do not include the honorary members, which by the rules are limited to 12 in number, and of whom at present there are 10. In the 30th volume, there is a table of interesting statistics as to membership, office-bearers, and other matters, and an index of contents of the thirty volumes, and also of the five volumes of "The Scottish Shipbuilders' Association."

The financial statement which will be laid before you at the next meeting indicates that the finances are in a good condition. Hitherto, the annual statement was made in time to be presented at the annual meeting of the session, in April. There were many disadvantages in doing this. The cost of the volume was divided between two sessions, so that it was impossible to keep the cost of each session distinct; while all subscriptions paid after the accounts were closed, figured as arrears in the following session. Now the financial year commences on 1st October, and terminates on 30th September.

The balance sheet shows that the capital accounts amount to £3,736, which includes £826 belonging to the various medal funds. The amount of the bond over the building for which the Institution is liable, has during the past year been reduced from £1,500 to £500, while the money invested, in the bank, and in hand, is £550. The books in the library have been valued at £500, and furniture and fittings at £65, both nominal figures.

I would call attention to the recommendation book which lies in the library. It is for the purpose of conveying from the members to the library committee, suggestions for the purchase of new volumes, so that the best books, as they are published, may be added to the catalogue. I may also say that the council will always be pleased to give careful consideration to any subject which may be brought under its notice by any member, tending to improve in any way, or add to the efficiency or usefulness of the Institution.

The subject next to be considered is—Has the Institution fulfilled the objects for which it was founded? In the original "Regulations" the first one was "The Institution of Engineers in Scotland shall devote itself to the encouragement and advancement of engineering science and practice, being established to facilitate the exchange of information and ideas amongst its members, and to place on record the results of experience elicited in discussion." When the Institution was incorporated the reading was somewhat altered. The second clause of the third article in the memorandum of association is as follows—"To facilitate the exchange of information and ideas amongst its members, to place on record the results of experience elicited in discussion, and to promote the advancement of science and practice in engineering and shipbuilding."

This is a wide field of operation, and affords scope for great variety. Theory and practice meet, and through interchange of ideas on the subjects discussed, each is benefited. The experienced practical engineer or shipbuilder, examines and criticises the speculations of the scientist; while on the other hand, the successes or failures of the practical man, may be explained on scientific grounds by the philosopher, thus bringing into harmony theory and practice. Again, there are many problems to be solved, which only experience can solve in carrying out practical work, and often many methods of obtaining the same results; but experience can point out the best known method, or at least one of the best, if various have been tried; and so the interchange of opinion in discussion is of the utmost importance. Much time is often wasted in making experiments and solving problems which have been settled over and over again, for want of the knowledge of what has been accomplished. To illustrate this, it is only necessary to look at the Patent Office records, to see that the same idea has been patented many times over, by persons who each believes himself to be "the first and original inventor thereof."

Discussions are consequently of the utmost importance in obtaining information; and the paper which is suggestive, and gives rise to a good discussion on any important subject, is often more valuable, even although it may be very short, than one of great length which raises little or no discussion. There are of course exceptions, and many are to be found in the volumes of our transactions, such as descriptions of important public works which have been successfully completed. When a paper describes a conspicuous success, the discussion generally takes the form of expressing admiration, there being no room for dissent. But what possesses greater interest than records of failure? I do not mean such failures as ordinary common sense could have predicted, but interesting failures, if such a term may be used, which looked promising and almost certain of success, till actually put to the test of experiment or practice, and failed in some way which was little suspected, and appeared at the outset very unlikely. The discussion on such a paper would be extremely valuable, and would often save others from traversing the same ground, and experiencing the same disappointment. There is often so little between failure and success—some missing link, as it were, that in free discussion might probably be supplied. Members therefore should bring forward their ideas, even although the printed report would occupy a very small space. The "American Society of Mechanical Engineers" have in their proceedings what they term "Interchange of data and topical discussion" when no paper is read at all, but a discussion is at once started with a very short introduction. It would enliven our proceedings very much, and make our transactions more interesting, if we were to adopt some similar procedure occasionally.

A paper which, for example, instead of describing closely, say a special machine, or a special vessel, or in civil engineering a special structure, lays down rules and proportions how such a machine, vessel, or structure should be made to fulfil certain conditions, and what modifications in construction should be introduced, if the conditions are varied, is of special interest and value; because it enables others who are giving attention to the same subjects, to compare their own practice or ideas with those of the author of the paper, and is all the more likely to lead to a useful discussion. Papers of this type have been more frequently contributed by our shipbuilding members as our transactions testify.

There is frequently to be observed a great lack of what may be termed individuality in mechanical engineering. In machines, machine tools, and engines, for example, the most notable difference is often the maker's name-plate. This clearly shows that the great bulk of manufacturers are copyists. If it were not so, divergence in design would be much more pronounced. Originality in designing, and the application of mechanical principles in machine construction, are practiced by comparatively few; the majority imitate. Discussions on general principles are therefore of much more interest and importance to the engineer and shipbuilder, who investigates fundamental principles, than a detailed description of a special example, although the latter may be more appreciated by the copyist.

The nature of the papers read and discussed, has been in the past mostly of the nature I have indicated as desirable; the discussions have generally been full and searching; and it is beyond any doubt, that the first forty volumes of our transactions are an important contribution to the literature of engineering and shipbuilding, and are of exceeding value as works of reference. I therefore claim, that the Institution has in a considerable measure fulfilled the objects for which it was founded.

In looking over the earliest volumes of transactions, it is curious and interesting to note that three subjects monopolise a great many of the papers and discussions. At that time, say thirty-five or forty years ago, important alterations and improvements seemed imminent in these subjects, from the vast amount of energy expended in their advocacy. But at the present time we do not seem to be much, if any, further advanced. These three subjects are, 1st, improvement of the patent laws; 2nd, adoption of a decimal system of measurement; and 3rd, prevention of smoke. Some improvements have been made on the patent laws, such as reducing the amounts payable in the initiatory stages, and spreading the payments following by annual instalments, but much yet remains to be done. Regarding the decimal system, the demand for it seems to have quite abated, and very little desire for a change has been apparent for many years. The smoke question has been in evidence all these years; agitations for smoke abatement are constantly recurring, but there is not much improvement. On the contrary, owing to the increase in number and extensions of public works in cities and towns, the smoky canopy is more dense than ever. On the river and firth of Clyde the scenery is obscured, and the air polluted by the steamers. There is no want of contrivances, more or less efficient, for smoke prevention, but there seems no hope of their adoption generally.

In order to still further extend the influence and efficiency of the

Institution it is desirable that suitable new members be constantly added; and I would respectfully urge upon all members to do what they can in this way. The class of associates might be very materially increased in number, as it includes every person, of whatever trade or profession, who takes any interest in engineering or shipbuilding matters, and to whom the reports of our proceedings may be interesting. The total number at present is only 47, and there is no reason why it should not be four times as many at least. The graduates' section, presently numbering 239, is fairly large in proportion; but the benefits to students and assistants, who are qualifying for membership, are such that this class should be also greatly increased. Besides the privilege of attending the general meetings of the Institution, the graduates have a series of meetings of their own, at which papers are read and discussed; and they have also the free use of the library, which to them is of special advantage.

The increase in membership, during last session, was very much more than in any previous session; and it is to be hoped that in this and succeeding sessions at least an equal increase will be recorded.

We begin the business to-night with a good supply of important papers assured, so that we have the prospect of an interesting and prosperous session. I hope the attendance will continue to improve as it has been doing of late years, and that the discussions will be conducted with that spirit and freedom requisite for eliciting information worthy of being recorded.

From the obituary in last volume, we see that we have unfortunately lost many of our number during the past year. We have specially to lament the decease of Mr Robert Dundas of the Caledonian Railway, who took a great interest in the affairs of the Institution, and also acted as president during the 34th and 35th sessions.

Recently the council have had under consideration certain improvements in the bye-laws, for the discussion and approval of which two special meetings will be convened shortly. The alterations which may then be made, and the alterations which have already been made since the incorporation of the Institution, will require the rules to be re-arranged and printed complete.

In conclusion, I have to congratulate the members that the Institution continues to flourish, and that after the lapse of forty years it has not abated, but rather increased, the vigour and enterprise of its early days.

Sir WILLIAM ARROL, LL.D., M.P., moved a vote of thanks to the President for his address.

The motion was carried by acclamation.

THE PROELL-CORLISS ENGINE AND THE PROELL VALVE DIAGRAM.

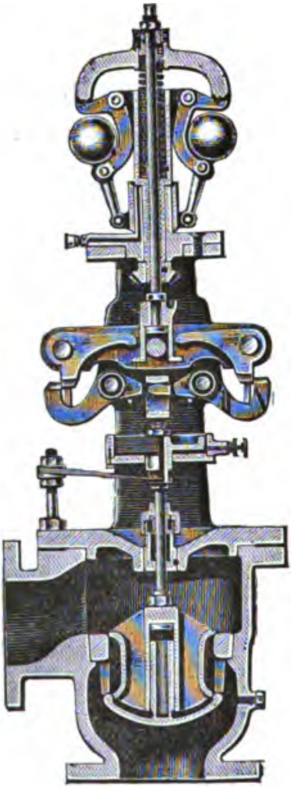
By Mr Hermann Kühne.

SEE PLATES I. AND II.

Read 26th October, 1897.

Although it may be assumed that most Members of this Institution are familiar with the construction and the working of the "Proell Expansion Apparatus," a short description of the same may be welcome, for a better understanding of the principal objects of this paper.

The Proell apparatus was originally designed to make ordinary slide-valve engines amenable to the benefits of automatic expansion. It consists of a double-beat valve enclosed in a suitable case with two flanges, one of which is fixed on the steam chest, while the other is connected with the steam supply. On the cover of the valve-case is arranged a two-legged stand, and the operating gear is fitted between the two legs, which carry on their top the governor, as shown in Fig. 1, page 14. Fig. 2 shows the expansion gear proper in mid-position, with the steel faces taken off the lifters. It consists of a double-armed lever, H, carrying the two bell-cranks K_1, K_2, which, if the lever H is oscillated, alternately engage the valve-lifters L_1, L_2; these, on being depressed at their outer ends, raise (by means of their inner ends) the valve-spindle V, and open the valve. Just before the oscillating downstroke of the bell-crank has been finished, the tail end of the bell-crank comes into contact with the tripping fork F of the governor, and releases the valve.



Figs. 3, 4, 5, and 6 illustrate the different positions of the parts of the gear during one downstroke of the double-armed lever H. It will be specially noticed that the steel faces of the bell-cranks K_1, K_2, carry each a stop, which prevent the bell-cranks from overlapping the valve-lifters more than a certain amount. The purpose of these stops is to prevent the tail ends of the bell-cranks from resting on the governor fork during the critical period when the valve V is being detached from its seat. At this point a rather considerable force has to be exerted. To ensure durability of the valve as well as tightness of closing, the seats of the valve, and consequently the unbalanced area of the same, must not be made too small. In a 5-inch valve, the area under pressure is about 4 square inches, and, taking the boiler pressure as 100 lbs. per square inch, it requires a force of 400 lbs. to detach the valve from its seat, apart from friction and pressure of the closing spring. Experience with apparatus without such stops, has shown that this force re-acts upon the governor, and throws an undue amount of work upon it. The addition of the stops relieves the governor entirely of this work, as it comes into action only when the valve is quite open and floating (entirely balanced) in steam. The governor has therefore been very appropriately called a "thinking" governor, as distinguished from a working one which has to actuate links, eccentrics, etc. The automatic action of the governor for effecting the longer or shorter cut-off, is apparent from the foregoing illustrations. The higher or lower the governor holds the tripping fork, the sooner or later the tail ends of the bell-cranks will come into contact with it, and the valve will be released at an earlier or later point of the stroke. A few words will be sufficient to explain the principle of the governor. The suspension of the balls is that of inverted pendulums, and, being guided in a peculiar manner by the hanging straps H_1, H_2, Fig. 7, the centres of the balls open out in a straight line, while in every other governor the balls open in an arc. The centrifugal force of the balls is counteracted by a strong spiral spring. It is well known that the power of such a spring increases in an equal ratio with its compression. A similar increase takes place in the centrifugal force of revolving balls in relation to the diameter of the circle in which they revolve. In order to balance spring power and centrifugal force for any position of the governor balls, the latter must move at right angles to the axis of turning. This rule is not fulfilled in any governor the balls of which open round a fixed point and describe an arc.

When first introduced, the Proell apparatus was simply fixed on the steam chest of the engine; and, as (especially in existing slide-valve engines) there is no other way to improve the regularity of speed and economy in steam, it is done to-day in the same manner, and very satisfactory results are obtained, if care is taken to reduce the waste spaces. Some types of slide-valve engines have very large steam chests, and there it is necessary to fill these up with cast iron or hard wood blocks. Fig. 8 shows a cross section of such an engine. The success of the apparatus on existing engines, and the great advantage that engine-builders were by its means enabled to buy the most delicate part of the engine ready made, led to its application on newly built engines. At first makers were satisfied to use their existing patterns, and to fill up the waste spaces as much as possible. An improvement on this plan was adopted by Messrs Westgarth, English & Co., of Middlesbrough. They fixed the apparatus with inverted valve to the steam chest, in which a piston-valve worked, cutting off the steam with the inside edges. Only sufficient space was left round the stem of the valve for the steam to pass to the ports, and the large number of engines built by that firm is witness to the excellent results obtained. The writer here wishes to anticipate a point of great importance in the Proell-Corliss engines presently to be described, which is also present in Messrs Westgarth's engine, viz., the judicious use of strong compression at the end of the exhaust, which almost entirely eliminates the otherwise harmful influence of the waste spaces. By closing the exhaust early enough, the steam remaining in the cylinder is compressed to the pressure of the fresh steam. At the moment, therefore, when the latter is admitted for the new stroke, the port is already filled with steam at that pressure, and no supply is drawn for that purpose from the boiler. With flat slides this cannot be done. There being very little pressure between the Proell and the slide-valve, the increasing compression forces the latter off its face, and, besides creating a rattling noise, loss of steam ensues. Flat springs have been used to press the slide to its face, but these result in great friction and undue wear. The piston-valve permits the use of sufficient compression, and the result is quiet working of the engine and increased economy. The objection has often been raised that strong compression takes away a considerable area of the diagram, and consequently power from the engine. Practical results and theoretical considerations prove this contention to be fallacious. The steam enclosed in the ports after the closing of the exhaust may be considered like a spring, which absorbs a certain amount of power on being compressed, but gives out nearly the same amount on being released. The effect may also be seen from the indicator diagram, Fig. 9. The full-line diagram represents the working of an engine with small waste (3%) spaces and little compression, the other of one with larger waste (15%) spaces and strong compression. The area of diagram lost by compression is restored by the higher expansion line. For the latter, however, the engine has not drawn its supply from the boiler, but from the waste spaces, as the cut-off in both diagrams is the same.

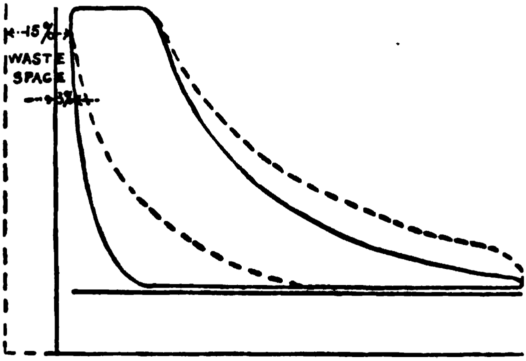


Fig. 9.

Although many engines were built according to one or the other of the above plans, it was not until the writer could submit to engine-builders the system of the Proell-Corliss combination that the Proell apparatus was used on a large scale on new engines. The principle is this, that the slide-valve is replaced by a single Corliss valve having a cavity for the exhaust, and arranged across the cylinder. The Corliss valve fills up nearly the whole of its case, leaving only sufficient space for the Proell valve to hang into a cavity, as shown in Fig. 10. The waste space between the two valves, which does not take part in the compression, is thus exceedingly small, and can be almost neglected.

The success of the system on new engines made it in turn desirable to apply it to existing engines, and in many instances this has given very satisfactory results. The application is, however, limited to such engines where (1) the cylinder is vertical and has either two open-flanged ports at its ends, or where the steam chest can be removed and the slide face laid open, or where (2) the cylinder is horizontal and has similar ports or a slide face on its top, Figs. 11 and 12.

The engines built on this plan are, as pointed out before, almost identical in economy of steam to the best examples of modern steam engines. The writer does not claim it to be absolutely the same, and quite admits the drawback that the larger clearances offer larger cooling surfaces to the steam. This can, however, to a great extent be overcome by efficient covering with non-conducting material. On the other hand, this defect is more than outweighed by the great advantage of simplicity of construction, and consequent cheapness; by the fewness and compactness of parts; and, last, but not least, by the possibility that the engine-builder can buy the most difficult, though most important, part of the engine—the expansion gear—ready made. The apparatus itself is made as a specialty by means of modern tools, and in quantities that admit of cheap production. Every Proell apparatus is tested under working conditions on a specially erected testing engine before being sent out, and is, during this test, fully adjusted to work correctly, so that perfect working is assured in practice, both as to economy in steam and to regularity in speed. As to the latter, it may be worth mentioning that a large number of Proell-Corliss engines are driving factory loads of a very variable nature, as well as dynamos for electric lighting, direct, without the use of accumulators, and this fact is proof of the excellent manner in which the speed of the engine is controlled.

THE PROELL VALVE DIAGRAM.

The question is often asked—"How far on the stroke does the Proell apparatus carry the steam? Can you obtain $\frac{7}{8}$ cut-off?" The following graphic consideration of the working of the Proell apparatus—the Proell valve diagram—gives answer to these and many other questions. Further, the diagram is of wider interest, as it is equally applicable to the investigation of the Corliss and other trip gears.

The piston has a linear reciprocating motion, while the crank describes a circle. Leaving out of consideration the finite length of the connecting rod, the relative positions of piston and crank are shown in Fig. 13. While the piston travels on the diameter AB, the crank describes the circle, and every point of the piston path corresponds with a point of the crank circle lying vertically above or below the former, as *a* with a^1, *b* with b^1, etc. In the same manner, we can trace the relative positions of the eccentric and the valve. In a slide-valve engine the circular motion of the eccentric is transferred to the linear motion of the slide-valve, and in the Proell apparatus to the vertical up-and-down motion of the bell-cranks. Figs. 3, 4, 5, and 6 show the actuating parts of the Proell apparatus. While the eccentric describes a circle, the bell-cranks perform a vertical up-and-down motion, which, for the purpose of our diagram, we can consider as a straight line. We will assume the diameter AB, Fig. 14, to represent the path of the bell-crank, then the circle with this diameter will show the path of the eccentric. In Fig. 3 the bell-crank is shown in its highest position, corresponding with the point A in Fig. 14. To ensure that the bell-crank will with certainty mount on the valve-lifter, a little margin *y* must be allowed in the upward motion of the bell-crank. If we draw this dimension from A to *m* downwards, and draw a horizontal line through *m* until it intersects the circle at D, it is evident that the eccentric must have moved through the angle *a* in order to produce the downward motion A*m*. If the turning motion of the eccentric continues, the bell-crank goes farther and farther down, depressing the valve-lifter, until a point is reached (as near as possible before the end of the travel of the bell-crank) where the latest desirable release must take place. Here, too, a little margin *z* must be allowed, so as to make sure that a disengagement of the two steel-faces takes place, otherwise the valve would only close slowly during the return stroke. We will take this point at *n*, and, by drawing again a horizontal line through the same, we find that the angle *b* corresponds with the active turning movement of the eccentric during which the valve is opened. The angle *c* corresponds with the turning of the eccentric, during which the bell-crank travels the inactive distance *z* after the release of the valve, which margin is required to ensure the tripping-off. The valve-lifter has arms of equal length, therefore the dimension *v* represents the highest lift which the apparatus can give to the valve; and it also follows that any lower lift of the valve corresponds with the turning angle of the eccentric, which we obtain by drawing a horizontal line through a point corresponding with that lift, and by connecting its intersection of the circle with the centre of the diagram. Supposing that the governor has effected a release when the bell-crank has travelled down to the extent of v^1, then the eccentric will have travelled through the angle b^1. The lift of the valve at the point of tripping-off is again $= v^1$. The same relations obtain for any intermediate position. If, for instance, the bell-crank has gone down to the centre of the circle, the gear, as well as the eccentric, stands in mid-position, and the valve-lifter is depressed to *x*, Figs. 2 and 14.

So far, we have only considered the relations between the eccentric and the valve. We have now to show the connection between these and the piston or crank.

Since we are only concerned with the effect which the relative angular position of the eccentric and crank have upon one another, we may imagine the case of an engine in which the piston and the eccentric have an equal stroke. Fig. 15 represents diagramatically such an engine, in which, by way of illustration, it is assumed that the crank disc and eccentric sheave are geared together by an intermediate wheel, and thus move in the same direction at equal speed. The crank is given a lead of 10°, and stands at D. As the eccentric now acts on a hanging arm, it pulls in a horizontal direction, and consequently we must bring the valve diagram in a horizontal position. It is now clear that, to ensure the valve opening when the crank is 10° before the dead centre, the eccentric must be keyed on in such a manner that it is ahead of the crank by the angle $a + 10°$—viz., at D_1. Now, let the system turn round by 10°, then the crank will be on the dead centre, and the valve will be open to the extent of *f*. Again, let the turning motion continue until the eccentric reaches point H, after describing the angle *b*; at this point we know the release of the valve takes place, and by adding the same angle *b* to the crank path, and drawing a perpendicular on the piston path, we find the position of the piston at the point of cut-off. Any intermediate position of piston and valve can be found in the same manner by drawing into both circles the same angle, then drawing from the intersecting point perpendiculars on both the crank and eccentric diameters. We can, however, much facilitate this operation by turning the valve diagram in such a manner that the two points D and D_1, where both diagrams require the valve to open, cover one another. The angle $a + 10°$ is now the required advance angle, and if from any part of the circle we draw perpendiculars on both the eccentric and the crank diameter, we ascertain at a glance the respective positions of the valve and the piston.

It is to be specially remembered, that the diagram does not show the actual relative positions of crank and eccentricity, as the advance angle is shown as following the crank instead of being ahead of it, but it enables us to ascertain the positions of the piston and valve at any point of the crank path. Supposing we want to know, what is the height of opening of the valve, and where stands the piston, when in Fig. 16 the crank is at G? We only draw the two perpendiculars on the two diameters and find that the piston has travelled from S to J, and the valve lift is *g*. What is the maximum cut-off? We know the valve is released at H, and SK is consequently the longest cut-off for the advance angle $a + 10°$.

From the foregoing, it will now be clear that the maximum cut-off of which the Proell apparatus is capable depends on the following considerations:—How small, with safety, can we make—(1) the advance angle; (2) the dimension *y*, Fig. 14, to ensure the steel-faces to engage; and (3) the dimension *z*, to ensure certainty of release? Fig. 17 shows an extreme, if unpractical, example. The diagram has been drawn with only 15° advance angle, and y and z reduced to a minimum. We find that the cut-off is carried to 94 per cent. of the stroke. It is obvious that this diagram cannot be carried out in practice; the slightest back-lash between the eccentric and the bell-crank would cause either y or z to disappear, and either no engagement of the steel-faces, or no release, would take place. The diagrams, Figs. 18-21, are drawn with normal dimensions for y and z, and varying advance angles, and show the resulting lead and maximum cut-off.

The cut-off shown by the diagram only gives mathematically the point of release of the valve. Between this and the actual closing lies a small, though appreciable, period, which cannot be neglected in practice, viz., the time of the drop of the valve, which to a certain extent can be regulated by the air-buffer, by the tension of the closing spring, the friction of the stuffing-box, and other causes. These are matters for the consideration of the engine attendant, while the valve diagram has shown that the Proell apparatus can be adjusted to suit any reasonable requirement in regard to lead and cut-off.

[The foregoing paper was further illustrated by photographs of different types of engines, showing the application of the Proell valve gear.]

Discussion.

In the after discussion,

Professor A. **Barr** (Member) said he had not expected to have been called upon to say anything on the paper at the present stage, and he did not wish to enter upon a discussion of it at this meeting. He would only congratulate the Institution upon having so interesting a paper read at its opening meeting. They had listened to a lecture delivered in an admirable manner, and had not only a lesson on valve gear, but also a lesson on the manner in which such a subject might be made attractive.

Mr James Welsh.

Mr JAMES WELSH (Member) remarked that Messrs A. & J. Inglis had applied this gear to marine work. They were asked to fit a simple and efficient expansion gear to a large triple-expansion paddle engine, working at a steam pressure of 160 lbs. per square inch. The space available was confined, and the working parts were to be few in number. The diameter of the H.P. cylinder was 30 inches, and the L.P., 75 inches, with a stroke of 84 inches. After careful consideration, it was decided to adopt "Proell's" gear as the most likely to fulfil the requirements. The difficulty of reversal was overcome by fitting a lifting lever below the dash-pot, and arranging the gear so that by simply turning a wheel, the spindle with all its connections was lifted above its working position, and clear of the cut-off toes. The gear so fitted, gave a sharp cut-off varying from ·11 to ·7 of the stroke. After some months' work, practical difficulties arose, and it might be of interest to describe how they were overcome. The valve was 11 inches in diameter, and with 160 lbs. pressure it became evident that at the moment of opening, the load on the spindle was considerable; when the valve left the seat, the load was immediately removed, so that the stress on the gear came in a series of jerks. The stress being transmitted from the driving lever at the side through a shaft to the inside levers, the keys on this shaft soon became slack. The owner substituted for the plain driving lever, one with three arms, and added an extra lever at the other side of the frame. The stress transmitted through the shaft was now reduced by one-half, and the pins carrying the bell-cranks were supported at each end, instead of being overhung as before. With this modification the gear has worked for some years with great success.

Mr G. THOMSON (Member) asked Mr Kühne, if in adopting the Corliss valve, the tendency to beat off the face when compression came on was done away with, as compared with the slide valve, also if he would explain how the stuffing-box of the valve spindle worked, and state what packing he used, and whether there was any tendency to stick due to the packing.

Mr KÜHNE, in reply, expressed thanks for the kind reception of his paper. With regard to Mr Welsh's remarks, he observed that

Mr Kühne.

Messrs. A. & J. Inglis' first installation dated a long time back, when there had not been very much experience with such large apparatus. He thought that the conditions of pressure under which Messrs Inglis' apparatus had to work were not made known to him at the time. To work an engine with an 11-inch steam inlet at 160 lbs. pressure was very unusual; and he would be glad if people who intended to apply the Proell apparatus, under such exacting conditions, would make them known at the time, when it would be easy enough to make provision for them. An 11-inch valve would have from about 12 to 13 square inches of unbalanced surface, which at 160 lbs. pressure meant mearly a ton strain at every stroke, for which the standard apparatus were not built. With regard to the stuffing-box, it had very often engaged his attention. He had tried every possible kind of stuffing-box, and had come to the conclusion that almost any kind would do good service if properly attended to. In some cases metallic packing had been used which lasted for five years, while in others, it had given out in as many weeks. When removed, it was found, in the latter circumstances, that the engine-driver had by sheer force screwed the packing so tight, that most of the metal rings were broken. In consequence ordinary asbestos stuffing had now been resorted to, with which most attendants were familiar. Whether a little steam escaped from the stuffing-box was not of much consequence; while it was of the greatest importance that the valve should not stick. Regarding the beating off the face of the Corliss valve, he would like to explain it by the photograph No. 22, upon the screen. (Shown on screen). He admitted that he did not know whether any forcing off had been experienced, but he thought he would have been the first to have heard if such had occurred. In all the valves very wide wearing surfaces were provided. He knew of no case where there had been any difficulty with the Corliss valve.

On the motion of the President, the discussion was adjourned till the next meeting, and a vote of thanks awarded to Mr Kühne for his paper.

Mr James Welsh.

The discussion on this paper was resumed on 23rd November, 1897.

Mr JAMES WELSH considered there was one point in connection with the working of valves of this type under high steam pressure which might be worth mentioning. When the valve left its seat there was a lifting force, due to the steam pressure acting on the area of the valve spindle, which prevented the valve shutting at the point of cut-off. It was therefore necessary to fit a spring to force the valve down on its seat, when released by the trip gear. He had found that, probably owing to the rush of steam past the narrow openings of the valve at early cut-off, this closing spring required to be much stiffer than was necessary to overcome the lifting force mentioned. In drop gears of Messrs A. & J. Inglis' design the spring was fitted above the gear, so that it could be easily adjusted, and, with steam pressures so high as 180 pounds per square inch, satisfactory results were obtained.

In reply to a question by Mr R. T. Napier, Mr WELSH remarked that the gear had been fitted to paddle engines and did not require a governor. The vessels ran between foreign ports, and as Welsh coal was burned, it was considered well worth the expense of fitting the gear.

Professor A. BARR observed that he could have wished the discussion on this paper had been fuller, because he thought there was a great deal of interest in the governor question. Since the President had called upon him, he might say that he considered a good deal of ingenuity had been misplaced in devising governors and expansion gears with the object of getting a sharp cut-off. That had often been stated to be the aim of the designer, and he would like to point out that it was a matter of very secondary importance. He was pleased to see that Mr Kühne had had other objects in view in applying the gear to valves of the Corliss type. Mr Kühne had there attained some of the advantages of the Corliss gear, but he did not think that he had attained all or even the most important advantages which the Corliss gear possessed. He had attained one of them by reducing clearance volume, and had

Prof. A. Barr.

gained another by reducing the area of surface exposed to the steam; but he had still left two of the objections to ordinary gears which the Corliss gear avoided, and he thought these two were probably the most important. In the Corliss gear the steam was taken out by another port from that by which it entered, and therefore the fresh steam was not cooled by coming in contact with the portion of the cylinder wall which was most reduced in temperature, viz., that portion over which the exhaust steam had passed most rapidly. The other advantage of the Corliss gear to which he referred was, that in horizontal engines it provided for the most perfect draining of the cylinder. The advantage to be got from the Corliss gear was largely due to this, as by thoroughly draining the cylinder at each stroke, little moisture was left to re-evaporate during the later part of the expansion and during exhaust, which re-evaporation cooled the cylinder and therefore led to condensation of more steam at the next stroke. Although these thermo-dynamic advantages were not provided for in this gear the chief mechanical advantage of the Corliss gear was obtained, viz., a rapid means of checking any tendency to change of speed. No gearing of this kind would do what Mr Napier wished in a marine governor, viz., anticipate what was going to happen; but for a governor of the inertia type he thought they had seen few to equal this one in niceness of design, and in attention to many of the most important points that should be considered in the design of valve gears.

Correspondence.

Mr **Hermann Kühne**, while thanking Professor Barr for his favourable criticism, wished to point out that even the soundest theoretical views often met with a great obstacle, viz., the disinclination of engine buyers to part with sufficient money to carry them into practice. In almost every respect the Proell-Corliss engine was a compromise between theoretical perfection and cheapness of manufacture, and he thought that considering its simplicity a fair measure of good theory had been secured. He was, Mr Kühne.

however, inclined to believe that the disadvantages which Professor Barr pointed out were not of such great importance as they might appear. It appeared to him (Mr Kühne) that at the point of opening of the exhaust the re-evaporation had already proceeded to such a point that not much condensed water could be left within the cylinder, and the temperature of the same would be fairly alike in every part. Even in the four-valve Corliss or Proell engine there must be one part of the cylinder which would be cooled by the escaping steam to a greater degree than the other. In the four-valve engine this part was at the bottom of the cylinder, while in the Proell-Corliss it was at the top. He thought, however, that the velocity of the freshly entering steam was such that it would fill up the clearance in an almost unmeasurably short time, and then it would be immaterial whether the cooled part was at the bottom or the top of the cylinder. In a similar manner, he inclined towards the belief that the advantage of perfect drainage through having the exhaust valves duplicated and placed below the cylinder was apt to be over-rated, and could be bought at too dear a price. He quite admitted that in case a cylinder at starting was partly or wholly filled with water, the bottom valves gave greater security for the water to escape. This was, however, quite abnormal, and in a well regulated establishment it should not occur. They tried to provide against it by liberally dimensioned relief valves. Taking, however, the normal state of the engine, that it was at work and fully warmed throughout, then the theory of bottom drainage assumed that the condensed water was swept by the piston from the cylinder faces into the waste spaces, and ran by gravitation into the exhaust opening at the bottom of the cylinder. He ventured to submit that, except in very slow-going engines, the flow of the water by gravitation alone was not rapid enough to be of great advantage. If it was assumed, however, that there was, when the exhaust opened, a mixture of steam and water, then the scavenging action of the steam would be the same whether it escaped at the bottom or at the top of the cylinder. Especially in steam-jacketed Proell-Corliss cylinders, the advantage of having the exhaust at the bottom seemed to disappear

Mr Kühne.

entirely. In any case, he thought it could be claimed that the possible remnant of disadvantage was more than counter-balanced by the great simplicity of the Proell-Corliss engine, which secured, at the expense of hardly more than that of a well made slide-valve engine, the greater part of the attainable advantages of automatic expansion.

WATER-TUBE BOILERS.

By Mr Fred. J. Rowan, Member.

SEE PLATES III., IV., AND V.

Read 26th October, 1897.

INTRODUCTORY.

The literature of this subject bears evidence that diversity of opinion exists in respect to various points connected with it, and it is improbable that the last word of the controversy will be said for some time to come. On this account, the writer considers that no apology is needed for his adding another to the existing papers and maintaining the position taken up in the one entitled "On the Design and Use of Boilers,"* which he published in 1878. As showing the change which has of late taken place in the mental attitude of certain technical circles, he records the fact that, that paper was in 1877 offered to the Institution of Naval Architects, and refused by the Council as being too revolutionary and disturbing in its views. It almost appeared as if there was a desire wholly to suppress the paper, as the writer had very great difficulty in obtaining the return of his manuscript.

Nevertheless, everything then advanced is now in principle accepted as good engineering by a large proportion of engineers and naval architects, and the design of a water-tube boiler (having three horizontal chambers connected vertically by bent water-tubes) to be worked by forced combustion, which the writer brought forward in that paper and submitted to the Admiralty, but which

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*Rep. British Assoc., 1878, p. 712 ; Engineering, Vol. XXVI., p. 164.

was then "not approved," is now actually introduced into the Navy, with the small variation from the original plan which consists of a different shape of bend in the water tubes, and a difference in the method of applying the forced combustion.

The writer wishes to direct attention to some historical points connected with water-tube boilers which have not been correctly stated by Mr C. Ward in America, Mr Thornycroft in this country, and perhaps other authors; and to some considerations which are of importance as bearing upon the circulation of water in these boilers.

HISTORICAL.

Mr Ward, in his paper on "Water-tube or Coil Boilers," read at the Engineering Congress in Chicago, was evidently inclined to consider the development of the water-tube boiler as dating from 1876, and this commencement enabled American engineers to be well to the front, the date of Herreshoff's first patent being given as in 1877, Belleville's in 1879, Ward's first in 1882, second in 1884, and third in 1892, Roberts' in 1887, Thornycroft's in 1887, Cowles' in 1888, Towne's and Worthington's both in 1889, Mosher's in 1890, and Normand's and Yarrow's in 1891. This, however, decidedly misrepresents the actual history, as also does the view that the water-tube boiler is only a modern outgrowth designed to meet the defects and evils of the Scotch or cylindrical boiler.

In the very earliest days of the use of steam both Woolf and Trevithick recognised that a high pressure would be more efficient than a low pressure, and both engineers designed steam boilers to suit that view, Trevithick producing what is well known as the Cornish boiler, whilst Woolf, in 1803, designed the first water-tube or sectional boiler, composed of horizontal cylinders (which in those days had to be constructed of cast iron) joined together by short pipe connections. In both of these plans, but more distinctly in the latter (although the Cornish boiler as compared with the wagon boiler carries out the same idea) a reduced diameter or size of parts was resorted to as suitable for the higher pressures. This was still further emphasised between the years 1821 to 1835, when several boilers were introduced for road traction by steam carriages, and in these cases the necessity for reduction of weight had its influence upon the designs. That was a very active period in the development of the water-tube boiler, and it would be both ungenerous and unscientific to dismiss a reference to it as "ancient history," because the germs of several more recent designs are to be found in the work of that time. Also, in 1831, Jacob Perkins patented his high-pressure boiler, formed of small tubes with one end closed, each having an internal concentric circulating tube.

In attempting to arrange chronologically the introduction of the different designs of sectional boilers, we find them in the following order of classification:—

1. *Woolf's boiler*, composed of horizontal cylinders or cylindrical chambers placed side by side. This design has been repeated with some variations in the boilers made by Mr Howden in 1861, in those of the steamers "Montana" and "Dakota," in the Howard marine boiler, in the "Kesterton" boiler, in the Wigzell boiler, and in a boiler made by Messrs Hawkesley, Wild & Co., in 1874. The French or "elephant" boiler may be included in this class.—See Figs. 3 and 4.

2. *Boilers composed of horizontal or slightly inclined water-tubes leading into tubes, headers, or boxes of various forms.* The first of this kind was evidently the boiler of Julius Griffith in 1821, followed by those of Alban, Benson, Root, Howard, Ramsden, Belleville, Watt, Loftus Perkins, Lane, Hardingham, Phleger, and a host of others, finishing up with the later boilers of Babcock & Wilcox, Durr, Gill, Heine, Lagrafel-D'Allest, Oriolle, and others.—See Figs. 5-14.

3. *Coil boilers.*—Goldsworthy Gurney (or James) first introduced this design in 1825, and was followed by Sir Charles Dance, and later by Matheson, Du Temple, Herreshoff, the boiler of the steamer "Peace" made by Thornycroft, and the boilers of C. Ward and Seller in America.—See Figs. 15-19.

4. *Boilers composed of leaves or cells.*—This plan had its first introduction in Hancock's boiler of 1831, but the only modifications of it which have been attempted appear to have been those of Rowan &

Horton in 1858 to 1862, results of the working of which will be found in the writer's paper on "The Introduction of the Compound Engine, and the Economical Advantage of High Pressure Steam."* —See Figs. 20 and 21.

5. *Jacob Perkins' boiler*, formed of small tubes, closed at one end, suspended from a common chamber, and containing an internal circulating tube. This is the forerunner of the Field boiler, the original Howard boiler, the Allen boiler, and, later, the boilers of Niclausse of Paris, and Mr John Thom of this city.—See Figs. 22-24, and Figs. 76, 77, pp. 136, 137.

6. *Boilers composed of vertical water-tubes.* Summers & Ogle in 1832, and Maceroni & Squire in 1835, introduced different arrangements of this plan of construction, as did also Thomas Craddock, in 1844. Then followed the boilers of the steamer "Thetis," in 1858; the boiler of the "Murillo" (by Professor Williamson), in 1861; the 1869 boilers of Rowan & Horton, in the steamers "Haco," "Propontis," "Nepaul," "Bengal," and others; the original Jordan boiler; and the boilers of Firminich, Stirling, Butman, and Cook, in America.—See Figs. 25-30, and Fig. 45.

7. *Boutigny*, who investigated many points connected with the spheroidal state of liquids, proposed a boiler to be worked by the admission of successive small quantities of water, which, by contact with the surfaces of the boiler, previously raised to a sufficient temperature, would be instantly flashed into steam. Boutigny found that the lowest temperature of metal surfaces which causes water to assume the spheroidal condition is 142° Cent., or 287·6° Fah. The temperature of the boiler must, therefore, be maintained at a point just below that for the best result to be obtained in this method of working. Following him, M. Belleville, and, it is believed, Mr Herreshoff also, originally proposed to work their boilers on this principle, but latterly abandoned it in favour of forced continuous circulation. Mr Loftus Perkins frequently claimed that his boiler worked on the principle of making steam by "foaming," there being no circulation, in the proper sense of the word, in it.

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* Transactions Inst. of Engineers and Shipbuilders in Scotland, Vol. XXIII., pp. 51-78.

The only boiler, however, which has minutely followed the lead of Boutigny is the one recently introduced by M. Serpollet* for steam motor cars.—See Figs. 31 and 32.

8. *Boilers composed of three horizontal chambers (arranged like an inverted* V), *with upright tubes connecting them.* This is closely allied to the vertical design, as the tubes may be almost straight for part of their length. They are more often bent to various curves, but, if straight, become nearly vertical, with a great height of boiler. This plan was first proposed and illustrated by the writer, in 1876, and has been widely copied—in Britain by Thornycroft, Yarrow, Blechynden, Maxim, Fleming & Ferguson, White, Reed, and others; in France by Normand; and in America by Cowles, and others. The illustrations of these boilers are placed side by side, in order that their general resemblance may be recognised.—See Figs. 33-44. This type has become so widely spread that it would seem to be fitting to mark its origin by calling it the SCOTCH WATER-TUBE BOILER, more especially as Messrs Fleming & Ferguson have already approached this conclusion by calling their modification of the three chamber design the "Clyde" boiler.

9. Outside of these distinct classes, there are some designs which it is not easy to place in any well-defined category, although all of them can lay claim to being water-tube or sectional boilers. Such we can, therefore, place only in a class of miscellaneous designs, in which we include the cast iron boilers of Miller and of Harrison (now called the Wharton-Harrison boiler), Shepherd's boiler, the American boiler of Roberts, Seabury's boiler, and a few others. In this division may be placed the early boiler of Church, which was obviously the forerunner of the Haythorn boiler, illustrated in a recent number of *Cassier's Magazine.*—See Figs. 46-50, Pl. IV. and V., and Fig. 53, page 53.

In his paper on "Water-tube Steam Boilers for Marine Engines," read before the Institution of Civil Engineers,† Mr Thornycroft commenced by stating that Mr Flannery's paper, of 1878, on "Steam Boilers for High Pressures,"‡ and the discussion thereon

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* Engineering, Vol. LX., p. 105.

† Minutes of Proceedings Inst. C.E., Vol. XCIX., p. 41.

‡ Minutes of Proceedings Inst. C.E., Vol. LIV., p. 123.

(in which the writer took part), proved that, "although considerable saving of fuel might be obtained with water-tube boilers, as then made they were unsuitable, *because the tubes forming the heating surface were burnt, owing to insufficient circulation.*"

Now, an opinion as to the suitability or otherwise of a certain boiler is one thing, but an explanation of the alleged unsuitability is quite another, and the reason then given by Mr Thornycroft is not borne out by the paper and discussion referred to, nor is Mr Thornycroft's account (given in that paper and in others) of the action of the Rowan and Horton boilers of the "Propontis" correct in almost any particular. The failure of any of the 2½-inch vertical tubes in these or any other boilers of the same design, was in no way connected with any fancied effects of insufficient circulation, nor occasioned by it, nor by "the accumulation of impurities brought in with the feed-water," which was filtered. The salt-water scale formed in some of the tubes during the last voyage of the vessel with these boilers was *purposely* made, and with great difficulty, in order to form a protective barrier to the internal corrosion which had begun. That difficulty of formation was due to the rapid water circulation in the boilers, which forcibly removed scale, and scarcely allowed sufficient time for its formation. Had the proper steam connections been provided by the makers to equalise the pressure in the different sections, it is not likely that these boilers would have been removed, as a letter from the owner of the "Propontis" is in the writer's possession, in which he stated that only 640 tons of coal were required with them to do the same voyage (with an increased speed of fully a knot) that formerly required 1200 tons. Such a saving could very well afford to pay for the renewal of even a considerable number of vertical 2½-inch tubes destroyed by corrosion.

Before leaving the historical part of the subject, the writer wishes to refer to the tables which he adds to this paper, containing the results of comparative and other trials of different boilers; and to suggest that evidence of economy and durability of water-tube designs may be found in them, as well as in additional particulars given in the paper by Mr C. Ward (from which some of these tables are taken), in a recent paper by Mr W. M. McFarland, and others. For instance, Mr Ward mentioned that one of his boilers had been at work for fourteen years, requiring the renewal of only two tubes during that time, and in the discussion on this paper Mr Roberts stated that he had one boiler in use for thirteen years, during the summer seasons, which had required no repairs. Other instances have been recorded—as, for example, those of the Rowan and Horton cellular boilers which worked almost without repair for over ten years on board Indian river steamers. It is unreasonable to suppose that, as experience accumulates, water-tube boilers will not be as durable as any others, in proportion to the work done by them.

CIRCULATION.

Mr Thornycroft introduced the "Propontis" as a preliminary to his remarks about the circulation of water in steam boilers, and in the light of an "awful example." On this subject, it appears to the writer that some engineers have preferred to imagine recondite or far-fetched ideas of the action, rather than accept the simple explanation of what should take place in a natural and orderly manner.

In the heating of water, two forces combine to cause upward movement of the heated particles; viz., the expansion of the water by heat, and the action of gravity; and, when steam is formed, there is at once its enormous difference in specific gravity and increase of volume, relatively to the water, thrown into the scale, along with the greater mobility of the vapour.

The expansion of water between 0° and 100° Cent., or 32° and 212° Fah., is stated by Watts and Ganot respectively, to be as 1·000 to 1·04299 and as 1·000 to 1·0466. Put in another way by Dalton, it is said to be equal to 1 in 21·3 parts. The force exerted by such expansion is equal to that which would be required to bring the expanded liquor back to its original volume, so that there is practically a resistless commencement of movement at once set up when heat is imparted to water. The heated particles, also, by virtue of their increase of bulk, lose in specific weight, and heavier particles are at once ready to assist in the movement already begun. Considering the water in a boiler as a whole, there need be no greater difference of specific gravity between the hottest and coldest portions, in order to cause its circulation, than there is between the heated air in a chimney and the colder column outside, *provided that there be in the boiler the equivalent of the cold air column.* Besides these considerations, there is the fact that heat is conducted by water, in the ordinary sense, from particle to particle (as in a bar or plate of metal) with extreme slowness, as would be seen if it were attempted to heat a boiler from the top. The only practicable way, therefore, in which the water in any vessel can become heated is by *convection*, or the continual transference of heated portions. That is the natural action in most liquids, and it should be provided for in boilers, by having means for the free escape upwards of the heated portions of water, and for the continual supply of colder portions at the lowest level of movement, the colder portions being conducted downwards to that level by channels free from the direct action of the hot gases. To this we must add the fact that the relative difference in volume between water and steam at 212° Fah. is as 1 to 1642 (at 150 lbs. pressure per square inch it is as 1 to 184, and at 250 lbs. pressure as 1 to 114), so that along with the available heat in the steam there is a much greater effect—on the water from which it arises and through which it passes—to be considered, than merely a mechanical "entraining" action of bubbles.

The picture drawn by Mr Thornycroft (at page 46 of the paper referred to*) of the supposed action of circulation in a tubulous boiler having the upper ends of the water-tubes above the normal water level of the boiler, represents a series of more or less violent explosions or outbursts of steam, such as are witnessed in the case, of geysers, but which should not be found in the case of boilers even though they be dignified by the title of "periodic discharges." They argue an interference with the orderly course of natural

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*Minutes of Proceedings Inst. C.E., Vol. XCIX., p. 46.

Fig. 1.

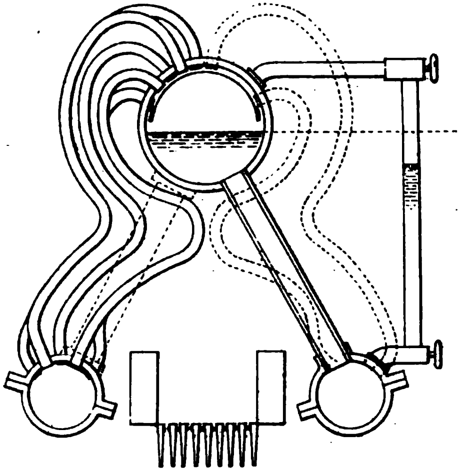
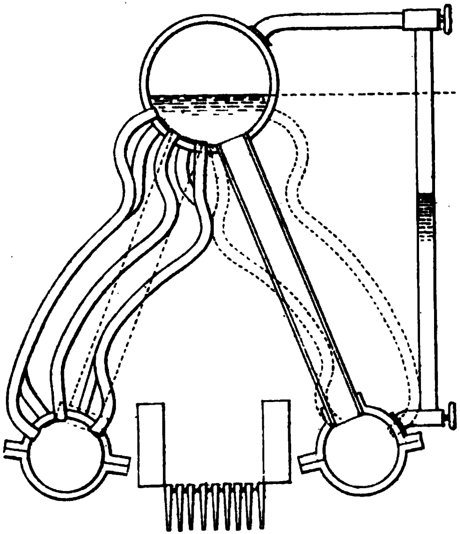


Fig. 2.



action, and, in the case of geysers, are no doubt caused by part of the steam formed below being condensed during its ascent by contact with colder portions of the bore or channel, which is probably rough, and not vertical, in the earth above. The condensed steam gradually accumulates as hot water, and narrows the channel until it causes a fresh volume of steam to force a passage for itself and the accumulated water. It is evident that such action ought not to be possible in boilers constructed and heated in a proper manner; and the possibility of such occurring would be an argument against the adoption of a very sinuous form of water tube.

When the upper ends of the tubes are "drowned," as it has been termed, or terminate at a point below the water line, the re-entry of water at the upper ends of these tubes would prove either that at the time steam was not being generated in them, or that the water supply from below had failed, both of which would show inadequacy in the means provided for the return of the water which is always thrown up by ebullition. Certainly this would not be "a condition of equilibrium" in a boiler in which the descending column *should* consist of water alone.

The conclusions drawn by Mr Thornycroft from the experiments on circulation which are recorded in his paper on "The Influence of Circulation on Evaporative Efficiency of Water-Tube Boilers"* are, it seems to the writer, not well founded, as it is quite possible to read these experiments in a totally different light. Mr Thornycroft relied entirely on the indications of a water-gauge or column connected with the upper and lower chambers, Figs. 1 and 2, and argued variation of pressure in the lower vessel from the alteration of the water level in this column, and consequent loss of energy in circulation from a fall in its height. But, in the two boilers experimented with, the distance between the upper and lower vessels was least where the length of the bent water tubes was greatest, in one, and *vice versa* in the other. That is to say, in the one which showed the smallest fall of water level, the water had

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*Trans. Inst. Naval Architects, Vol. XXXVI., p. 40.

the longer distance to ascend and the shorter to return, whilst the other presented the opposite conditions. It is evident that the variation of water level was caused by *a more rapid circulation in the boiler which showed the greatest fall* in the test column, unless we are to believe that longer and more crooked tubes offer less resistance to the flow of water than the shorter and straighter ones.

The slower the circulation, the larger the quantity of water which would be quiescent in the lower vessel or chamber, and therefore able to maintain the water column at its original level. But if all the water were in rapid and violent circulation, that would in effect be an enlargement of the steam space, because a large quantity of the water would be always broken up into the state of foam, and this would lower the level in the test column. As the test column was so connected that none of the water carried by ebullition into the upper chamber could return by it, or enter it at the top, it seems illusory to endeavour to judge of the available "head" of water in the boiler by such a gauge glass. In fact, much of the reasoning as to the "head" of broken and foaming water in rapid circulation in boilers appears to the writer to be misleading. The greater fall of water level in the column of boiler Fig. 2, in Mr Thornycroft's experiments carried out at a low pressure, can be accounted for by the greatly increased relative volume of steam to water at that pressure.

Prof. Watkinson, in his remarks on circulation,* assumed as a condition that the water in the boiler *would be all at the same temperature.* That assumption, however, necessarily vitiates several of his conclusions, because such a condition is absolutely impossible of realisation under any ordinary circumstances. Similarly, the experiment or illustration with beads on a string is not conclusive as to the action in boilers, because the vital element of temperature is not present in the production of the result. The results obtained with small glass models worked at atmospheric pressure in the quiet atmosphere and comparatively even temperature of a labora-

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*Trans. Inst. Engineers and Shipbuilders in Scotland, Vol. XXXVIII., p. 133, and Trans. Inst. Naval Architects, Vol. XXXVII., p. 267.

tory, although interesting, cannot form a sure guide in any case, to what takes place in boilers subject to fluctuations of temperature and pressure caused by the cooling influence of radiation from a mass of metal, the operations of stoking, and other disturbing circumstances.

VALUE OF HEATING SURFACE.

The full realisation of the value of heating surface depends almost entirely, if we assume the proper application of the heat to it, upon thoroughly efficient circulation of the water. Few, however, seem to realise the limits of the capabilities of heating surface. Taking Peclèt's formula and co-efficient for the amount of heat which can be transmitted through iron, we have the following result:—

$$M = (t - t_1)\frac{C}{E},$$

where M = the total heat transmitted in a given time;

$(t - t_1)$ = the difference between the temperatures on the two sides of the iron;

C = the quantity of heat transmitted per hour per degree of difference of temperature through unit thickness; and

E = the thickness of the metal.

If we assume 1500° Fah. as the temperature of the fire and hot gases on one surface of the iron, and 400° Fah. (the temperature of steam of 250 lbs. per square inch pressure) as the temperature at the other surface, we have—

For plates or tubes $\frac{1}{8}$-inch thick, $(1500^\circ - 400^\circ)\frac{225}{\cdot 125} = 1{,}980{,}000$ Fah. units per square foot per hour; and,

For iron $\frac{3}{8}$-inch thick, $(1500^\circ - 400^\circ)\frac{225}{\cdot 375} = 660{,}000$ Fah. units per square foot per hour.

That is to say, taking 14,500 units as the heating value per lb. of coal, each square foot of heating surface exposed to these temperatures, when the metal is $\frac{1}{8}$-inch thick, is capable of transmitting all the heat produced by the combustion of 136·5 lbs. of coal per hour, and, if the iron is $\frac{3}{8}$-inch thick, the whole heat of 45·5 lbs. of coal per hour.

This, if expressed in lbs. of steam at 212° Fah., means that iron ⅛-inch thick, is capable of a production from its surface of 1717·75 lbs. of steam, and iron ⅜-inch thick, of 576 lbs. of steam, per square foot per hour.

How far short of this boilers come in actual practice may readily be seen by comparing the records of their performance, even when we make due allowance for unavoidable losses of heat, and for the fact that it is impossible that all the heating surface in any boiler can be equally valuable.

FORCED COMBUSTION.

Closely allied to the problem of the circulation of the water, and offering a direction in which improvement is likely to be made, is the means of obtaining and imparting to the boiler surfaces the heat of combustion. It is fairly well recognised now, that the method of effecting combustion at a high temperature by means of mechanically produced draught, or air-supply, ought to be economical in steam-raising.* But the arrangements for forced combustion hitherto used have various drawbacks, foremost among which must be counted the variations of temperature caused in the boiler, and the augmented labour caused to the men by the operation of stoking. The latter introduces what has been called "the uncertain human factor." Opinions seem to be divided amongst the different systems of closed stokehold, closed ashpit, forced draught, and "suction" draught, but the writer ventures to urge that the plan which he has proposed of an outside fuel chamber, or producer grate, has features which recommend it above these others. With it, nothing but flame is continually sent into the space containing the boiler-heating surfaces, and all fluctuations of temperature caused by opening furnace doors are prevented. The quantity of ash, dust, and soot projected amongst the boiler surfaces is much reduced by this arrangement, and it offers a means of entirely doing away with the severe manual labour of stoking, which has become more arduous in consequence of the greatly increased temperatures

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* See "Some Notes on Chimney Draught and Forced Combustion," by the Author. Trans. Inst. of Engineers and Shipbuilders in Scotland, Vol. XXXII., p. 109.

produced by forced combustion. Mechanical feeding of the coal from the bunkers to the hoppers of these fuel chambers would ensure perfect regularity in the production of steam, and a continued maintenance of the highest temperature for the parts which require it. These, it will be admitted, are amongst the most essential conditions of the most efficient steam production.

The following volumes and memoirs may be consulted for particulars of the various forms of boilers referred to in the preceding remarks:—

A Historical and Practical Treatise upon Elemental Locomotion by means of Steam Carriages on Common Roads, etc., by Alex. Gordon, C.E. London, 1832.
Album du Constructeur de Chaudières à Vapeur, par MM. Laurent et Dunkel. Paris, 1875.
The Chemistry of the Steam Engine, etc., by Thomas Craddock, London, 1848.
Journal of the Society of Arts. 1865-1896.
Proceedings of the Institution of Mechanical Engineers. 1859-1866. 1869-1871, 1877-1881.
Minutes of Proceedings of the Institution of Civil Engineers. Vols. LIV., XCIX.
British Association Reports. 1878, 1894.
Transactions of the Institution of Naval Architects. 1876-1877, 1884-1886, 1889-1892, 1894-1896.
Transactions of the Society of Engineers. 1867-1874.
"Engineering" from Vol. VIII.
"Industries and Iron." 1896.
"The Engineer." 1857-1897.
"Electrical Industries." Vol. III., 1892.
Report of the Engineering Congress at Chicago. 1894.
"Cassier's Magazine." Aug., 1897.
Transactions of the Society of Naval Architects and Marine Engineers. 1894.
Chemical Technology, edited by Groves and Thorp—Vol. I.; Fuel and its Applications, by E. J. Mills, D.Sc., F.R.S., and F. J. Rowan, C.E. 1889.
Neuere Dampfkessel Konstructionen, etc. Berlin.
The Steam Engine, by D. K. Clark. Vol. I.
Steam Boilers, by George Halliday. 1897.
Les Chaudières Marines, par M. L. de Chasseloup-Laubat. 1897.

On the motion of the President, the discussion on this paper was adjourned till next meeting.

Table I.—Published by Asst. Eng. S. H. Leonard U.S.N. in Jour. Am. Soc. Nav. Eng., Vol. II., May, 1890.

Type.	Grate area.	Heating surface.	Ratio $\frac{\text{H.S.}}{\text{G.A.}}$.	Combustion per square foot of grate, per hour.	Evaporation from and at 212° Fah.				Per cent. moisture, in steam.	Weights in lbs.					Air pressure, inches of water.	Steam pressure, lbs.	Coal.
					Per lb. coal.	Per lb. combustible.	Per square foot heating surface.	Per cubic foot space.		Empty.	Steaming level.	Per I.H.P.	Per square foot heating surface.	Per lb. water evaporated.			
Belleville	34·17	804	1 to 23·5	12·8	9·6	10·42	5·2	6·4	6·31	40,670	42,700	204	53·2	10·1	Natural draught	111	Bituminous
Herreshoff	9	205·3	1 „ 22	9·3 25·8	7·6 7·14	10·23 8·68	3·1 8	9·1 23·8	3·5 —	2,945	3,050	96 36	14·8	4·8 1·8	Jet Jet	120 195	Anthracite „
Towne	4·25	75	1 „ 17·6	4·3 24·5	10·46 5·6	13·4 6·77	2·7 8·2	10 30·4	—	1,380	1,640	172 56	21·8	8·1 2·6	Natural 1·14	148 152	Anthracite „
Ward (Launch type)	3·68	145·8	1 „ 39·5	7·9 15·5 62·5	8·59 8·28 6·34	10·77 10·01 7·01	1·7 3·2 10	5·8 11 36·2	—	1,682	1,930	154 82 26	13·2	7·7 4·07 1·3	Natural Jet Jet	0 17 161	Anthracite „ Bituminous
Scotch	31·16	727·2	1 „ 23·3	24·8 38	8·13 7·87	9·93 9·06	8·6 12·8	11 16·3	3·44 4·29	18,900	30,000	120 80	41·2	4·7 3·1	2·08 4·01	77 78	Anthracite „
Locomotive (torpedo boat)	28	1116	1 „ 39·8	98·3 120·8	6·97 6·62	—	17·1 20·05	30·5 36·2	—	—	34,990	47·7 33·3	31·3	1·8 1·2	3·13 4·95	125 123	Bituminous „
Ward (Large type)	53 66·5	2473·5 2490	1 „ 46·6 1 „ 37·4	55·04	8·03	8·44	9·47	32·1	11·6	26,533	30,474	26	12·3	1·3	2	160	„
Thornycroft U.S.S. "Cushing."	38·3	2375	1 „ 62	45	—	—	—	—	—	20,160	24,640	31	10·3	—	3	245	„

Table II.—Boilers in Table I. with Thornycroft boiler of Torpedo boat "Ariete" added. Arranged by Engineer R. S. Giffen, U.S.N.

Boilers.	1 Combustible per sq. ft. of heating surface	2 Evaporation per lb. of combustible	3 Heating surface per cubic foot	4 Weight per sq. ft. heating surface	5 $\frac{1 \times 2 \times 3}{4}$
Ward (Launch)	·159	10·77	3·413	13·2	·443
Towne	·190	13·40	3·694	21·8	·431
Herreshoff	·301	10·23	2·945	14·8	·613
Ward (Launch)	·323	10·01	3·413	13·2	·836
Belleville	·501	10·42	1·228	53·2	·120
Thornycroft	·823	10·83	2·180	10·2	1·905
Scotch	·870	9·93	1·268	41·2	·266
Herreshoff	·930	8·68	2·945	14·8	1·606
Ward (Large)	1·122	8·44	3·391	12·3	2·615
Towne	1·148	6·77	3·694	21·8	1·317
Scotch	1·415	9·06	1·268	41·2	·395
Ward (Launch)	1·427	7·01	3·413	13·2	2·586
Locomotive	2·220	7·74	1·771	31·3	·978
Locomotive	2·728	7·35	1·771	31·3	1·134

Table III.—Ward and Scotch boilers in "Monterey" and navy tugs.

	Weight	Grate Surface	Heating Surface	I.H.P.	Speed of Vessel
Scotch	90,040 lbs.	88 sq ft.	2,840 sq. ft.	373	11·14 knots
Ward	34,720 lbs.	308 sq. ft.	11,880 sq. ft.	524	13·1 knots.

Table IV.—Comparison of Ward and Cowles' boilers.

	Ward.	Cowles.
Grate surface, square feet	53	47
Heating surface, square feet	2473·5	2026·75
Ratio of heating surface to grate surface,	46·67	43·12
Weight of boiler empty, no smoke pipe, tons	11·84	9 75
Weight of boiler with water, tons	13·85	11·55
Boilers for "Monterey," number	4	6
Grate surface of each,	75	47
Heating surface of each,	2,938	1998·5
Weight empty, tons	13·58	9·6
Weight with water tons	15·86	12·65
Duration of test, hours	24	24·15
Fuel consumed, total, pounds	70,022	45,620
Refuse from fuel, pounds	3,389	6,327
Combustible consumed, total, pounds	66,633	39,293
Total feed water, pounds	461,885	280,822
Temperature of feed, degs.	50·4	58
Steam pressure, pounds	160	160
Air pressure = inches of water,	2	2
Coal per hour per square foot of grate surface,	55·05	40·19
Combustible per hour per square foot of grate surface,	52·4	34·62
Apparent evaporation from feed temperature at steam temperature per lb. of coal,	6·60	6·16
Same per pound of combustible,	6·93	7·15
Actual evaporation per hour for 10 hours' feed at 120°, steam 160 lbs. pressure,	19,105	14·192
Actual evaporation per hour per square foot of heating surface,	7·724	7·002
H.P. which 1 boiler will furnish from heating surface @ 20 lbs. steam per I.H.P. per hour,	1139·5	709·6
H.P. from whole number of boilers,	4558	4257·6

Table V.—Comparison of results of tests of the Ward, the Cowles, and the Scotch boilers of the "Swatara," each made with an air pressure = 2 inches water.

	Ward.	**Cowles.**	**Scotch.**
	lbs.	lbs.	lbs.
1. Coal per square foot heating surface, - - per hour	1·1795	·93204	1·0658
2. Combustible, - - „	1·1224	·80278	·8717
3. Water evaporated, - „	6·8093	5·7376	6·9710
4. Equivalent evaporation from and at 212° and atmospheric pressure, - - -	8·2941	7·3287	8·7678
5. Evaporation per hour per cubic foot space occupied, and as above, - - -	18·6075	14·0188	8·396
6. Evaporation per hour per ton of steaming weight, and as above,	1485·4	1209·8	455·762

Table VI.—Comparison of boilers in steamers "Zenith City" and "Victory."

Kind of boilers and number, -	2 Water-Tube	2 Scotch
Grate surface, - - -	134 sq. ft.	144 sq. ft.
Heating surface, - - -	6800 sq. ft.	5715 sq. ft.
Ratio of heating surface to grate surface, - - - -	50·7 to 1	39·6 to 1
Total weight with water, - -	173,876 lbs.	335,787 lbs.
Weight per square foot of heating surface, - - - -	25·57 lbs.	58·7 lbs.
I.H.P. developed, - - -	1540·19	1438·8
I.H.P. per square foot grate surface,	11·15	9·99
Coal burned per square foot grate surface, - - - -	25·94 lbs.	22·52 lbs.
Coal burned per I.H.P. per hour, -	2·256	2·24
Duration of run, - - -	24 hours	9¼ hours
Steam pressure per square inch, -	200 lbs.	175 lbs.
Moisture in steam, - - -	$\frac{3}{10}$ths of 1 %	2¾ %
Weight per I.H.P., - - -	106 lbs.	213 lbs.

Table VII.

Kind of boiler and maker	Tubulous, Thornycroft				Tubulous Towne		Tubulous Cowles	Tubulous Ward	Shell cylindrical, single-ended	Shell locomotive.	
Where used	U.S.S. "Cushing"				On shore		On shore	On shore	s.s. "Iona."	Italian tor. cr. "Tripoli" and "Folgore."	
Outside dimensions	10′ × 7′ × 8′				6′9½″×5′4″ ×8′		11′5″×7′9″ ×12′2″	10′3″diam 11′8″ high	13′3″ diam. 10′ long	16′8″×6′4″× 7′6″	
Grate surface, square feet	38				15·6		47	53	21	28	
Heating surface, square feet	2451				577·0		2026·75	2473·5	1580	1116	
Ratio heating surface div. by grate surface	64·5				37·0		43·12	46·67	75·2	39·8	
Weight of boiler, empty, tons	9·00				3·57		9·75	11·84	29·30	—	
" and water, tons	11·00				4·52		11·55	13·85	47·17	15·60	
Duration of trial, hours	2·5	11·5	11·5	1·0	6·25	6·5	12	12	16	—	—
Air pressure in inches of water	*0·0	0·35	3·0	4·0	†0·0	2·0	2·0	2·0	‡0·2	3·13	4·95
Feed temperature, degrees Fah.	52	58·5	58	52	45·3	39	58	50·4	106	—	—
Steam pressure above atmosphere, lbs.	250	250	250	250	160	160	160	160	165	125	123
Coal per hour per sq. foot grate surface, lbs.	7·58	24·12	40·23	66·32	14·35	33·78	40·19	55·05	22·4	98·6	120·8
Refuse, per cent.	6·11	8·04	7·53	6·27	10·65	8·82	13·87	4·84	2·9	—	—
Moisture, "	8·09	2·11	3·89	6·68	8·66	10·62	—	12·48	2·87	—	—
Superheating, "	—	—	—	—	—	—	5·7	—	—	—	—
(*a*) Apparent evaporation from temperature feed at temperature steam per lb. coal	10·55	8·13	7·53	5·69	6·36	5·30	6·16	6·60	9·15	—	—
(*b*) Same from and at 212° Fah.	12·95	9·93	9·19	6·98	7·78	6·51	7·45	8·04	10·63	6·97	6·62
Actual evaporation as in (*a*)	9·69	7·96	7·23	5·30	5·82	4·74	6·16	6·00	8·90	—	—
Same as in (*b*)	11·90	9·72	8·84	6·51	7·12	5·82	7·45	7·31	10·20	6·97	6·62
Actual evaporation from and at 212° Fah. per square foot of heating surface,	1·40	3·63	5·51	6·70	2·76	5·32	6·96	8·62	3·08	17·20	20·09
Horse power per 100 square feet of heating surface on basis of 20 lbs. steam per hour from and at 212° Fah.	7·00	18·15	27·55	33·50	13·80	23 60	34·80	43·10	15·40	86·00	100·45
Horse power per ton of boiler and water on same basis,	15·6	40·44	61·38	74·65	17·60	33·90	61·07	76·98	5·16	61·52	71·85

* Blowers discharging into open fire room. † Smoke pipe 21 ft. 6 ins. above grate. ‡ Smoke pipe 52 ft. above grate.

Table VIII.—Tabulated Results of Tests of Elephant and Water-Tube Boilers made at San Francisco, according to Forms Nos. 80-4 and 80-5 of the U.S. Navy Department.

	Babcock & Wilcox	Heine	Elephant
Average steam pressure, absolute, p,	119·76	117·67	116·785
Average temperature of feed water, t,	150·13	130·73	135·69
(a) No. of lbs. of water evaporated, $W_1 \times Q$,	135,832·35	95,446·14	168,441·57
(b) No. of lbs. of water carried over with steam, $W_1(1-Q)$,	1818·50	674·02	1191·33
Total heat of steam at pressure p,	1185·98	1185·576	1185·41
Total heat of water at temperature t_1,	118·32	98·845	103·91
(c) Units of heat to vaporize 1 lb. water from t at p,	1067·66	1086·73	1081·50
(c_1) Units of heat to raise 1 lb. water from t_1 to temperature of p,	194·59	212·70	207·0
(d) Units of heat to vaporize 1 lb. water from and at 212° Fah. and atmospheric pressure,	965·7	965·7	965·7
Total heat required to vaporize the water $a \times c$,	145,022,766·8	103,724,183·7	182,169,557·9
Total heat required to raise the temperature of the water $b \times c_1$,	353,861·9	143,364·0	246,605·3
(e) Total heat obtained from fuel measured by steam discharged,	145,376,628·7	103,867,547·8	182,416,163·3
(f) Units of heat obtained per lb. of dry fuel,	6254·9	7341·82	7355·63
(g) Units of heat obtained per lb. of dry combustible,	7606·75	8753·83	9036·1
$\left(\frac{f}{c}\right)$ Potential evaporation per lb. fuel from t_1 at p,	5·8585	6·7558	6·8013
$\left(\frac{g}{c}\right)$ Potential evaporation per lb. combustible from t_1 at p,	7·1246	8·0550	8·3551
$\left(\frac{f}{d}\right)$ Equivalent evaporation per lb. fuel from 212° at atmospheric pressure,	6·4770	7·6025	7·6168
$\left(\frac{g}{d}\right)$ Equivalent evaporation per lb. combustible from 212° at atmospheric pressure,	7·8769	9·0647	9·357
ntities. Duration of test in hours,	19·8833	19·9083	20·1
Wet fuel consumed,	23,760·85	14,577·8	25,761·13
Moisture in fuel,	518·83	430·42	961·62

Tot	Water fed to boilers by tank measurement W_1,	[illegible]	[illegible]	[illegible]
	Per cent. of fuel in dry refuse, etc.,	17·43	15·72	17·98
Average quantities.	Temperature of feed water t_1,	150·129°	130·728°	135·69°
	Temperature of steam by thermometer,	340·39° 331·29°	343·43° 339·65°	339·89° 331·96°
	Temperature of uptake,	510·70°	569·42°	458.89°
	Temperature of atmosphere,	64°	62°	53°
	Temperature of fire room,	82°	71·22°	69·1°
	Barometer in inches of mercury,	29·78	29·968	30·061
	Pressure of steam at boiler in lbs. per sq. in. above perfect vacuum 14·62 14·76 + pressure by gauge in lbs. p, 14·71	119·76	117·673	116·785

Rates of Combustion.	Dry Fuel.	Combustible.	Dry Fuel.	Combustible.	Dry Fuel.	Combustible.
Amount consumed per hour, dry,	1168·92	961·184	710·8	596·15	1233·8	1004·35
Amount consumed per square foot of grate surface,	31·18	25·64	34·3	28·77	20·57	16·74

Vaporisation in Pounds of Water.	Per lb. of Fuel.	Per lb. of Comb.	Per lb. of Fuel.	Per lb. of Comb.	Per lb. of Fuel.	Per lb. of Comb.
Apparent evaporation by tank measurement from temperature t and under pressure p,	5·922	7·2025	6·794	8·1008	6·840	8·403
Equivalent apparent evaporation from and at 212° and under atmospheric pressure,	6·5477	7·963	7·645	9·116	8·201	10·075
Actual evaporation into steam of quality Q, from temperature t_1 and under pressure p,	5·848	7·1073	6·746	8·044	6·792	8·3438
Equivalent actual evaporation from and at 212° and under atmospheric pressure,	6·4613	7·8577	7·592	9·0522	7·6065	9·3443
Potential evaporation, or evaporation if all the heat obtained from fuel had been used in converting the water into dry saturated steam from temperature t_1 and under pressure p,	5·8585	7·1246	6·7558	8·0550	6·8013	8·3551
Equivalent potential evaporation from and at 212° and under atmospheric pressure,	6·477	7·8769	7·6025	9·0647	7·6163	9·3570

Exhibition of Lantern Slides, illustrating various types of Water-Tube Boilers.

In addition to the illustrations given in Plates III, IV, and V, Mr Rowan exhibited, on November 23rd, by means of lantern slides, the designs of the following boilers. In Class I, the Crosland boiler and the boiler of the steamer "Red Rose"; in Class II, the boilers of Belleville (old and new forms), Watt, Lane, Hardingham, Dickerson, Phleger, Seaton, Yarrow, the steamer "Ailsa Craig," Sinclair, Griffiths, Caldwell, Wood, Poole, Towne, and Mills; in Class III, the boilers of Du Temple, the steamer "Peace," C. Ward, and Seller; in Class IV, two further views of Rowan and Horton's cellular boilers of 1860; in Class V, the boilers of J. Perkins and Howard; in Class VI, the boilers of the steamer "Murillo," further illustrations of Craddock's boiler, and the boilers of Butman and Cook; in Class VIII, the boiler of Mosher; and in Class IX, the boilers of Miller, Shepherd, Roberts, Martin, Scott, Lyall, Hazleton, and Fouché and Laharpe. Mr Rowan called attention to the diagrams *a*, *b*, and *c*, in Fig 33, Plate V, in order to emphasise the difference between the three-chamber arrangement *c*, and other forms, *a* and *b*, which had been introduced prior to it. The level of the fire grate was shown in all cases, and in both *a* and *b* there were horizontal chambers over the fire.

Discussion.

The discussion on this paper took place on 23rd November, 1897.

Professor W. H. WATKINSON (Member) considered that the writer of a paper might have one of two objects in view. He might desire to contribute something new regarding his subject, or to provoke a full discussion of the subject. If the latter was Mr Rowan's object, then he had to congratulate him most heartily, because his paper was filled with matters which would give rise to a very strong discussion. In his treatment of the historical portion of the subject, Mr Rowan had omitted to mention the boiler invented by John

Blakey, in 1774, and in referring to the Serpollet boiler, he spoke of it as having been recently introduced, whereas it was an older boiler than the Yarrow, having been invented about nine years ago. Great credit was undoubtedly due to Mr Rowan for the foresight and ingenuity displayed in the boilers which he described in his 1876 paper, but he was certainly in error in thinking that he was the first to propose the type of boiler consisting of three horizontal chambers, with tubes connecting them as in the Thornycroft and Yarrow boilers. According to a paper in his (Professor Watkinson's) possession, the Firminich boiler was produced in 1875; and Green of Wakefield, the inventor of the Green Economiser, had boilers of that type constructed about the year 1850. Two of these were shown in Figs. 51 and 52. Mr Rowan proposed to call that type of boiler the Scotch water-tube boiler, but, if any distinctive name was to be given to it, he, as a Yorkshire man, would claim it as the Yorkshire water-tube boiler. In saying that the Church boiler was obviously the forerunner of the Haythorn

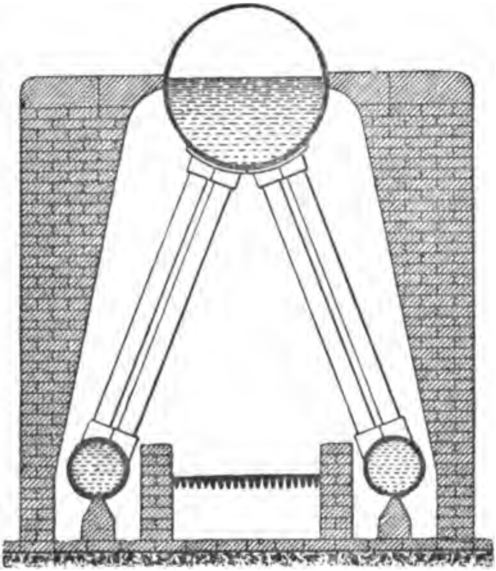

Fig. 51. Green.

boiler, Mr Rowan was certainly far from correct. It would be difficult to find any two boilers which differed so greatly in almost every detail. The Church boiler was a tank boiler, having internal tubes, which happened to be approximately of the same shape as the tubes of the Haythorn boiler, Fig. 53. Similarity in the form of tube was no indication of similarity in type or principle of different boilers. On page 34, Mr Rowan said, "Before leaving the historical part of the subject, the writer wishes to refer to the tables which he adds to this paper, containing the results of comparative and other trials of different boilers; and to suggest that evidence of economy and durability of water-tube designs may be found in them;" and on page 35 he referred to boilers that had been at work for a considerable time as evidence that the durability of water-tube boilers might be as great as that of other boilers. He was pleased to note

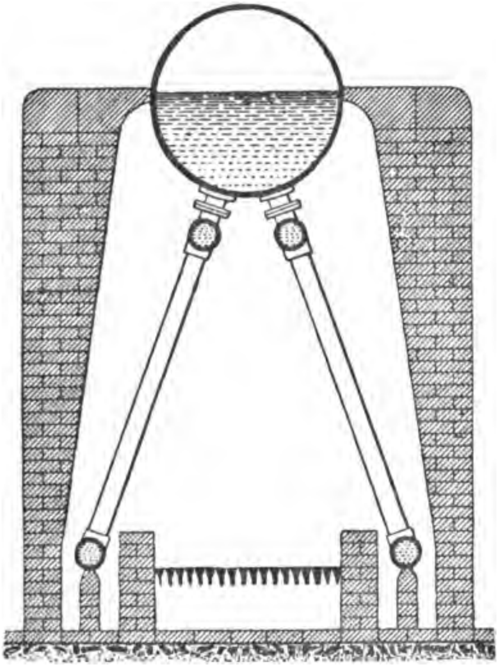

Fig. 52. Green.

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the great advance which Mr Rowan had made within the last twelve months in his appreciation of the durability of water-tube boilers. During last session, in the discussion on Mr Sinclair Couper's paper on "Internal Corrosion in Steam Boilers," he (Professor Watkinson) had ventured to say, "Everyone seemed to agree that corrosion was mainly due to the action of the gases, or to acids in a liquid or gaseous form settling on the surfaces. That action would be very much less when the circulation was rapid; therefore, they might expect, and they found in a great many cases, that with rapid circulation, and with systematised circulation such as could be obtained in water-tube boilers, corrosion was less likely to take place than in ordinary boilers where the circulation currents were confused." He was surprised to learn afterwards that Mr Rowan had attacked that statement at a later period of the discussion as follows:—"It happened, unfortunately for that idea, that it was in water-tube boilers that the evil effects of corrosive action had been, first of all, and most of all, experienced. As a matter of fact, they corroded more rapidly than other boilers, simply on account of the thinness of the material of which they were constructed." In this incorrect statement Mr Rowan obviously confused *rate* of corrosion with the time taken to corrode through a given thickness of metal. In the last paragraph of page 35 of Mr Rowan's paper there was a most remarkable statement, viz., that "The force exerted by such expansion is equal to that which would be required to bring the expanded liquor back to its original volume, so that there is practically a resistless commencement of movement at once set up when heat is imparted to water." In an earlier part of the same paragraph, he said that the increase in volume due to the increase in temperature was approximately 5 per cent. The force required to bring the water back to the original volume would be about 1000 atmospheres, and surely Mr Rowan did not imagine, as his statement seemed to imply, that that was a measure of the circulating force. As a matter of fact, with the 5 per cent. increase in volume mentioned, the accelerating force on a particle of water would be only $\frac{1}{20}$th of the weight of the particle. Then on page 36 he said :—

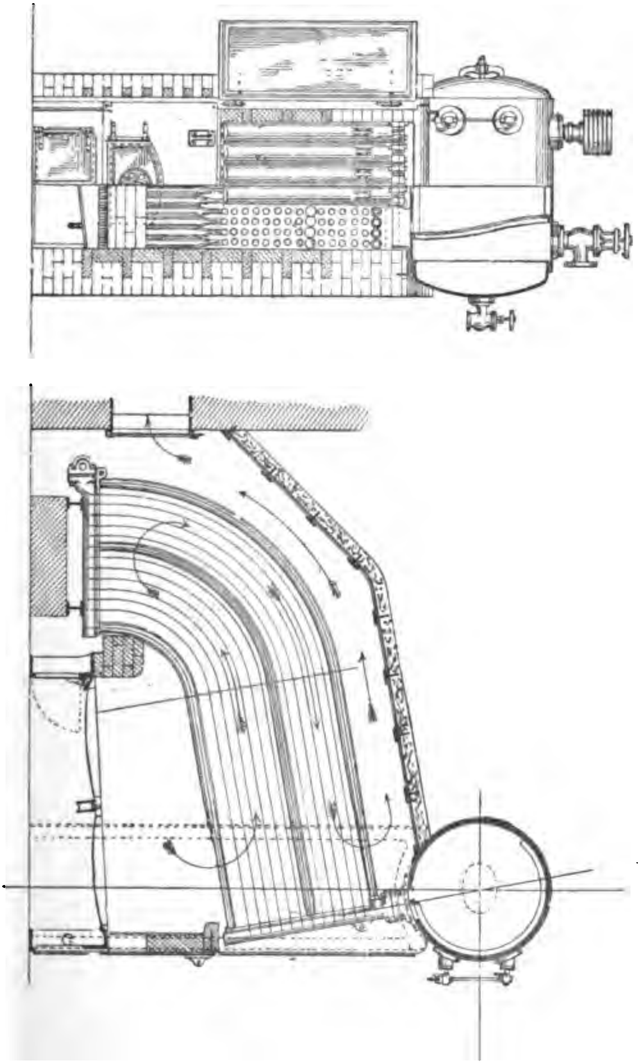

Fig. 53. Haythorn Boiler.

"Considering the water in a boiler as a whole, there need be no greater difference of specific gravity between the hottest and coldest portions, in order to cause its circulation, than there is between the

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heated air in a chimney and the colder column outside, *provided that there be in the boiler the equivalent of the cold air column.*" If by this statement Mr Rowan meant the *difference of specific gravity*, as stated, then the circulating force would be altogether insufficient; because, (*a*) the heights of the columns in a boiler are insignificant as compared with those of a chimney, (*b*) the accelerating forces necessary are enormously greater for water, on account of its greater density, than for air. If, instead of difference of density, he meant *percentage difference of density*, he was still wrong, because the difference in density of the water in a boiler would not exceed say 5 per cent., whereas, in the case of a chimney, the density of the cold column was often 100 per cent. greater than that of the hot column. On pages 37 and 38, Mr Rowan attacked Mr Thornycroft's conclusions regarding the experiments made with the models illustrated in Figs. 1 and 2, opposite page 37; and on page 38 he said:—" As the test column was so connected that none of the water carried by ebullition into the upper chamber could return by it, or enter it at the top, it seems illusory to endeavour to judge of the available head of water in the boiler by such a gauge glass." Mr Thornycroft's conclusions regarding these experiments were undoubtedly correct, and the gauge column as used was the most satisfactory arrangement for the purpose with which he (Professor Watkinson) was acquainted. If the test column had been connected so that some of the water carried into the upper drum could have returned by it, the column would have been absolutely useless for the purpose. The velocity of flow through the downcomer was proportional to the square root of the difference between the level of the water in the upper drum and that in the test column. Another way of stating the matter was to say, that the height of the test column was proportional to the average density of the water and steam in the "upcomers." That way of regarding the matter enabled them to conclude at once that, other things being equal, the arrangement in which the test column fell most, was the one in which the tubes would be burned soonest, assuming them both to be forced to destruction. While the gauge column method was the best for the purpose, it was important to note that it was very easy to draw wrong conclusions from the readings obtained, especially when boilers of different types were being compared. On page 38, Mr Rowan said, "Professor Watkinson, in his remarks on circulation, assumed as a condition, that the water in the boiler *would be all at the same temperature.* That assumption, however, necessarily vitiates several of his conclusions, because such a condition is absolutely impossible of realisation under any ordinary circumstances." Which conclusions did it vitiate? He would be glad if Mr Rowan would point them out. If it were assumed that the density of the water in the downcomer was 5 per cent. greater than the density of the water in the upcomers, due to difference in temperature, then there would be a circulating force on each particle, due to that of $\frac{1}{20}$th of the weight of the particle, but that force was very slight in comparison with that due to the lower density of the steam. Mr Thornycroft had found that the mass of water carried round by the steam in a given time was about 50 times the mass evaporated in the same time, and he, in his own experiments, had found as much as 240 times carried round, so that in the last case, each particle of water was, on the average, carried round the circuit 240 times before being evaporated. From those facts it was evident that the water would be at approximately the same temperature in all the principal types of water-tube boilers, when they were properly in action. At the bottom of page 38, Mr Rowan said:—"The results obtained with small glass models worked at atmospheric pressure in the quiet atmosphere and comparatively even temperature of a laboratory, although interesting, cannot form a sure guide in any case to what takes place in boilers subject to fluctuations of temperature and pressure, caused by the cooling influence of radiation from a mass of metal, the operations of stoking, and other disturbing circumstances." Mr Rowan, surely, had not taken account of the fact that ordinary boilers were surrounded by non-conducting material, and covered in with the object of preventing loss of heat, whereas his experimental models were not covered in, and were usually not shielded in any way from the currents of air in a very draughty laboratory. As a matter of fact, however, that was a matter of absolutely no importance, so far as conclusions regarding the nature of the circulation in the models of the different types of boilers were concerned. Experiments made with models of water-tube boilers at atmospheric pressure, could be made to exhibit the conditions which obtained in actual boilers, if the simple precaution was taken, to make the rate of evaporation vary approximately directly as the pressure; for example, if it was desired to observe the condition within a boiler when working at 150 lbs. pressure, at a given rate of evaporation, it was only necessary to arrange the rate of evaporation in the model, so that it was approximately one-tenth of the rate in the actual boiler. Care should also, of course, be taken to distribute the heat over the whole of the heating surface, and not to concentrate it by using only two or three large Bunsen burners. The calculation given on page 39, relating to the rate of transmission of heat from the fire to the water, was altogether misleading. The rate of flow of heat from the flame to metal did not vary simply as the difference of temperature. The results given by Mr Rowan would be approximately half the true results if the temperature of the metal on the fire side of the heating surface were 1500° Fah.; but it was evident that it could not possibly be at anything like that temperature, for if it were, the heating surface would be burned through in a week, and probably sooner. The quantity of heat flowing through the metal might be found by the following equation:—

$$Q = k\frac{T - T_1}{t}A$$

where Q was the quantity of heat transmitted in thermal units per second.

A, the area of the plate.

t, the thickness of metal.

$T - T_1$, the difference in temperature of the two sides of the metal.

k, a constant which, according to Angström, was equal to ·16 for iron when C.G.S. units were used. When using British units, k was equal to ·011.

e.g. If the rate at which the heat was transmitted through the metal was 20,000 British thermal units per square foot per hour; or the rate of evaporation roughly 20 lbs. per sq. ft. per hour, and the thickness of the plate or tube $\frac{1}{16}$ of an inch,

Then they had

$$20{,}000 = \cdot 011 \times \frac{T - T_1}{\frac{1}{16 \times 12}} \times 60 \times 60$$

$$\therefore T - T_1 = \frac{20{,}000}{16 \times 12 \times \cdot 011 \times 60 \times 60} = 2\cdot 6^\circ \text{ Fah.}$$

Therefore the difference in temperature between the two sides of the metal under the above conditions was only 2·6° Fah. Using Peclèt's results (not those given by Mr Rowan) in working out the above problem, the difference in temperature between the two sides was 12·5° Fah. But Peclèt's constant was obtained from measurements of the temperatures of the fluids on the two sides of the plates, and, although he used mechanical stirrers to rapidly change the fluid in contact with the plate, he did not and could not in this way determine the temperatures of the metallic surfaces. Fig. 54 was a copy of a diagram which he (Professor Watkinson) had used for some years, in order to show his students the approximate temperature gradients from the flame to the water. The most rapid fall in temperature took place near the surface of the metal on the fire side. Apart from the radiant heat, the rate of transfer of heat from the hot gases to the heating surface depended on the rate at which the hot gaseous molecules could be brought up to the surface, and then got rid of after they had been cooled. The difference in temperature between the water and the plate was taken as 10 degrees, and, when the circulation was rapid, this would never be exceeded in practice, unless there was a scale or other deposit on the metal. The thickness of the metal represented was $\frac{1}{16}$-inch, so that, when evaporating at the rate mentioned above, the temperature of the plate on the fire side would be 2·6° higher than the temperature on the water side, and the temperature of the plate on the fire side would be only 394·6 degrees. It was useful to remember that the low efficiency of the steam engine was due mainly to the great drop in temperature

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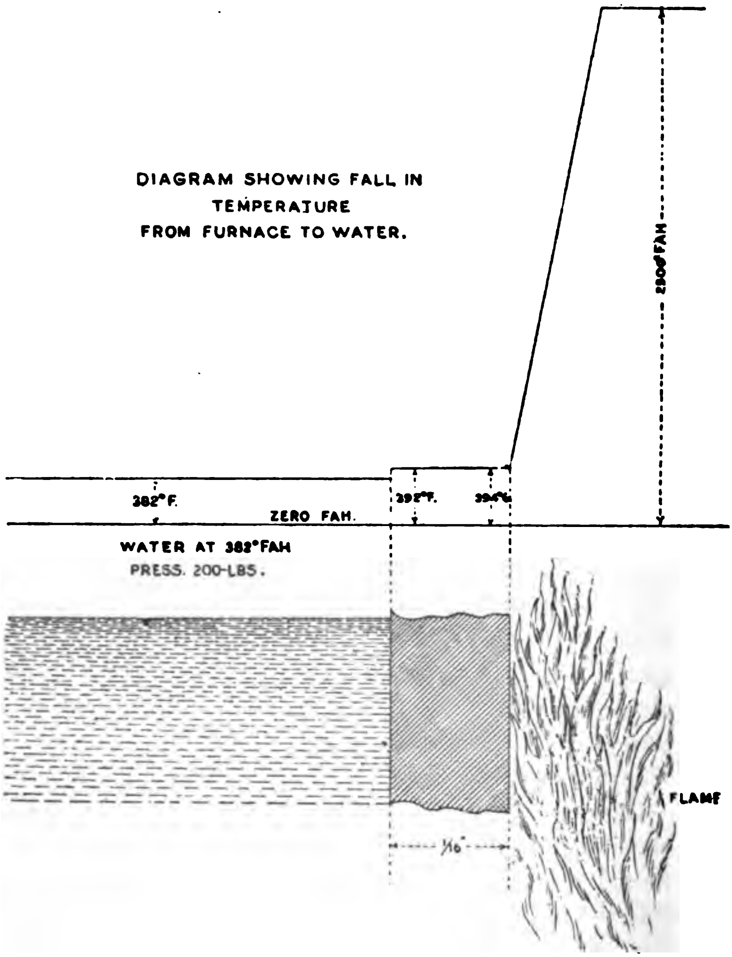
from that of the furnace to that of the steam. Figs. 55 and 56 were copies of diagrams which he had used for some years to illustrate

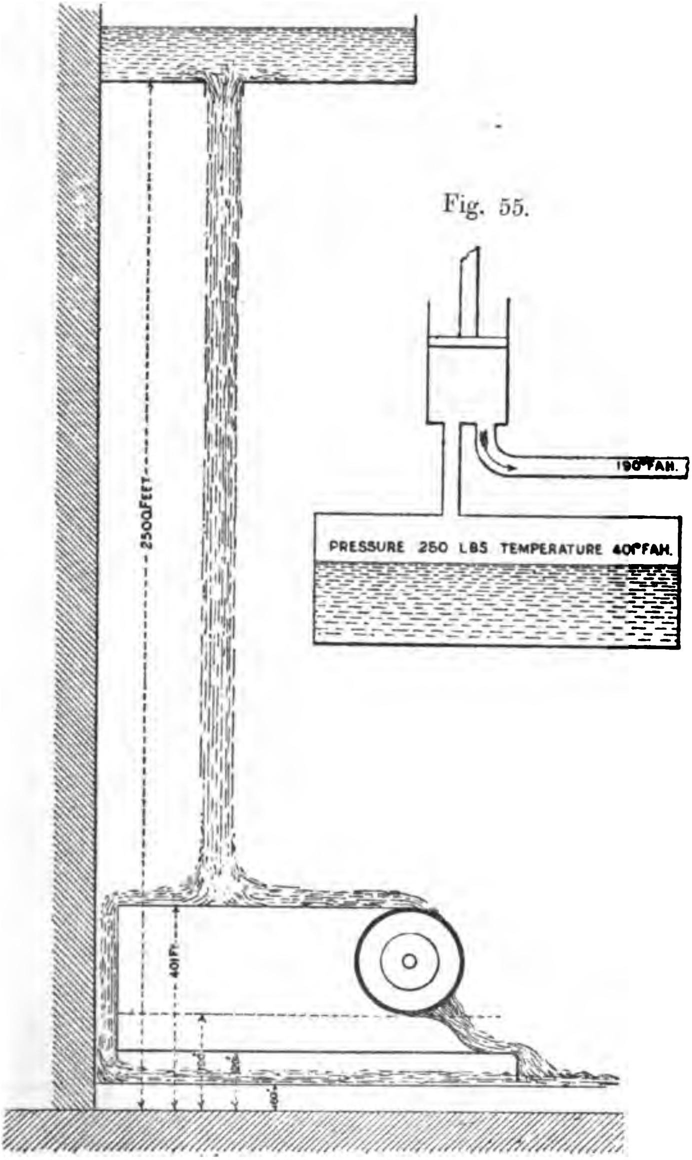
Fig. 54.



these losses. Fig. 55 was a diagrammatic view of an externally fired boiler, and an engine; the temperatures of the furnace, of the steam in the boiler, and of the steam going to the condenser were assumed

Fig. 56.

Fig. 55.


2500 FEET
401 FT.
190°FAH.
PRESSURE 250 LBS TEMPERATURE 401°FAH.

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to be 2500°,401° and 190°Fah. respectively. Fig 56 showed the analogous case of a water-fall and water-wheel; the water was shown falling from a height of 2500 feet, to a height of 401 feet, without doing any work; 30 per cent., say, of this water flowed away to the left, and fell again through the remaining distance without doing any work. That corresponded to the chimney and other losses at the boiler, the remaining 70 per cent. of the water entered the water-wheel, but during admission some of it leaked through the circumferential buckets into an inner circle of buckets, indicated by the inner circle; the loss due to that corresponded roughly to that due to cylinder condensation. The slight losses due to spilling from the buckets corresponded to the losses of heat from the outer walls of the cylinder of the engine, and the loss due to rejecting the steam at 190° Fah., instead of at the temperature of the condenser, say 120° Fah., was represented by the drop from the wheel to the level, 120 feet. That diagram showed how hopeless it was to attempt to get a high thermo-dynamic efficiency by means of steam. He heartily agreed with Mr Rowan's remarks under the head of "Forced Combustion," but he believed that in water-tube boilers it was possible to put the gas-producer within, instead of without the boiler, and thus secure many advantages.

In reply to a question by Mr A. S. Biggart, Prof. Watkinson said that he would be pleased to show his models, illustrating the circulation in water-tube boilers, at the next meeting, if it was the desire of the members that he should do so. He would have shown them earlier, only he did not like to obtrude them on the Institution.

On the motion of the President, the discussion on this paper was adjourned till the next meeting.

Correspondence.

Professor R. H. THURSTON—This subject, and the paper which had been here presented, were particularly interesting to him, for the water-tube boiler had been familiar to him from its first general introduction, a generation or more ago, and he had always felt certain of its ultimate use, in substitution for the shell boiler, which had been so often responsible for such fearful losses of life and property, and so invariably for serious costs of maintenance. As long ago as 1871, in a study of the famous American Institute trials of the various types of boilers then in the market—of which trials he had the honour and the pleasure to have had charge—he wrote, in conclusion of the report of the committee on the work*:—"The introduction of this class of steam boilers will do much toward the removal of the cause of that universal feeling of distrust which renders the presence of a steam boiler so objectionable in every locality. The difficulties in thoroughly inspecting these boilers, in regulating their action, and other faults of the class, are gradually being overcome, and the committee look forward with confidence to the time when their use will become general, to the exclusion of older and more dangerous forms of steam boilers." He saw made in his father's establishment, about 1856, the first Wilcox boiler; criticised for its inventors the first Babcock & Wilcox boiler; knew Mr Root, the designer of the tubular boiler of that name; and had at all the international exhibitions (including and since 1873) at Vienna, usually as a member of the International Jury, compared the types built in all countries; and had thus been gratified in being able to see the steady progress which had occurred in the direction of fulfilment of his prophecy. The water-tube, or "tubulous," boiler, as Mr Babcock proposed calling it, was now the recognised best standard type for stationary use in the United States, and largely so in Europe. Its history, however, ante-dated the time given in the paper. See the Greenwood-Woodcroft translation of Hero's Pneumatica, pages 100, 103, for two drawings of boilers of a semi-tubulous type, with gauge-cocks and feed-pumps attached properly. As early as 1787, Voight and Fitch put a "pipe-boiler" into their steamboat on the Delaware River, near Philadelphia. It was figured at page 238 of his (Prof. Thurston's) "History of the Steam Engine," Fig. 68. In 1793 Barlow and Fulton put a boiler, of what was here Class II., into a boat on the Seine. This was figured also in the same work, Fig. 70, p.

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* Trans. American Inst. of the State of New York, 1871.

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256. In 1805 Col. John Stevens patented in Great Britain a boiler, of which the following was the specification*:—"From a series of experiments made in France, in 1790, by M. Belamour, under the auspices of the Royal Academy of Sciences, it has been found that, within a certain range, the elasticity of steam is nearly doubled by every addition of temperature equal to 30° of Fahrenheit's thermometer. These experiments were carried no higher than 280°, at which temperature the elasticity of steam was found equal to about four times the pressure of the atmosphere. By experiments which have lately been made by myself, the elasticity of steam at the temperature of boiling oil, which has been estimated at about 600°, was found to equal 40 times the pressure of the atmosphere. To the discovery of this principle or law, which obtains when water assumes a state of vapour, I certainly can lay no claim; but to the application of it, upon certain principles, to the improvement of the steam engine, I do claim exclusive right. It is obvious that to derive advantage from an application of this principle it is absolutely necessary that the vessel or vessels for generating steam should have strength sufficient to withstand the great pressure from an increase of elasticity in the steam; but this pressure is increased or diminished in proportion to the capacity of the containing vessel. The principle, then, of this invention consists in forming a boiler by means of a system, or combination of a number of small vessels, instead of using, as in the usual mode, one large one; the relative strength of the materials of which these vessels are composed increasing in proportion to the diminution of capacity. It will readily occur that there are an infinite variety of possible modes of effecting such combinations; but, from the nature of the case, there are certain limits beyond which it becomes impracticable to carry on improvement. In the boiler I am about to describe, I apprehend that the improvement is carried to the utmost extent of which the principle is capable. Suppose a plate of brass of one foot square, in which a number of holes are perforated; into each of which holes is fixed one end of a copper tube, of about an inch in diameter and two feet long; and

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* Ibid., p. 266.

the other ends of these tubes inserted in like manner into a similar piece of brass, the tubes, to insure their tightness, to be cast in the plates; these plates are to be inclosed at each end of the pipes by a strong cap of cast-iron or brass, so as to leave a space of an inch or two between the plates or ends of the pipes and the cast-iron cap at each end; the caps at each end are to be fastened by screw-bolts passing through them into the plates; the necessary supply of water is to be injected by means of a forcing-pump into the cap at one end, and through a tube inserted into the cap at the other end, the steam is to be conveyed to the cylinder of the steam engine; the whole is then to be encircled in brick-work or masonry in the usual manner, placed either horizontally or perpendicularly, at option. I conceive that the boiler above described embraces the most eligible mode of applying the principle before mentioned, and that it is unnecessary to give descriptions of the variations in form and construction that may be adopted, especially as these forms may be diversified in many different modes." Boilers of the character of those described in the specification given above were used on the locomotive built by John Stevens in 1824-'25, and one of them remains in the collections of the Stevens Institute of Technology; which institution was founded by one of his sons, who employed capital largely acquired in the later successful introduction of steam navigation on the Hudson, Delaware, and Connecticut rivers.* The same inventor

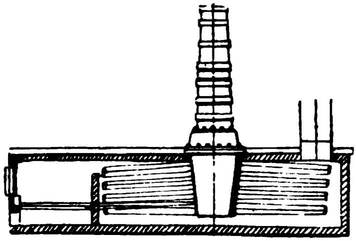

Fig. 57, Stevens' Steam Boiler, 1804.

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* Ibid., Fig. 3, p. 264.

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employed a boiler of the form here shown, Fig. 57, in a *screw-boat*, built by him in 1804, or earlier, and in the same boat fitted with *twin-screws* in 1805.* "It was quite similar to some now known as sectional boilers, and contained 100 tubes, 2 inches in diameter and 18 inches long, each fastened at one end to a central water-leg and steam-drum, and plugged at the other end. The flames from the furnace passed around and among the tubes, the water being inside them. The engine was a *direct-acting high-pressure* condensing engine, having a 10-inch cylinder, 2 feet stroke of piston, and drove a *screw* having four blades, and of a form which, even to-day, appears quite good. The whole is a most remarkable piece of early engineering."* The specification above quoted is a most remarkably clear and complete exposition of the principles upon which the construction of this class of boilers is based. None better has been written up to the present time. In the author's "Class IV." should, he thought, be placed the "Lamb and Summers" boiler of about 1860, a good specimen of which he remembered seeing in a ship at Aspinwall during the American civil war, when the "double-ender" gunboat to which he was then attached visited that port, convoying a Pacific Mail Co.'s boat which was thought possibly endangered by the presence of a Confederate naval vessel in the Gulf of Mexico, or on the coast. It may interest the readers of these remarks to see the various forms of water-tube boiler now built and actually in the market in the United States. The following were some of the boilers exhibited at the International Exposition of 1893 at Chicago:—

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* Ibid.

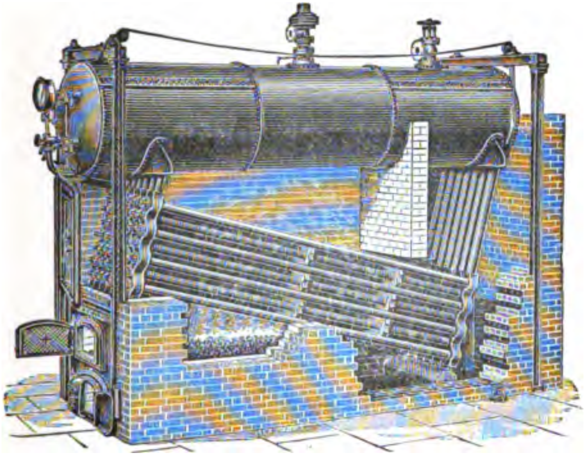

Fig. 58. Babcock and Wilcox.

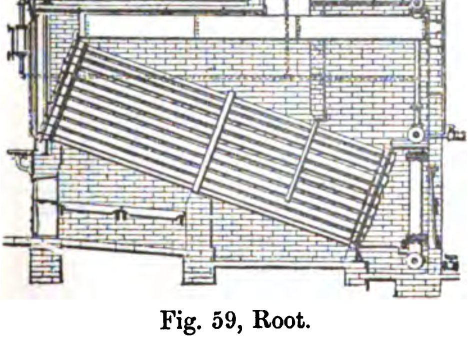

Fig. 59, Root.

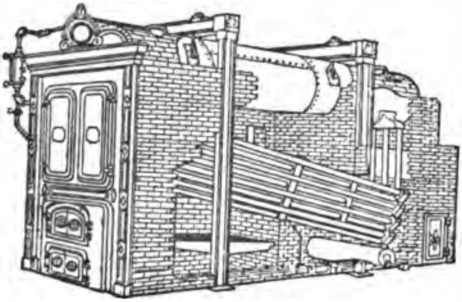

Fig. 60, National (Kelly).

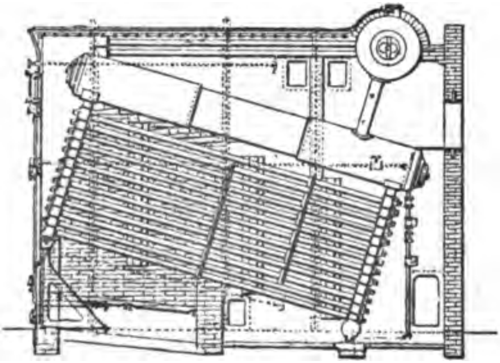

Fig. 61, Zell.

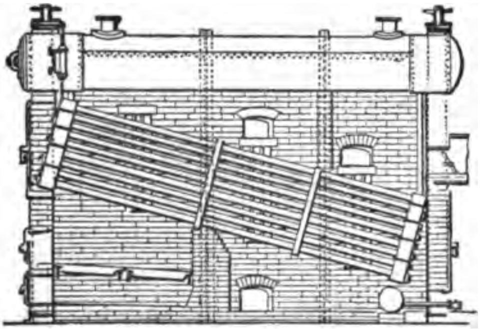

Fig. 62, Gill.

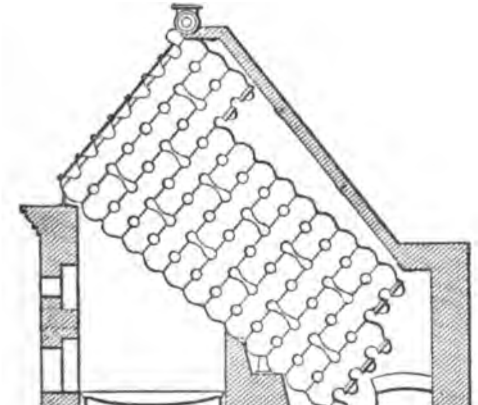

Fig. 63, Harrison (1876).

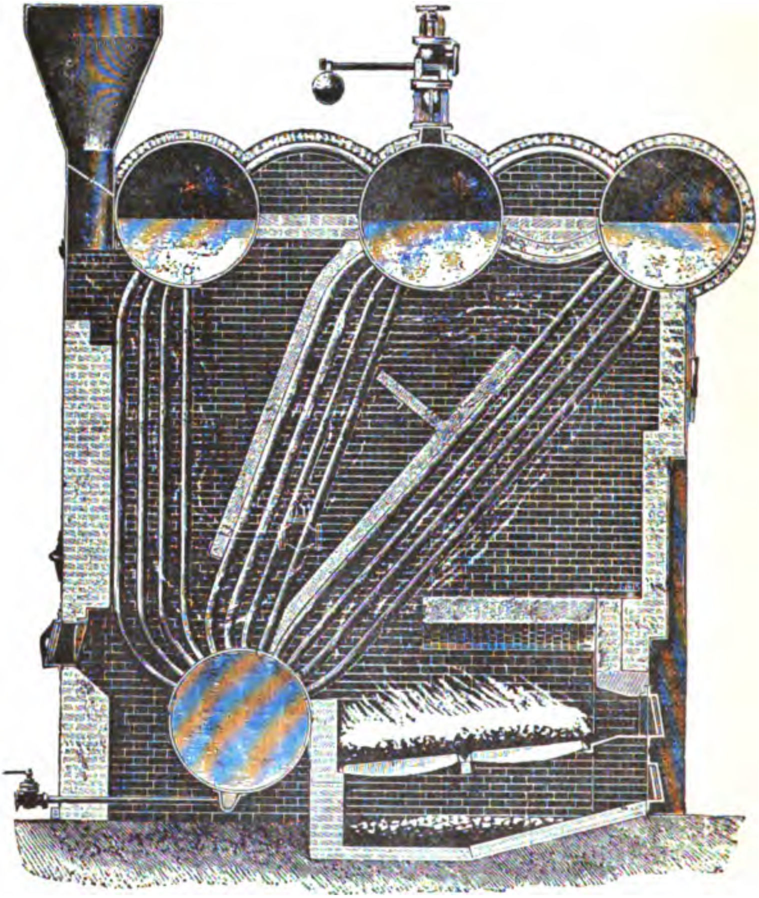

Fig. 64, Stirling.

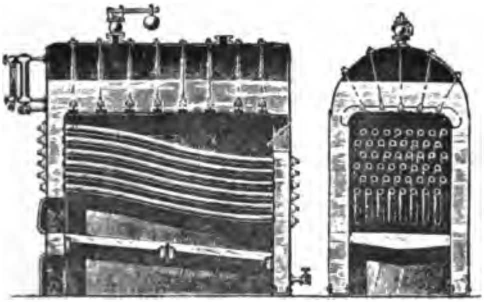

Fig. 65, Wilcox design (1856).

The original Wilcox boiler of 1856, Fig. 65, is added to the list, though not in use at the date mentioned, in order that a comparison might be made with its numerous progeny of the next generation. The number of forms which had recently been introduced was most extraordinary, and the ingenuity displayed in reconstructing old designs, and in securing every imaginable arrangement of water-tubes, and of steam and water and mud drums, to produce a boiler that could be sold as new and original, had been no less remarkable. But they all reduced to a few fundamental types, all of which had not been long known. Experience in this country had been very satisfactory with the stationary water-tube boiler, but much less so with the marine forms. There seemed no satisfactory reason for so marked a difference in experience, and he was compelled to believe that, after a little experience in handling them, and especially after the existing prejudice against them on the part of the men in charge had worn off, they would become as common at sea as on shore. Prejudice always counted for much in such matters. He attempted to introduce an " Injector " on the Providence and Stonington Railway in 1860. After much persuasion of an old friend who happened to be the " master mechanic," he secured permission to try it. He put it on the engine hauling the fast steamboat train, leaving Providence at 7-15 in the evening, and returning at early daylight next morning. He made every trip with the engine for several days, and without trouble. The day after he left the engine and the injector, the latter

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was taken off at the request of the engine-driver. Yet, to-day, all engines are fitted with it. Experience at sea with the water-tube boiler was now passing through this friction-creating stage. Durability was a marked feature of this class of boiler with them, and the cost per horse-power hour or year was remarkably small, as reckoned on the repair and maintenance account. Their most extensive builders, after obtaining the statistics of between 100,000 and 200,000 H.P. of their boilers in use, and from one to above twenty years' service, reported these costs, as an average, to fall under five cents per horse power year. As to economy, they found records of trials in which an aggregate of above three thousand tons of water was evaporated by two hundred and seventy tons of fuel, an average efficiency which he thought the older types of boiler did not attain; it was within ten, perhaps seven, per cent. of unity efficiency. During an experience in professional work of now thirty-five years, and dating from the earliest days of commercial use of this class of boiler, he had never known of their causing loss of life or of property by explosion. The comparatively few minor accidents recorded, had been due to isolated cases of incomplete utilisation of the fundamental principles of construction, or to exceptional mismanagement. If properly built, and maintained in good order by regular and wise repair, they practically never wore out, and never endangered life or property. They bore hard driving, and to an extraordinary amount; he thought their record was to-day vastly higher in this respect than any shell boilers. They enormously economised weight and space, and had always seemed to him certain, in time, to displace the older types, even at sea, where, indeed, they were particularly needed. Their latest experience with them lent additional confidence in their ultimate adaptation to even this trying duty, and, if steam pressure continued to rise fifty per cent. per decade, it could not be long before they would entirely supplant the shell boiler in all naval and long-voyage craft, and probably in all sea-going ships. The report of the Engineer-in-Chief of the United States Navy, just issued, dated October 1st, 1897, includes the following statements relative to the introduction of water-tube boilers into the batteries of boilers on naval vessels, a movement of supreme importance, and one which had, as already noted, been going on for a long time in that service:—"The gradual replacement on war vessels of the familar cylindrical boiler by various forms of the water-tube boiler constitutes the most important fact in marine engineering at this time. For torpedo boats their superiority was so evident that they quickly displaced the older type and have been used exclusively for some years, although their first appearance (on the *Ariele*) was only ten years ago. The particular form used in torpedo boats is, however, of such light scantling that hitherto there has been a fear that its longevity would not be sufficient to warrant the use of such boilers in large vessels. A different form has been in use in the French navy since 1879, and has also been used in other navies, in some very extensively, but the saving of weight due to its use has not been so great as seems desirable if the cylindrical boiler is to be definitely abandoned. In 1888, this Bureau, alive to the supreme importance of light machinery for naval vessels, advised the Department to invite a competition of manufacturers of water-tube boilers with a view to the adoption of the successful one for use in a naval vessel. As a result of this action, coil boilers were installed in the *Monterey* in 1892, and have been in successful use ever since This was the first instance of the use of light water-tube boilers for a large power (over 4,000 I. H. P.) on a large ship. It would have been easy for the Bureau to gain a cheap reputation for progressiveness by adopting this type of boiler at once for all ships, but there had not been sufficient experience in the use of these boilers for extended cruising at sea to make such a step judicious and for the highest efficiency of the fleet. The *Monterey* was expressly designed for coast defence, so that she would always be near repair shops if necessary, and her case was different from that of ships designed for general cruising. The conditions of the building of our new Navy made it imperative that every unit should be absolutely reliable. We were not adding to a navy up to date, but were replacing obsolete ships with modern ones. With only three battle ships in commission, we could not experiment on the few

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additional ones authorised. Consequently, although realising the advantages of a reduction of boiler weights, if obtained without sacrificing reliability, the Bureau has used cylindrical boilers in the recent battle ships. Meanwhile experience of our own has been acquired from the service of the *Monterey*, the *Cushing*, and the *Ericsson*, and careful attention has been paid to what is doing in the merchant marine and in foreign naval services. The last report of the Bureau showed the adoption of Babcock & Wilcox boilers for the *Chicago* and for the *Annapolis* and the *Marietta*. Since then it has been decided, in the modernising of the *Atlanta's* machinery, to use this same make of boiler for about two-thirds of her power. The *Nashville* has Yarrow boilers for about the same fraction of power. As is shown elsewhere in this report, the *Annapolis*, *Marietta*, and *Nashville* have passed their contract trials successfully and there water-tube boilers were entirely satisfactory. The Bureau feels that, with the experience now gained, the efficiency of the fleet will be best served by using water-tube boilers on future ships. As yet it can certainly not be said that any one of the numerous varieties of water-tube boilers is absolutely the best. Some of the ablest engineers in the world, who to cultivated talent add vast practical experience, have identified their names with particular forms of this type of boiler, and it is probable that, as experience accumulates, a form of boiler will be evolved embracing the best features of all of them. With respect to the form used on our recent ships—the Babcock & Wilcox—it may be said that it is a marine form of their well-known land boiler, which is used extensively all over the world, and which has all essential features in common with a number of other well-known land boilers, so that the fire-room force of our ships is more likely to have some acquaintance with this boiler than others of the type. The straight tubes can be readily removed and replaced, and can be purchased wherever engineering materials are kept in stock."

Admiral J. H. SELWYN—Having, as he believed, been the first to differentiate certain types of boiler by the name of "Tubulous," in order to separate them from "Water-tube" boilers, whose name was legion, Admiral J. H. Selwyn.

perhaps he might be allowed, by way of remarks on Mr F. J. Rowan's paper, to state what he understood to be the true characteristics of the Tubulous boiler.

(1) No boiler in which the circulating tubes are bent or twisted, and used as legs is a Tubulous boiler.

(2) No boiler in which there is a difference in the diameter or thickness of the water tubes, is a Tubulous boiler.

(3) No boiler is fit to be called a Tubulous boiler, of which the tested pressure is less than 2,000 lbs. on the square inch.

(4) No boiler is a tubulous boiler which is not worked continuously at above 300 lbs. on the square inch, during its whole life of at least 30 years.

(5) No boiler deserves the name of Tubulous boiler whose margin of safety is not tested and certified to be four times its working pressure, every year of its life.

(6) None are Tubulous boilers that do not peroxidise automatically the whole interior surface at the permanent working pressure.

(7) If the working pressure ever requires diminution, on account of rust or wear, that is not a Tubulous boiler—maltreatment is of course not included.

(8) No *seams*, *stays*, *rivets*, or *holes for tube ends* must be permitted in a Tubulous boiler.

(9) When under full steam if a shot should strike and perforate the boiler, there should be no dangerous escape of steam, and no injury that cannot quickly be repaired— certainly no explosion —in a Tubulous boiler.

(10) A Tubulous boiler must be capable of being at any time renewed or repaired in the stoke hole, without any cutting of decks or bottom plates.

As far as he knew those conditions were only to be found in the boilers designed and manufactured by the late Mr Loftus Perkins, and until better informed, he should continue to regard those boilers as the most perfect form for marine use, if not for all steam raising purposes. They fulfilled, more than any others, the desiderata of great economy, abnormal durability, and perfect safety. As to priority in the use of really high pressure steam, the three Perkins, Jacob, A. M., and Loftus were first, and all the rest nowhere, as the Patent Office records clearly show. Of incompetent and unblushing imitators there were dozens, but not one yet had dared to soar to their height.

Mr J. I. THORNYCROFT—Mr Rowan considered no apology was necessary for adding another to the existing papers on water-tube boilers, and that idea might be entertained if he had either brought improved construction to notice, or shown more clearly what were the faults of the old, but that he had not done. The author claimed to have first proposed the use of "three horizontal chambers connected vertically by bent water-tubes," but that was a mistake; that construction was patented by Clarke and Motley in 1849. With regard to the classification of boilers given by the author, he found that many errors had been made; the boiler of the "Peace" was not a "coil boiler," and also the dates given for the origin of many forms were not the earliest on record. Mr Rowan credited him with having given incorrect historical information in connection with water-tube boilers. Priority of invention was not considered a subject open to discussion at either the Institution of Civil Engineers, or the Institution of Naval Architects, and he (Mr Thornycroft) did not attempt to give a history of their origin, and with regard to the statement that he had copied Mr Rowan's boiler, that was not correct; the two boilers were as dissimilar as their performance. On page 35 of Mr Rowan's paper he said that Mr Thornycroft introduces the boilers of the "Propontis" as an awful example. He thought Mr Rowan would find that the unsatisfactory nature of those boilers was demonstrated at a previous meeting to the one referred to by Mr Rowan (namely at the Institution of Naval Architects the same year), by the discussion which followed a paper on "Water-tube Boilers for War-ships," by himself, when Mr Parker exhibited a piece of tube from the "Propontis" boiler, which contained a scale of nearly $\frac{3}{16}$-inch in thickness, and said that the failure of this boiler had kept back the great introduction of Dr Kirk's triple-expansion engine for nearly ten years. Mr Rowan

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would have them believe that he was the only one who understood the theory of circulation in steam boilers; it would appear however, that even he called in more elements than necessary to explain what took place. Mr Rowan said "in the heating of water two forces combine to cause the upward movement of the heated particles, namely the expansion of the water by heat and the action of gravity." As a matter of fact circulation depended on gravity, and gravity was the only force by means of which the water would be circulated. Expansion by heat, and even the formation of steam, would not provide circulation without gravity, but simply drive away the water from the heating surface in the path of least resistance, independent of whether that was upwards or downwards. It also appeared that Mr Rowan termed the element of temperature "vital," but in doing that he was splitting hairs; saturated steam was always supposed to be of the same temperature as the water producing it, and a volume of steam under the additional pressure of a column of water found in an ordinary boiler, required a very slight addition to its temperature to support this column, while the circulation depending on that immersed volume was in no way affected by the temperature itself. No practical difference would be made in the conditions for circulation if air took the place of the steam, and the whole contents of liquid and gas were at one and the same temperature. He would be glad if Mr Rowan would explain what he meant by a "mechanical entraining action of bubbles." With regard to the intermittent character of discharge from generating tubes, what he (Mr Thornycroft) had described was simply the result of what he had seen, and the idea was not the result of any theory that he claimed. For the theoretical explanation of this action, he would refer Mr Rowan to Professor Osborne Reynolds. In contradiction of what Mr Rowan had said he wished to say that periodic discharges should, and did take place in efficient steam generators. Mr Rowan had taken much pains to discredit his reading of the experiments made with two small boilers, the details of which had been given partly at the spring meeting of the Naval Architects in 1894, and partly at their summer meeting of the same year. Mr Rowan did not refer to

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the first paper, and appeared to be ignorant of the fact that the flow of water down the down tubes was measured for both those boilers. He (Mr Thornycroft) therefore did not rely "entirely on the indications of water gauge or column connected with the upper and lower chambers" for information as to what had taken place. The principal object of the second paper was to show that the safe rate of working in boilers with drowned tubes, was not so high as in those where the tubes discharged above water, other things being as nearly as possible the same; and further, that the lack of a special down tube further diminished the safe rate of working. It seemed needless to say that when a boiler was nearly filled with foam, a condition which Mr Rowan suggested, rapid natural circulation was impossible, and even in this case, he (Mr Thornycroft) would claim, the test column was not illusory, but the steam generator would be in a dangerous condition.

Mr George Halliday—Mr Rowan's historical delineation of the chief types of boilers was most pleasing. He gave but a hint of the origin of a group, and the present day forms of that group stood at once alone and apart from all the others. It was always clear that the Thornycroft, the Yarrow, the Fleming and Ferguson, and the Normand had a common origin. Some thought, however, that the Thornycroft came first. The author's modesty had till now hid from them that the best of the water-tube boilers, just as much as the best of the cylindrical tubulous boilers, was of Scottish origin. His paper provided them with another historical treat. It would be news to many that boiler tubes closed at one end, and with an internal circulating tube, should have the generic name of Perkins instead of Field, and that Griffith was the parent name of boilers of the Belleville, Root, Dürr, and Lagrafil-D'Allest type. Water-tube boilers of the Griffith type were perfectly understood. The controversy now confined itself entirely to the question of circulation, and the principles which governed the construction of the perfect express water-tube boiler; for the ways of the express water-tube boiler were not by any means understood. Mr Normand's paper, read at the Institution of Naval Architects in 1896, gave anything but a clear

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idea of what went on, and in his conclusions he sometimes came into direct disagreement with Mr Thornycroft. Some of the experiments he cited in support of his opinions were not fully convincing. To resist the effect of intense firing on the tubes, M. Normand favoured rapid movement of the water through the tubes. He thought the tube which entered the upper drum in the water space best; the arguments mentioned seemed to favour that which entered in the steam space. M. Normand held that active movement of the water was most favourable to vaporisation, and concluded that rushing the water through the tubes was the supreme good, and whichever tube favoured that was the best tube. Others held, and with great reason, that circulation in itself was an evil. If they were right, then the most rapid circulation was not the supreme good, and the tube which promoted it most was not necessarily the best tube. Circulation in these express water-tube boilers was indispensable; but the boiler which promoted the most rapid circulation might not be the best. Circulation should be sufficient to prevent steam remaining in contact at any part of the tube for any length of time. That provided for, would be sufficient. The saving of the tube from "burning" was not the aim and end of the design of the boiler. The boiler was primarily designed to provide steam. To save the tube from being "burned" was a secondary point. The "burning" of the tube would depend on the intensity of heat, and the rapidity with which the heat was carried away by the water. For the most rapid production of steam, the longer the water took to go along the surface of the tube, the better. Should the water move too slowly, only steam might be left in contact with the tube. The rate of motion of the water lay between good and evil. There must be a right rate of motion which would be a function of the intensity of heat of the furnace. That rate of circulation would be the best. When the upper end of the tube entered the upper drum below the water level, the bubbles of steam had to pilot their own way through the water in the drum. The bubbles of steam did not get directive assistance. Even with that resistance it might be an advantage to the boiler; for the resistance might provide longer and better contact of the water with the surface of the tube,

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and by that produce better vaporisation. When the author estimated the quantity of heat which might be transmitted through a square foot of iron ⅛-inch thick, had he allowed for the enormous resistance offered by the skin? To say that heat would travel at a certain rate through iron of a given thickness was not the whole question. That, indeed, was the least part of the question. If they could tell how rapidly it would be transmitted across a contact joint of two metals, or across any gap, they would get nearer the solution. It was the resistance of the passage of the heat of the flame to the surface particles of the iron which was the first difficulty. There was another, and he thought worse, in getting the surface of the iron on the other side to give up its heat to the surface of the water. When there was scale on both sides of the iron, the resistance was still further enormously increased. The resistance through the first scale itself, through the iron itself, and through the second scale itself, was simply nothing compared with the resistances of the contact joints. A wire, with the circuit complete, offered comparatively little resistance to the electric current; but if the wire was broken, and the current made to leap over a gap, the resistance would be increased. To himself, the vibratory theory of heat explained it all. So long as the medium was uniform and of the same material, the vibrations were transmitted from one place to another with great facility. If the vibrations were made to jump from one body to another, or through a series of bodies; from flame to scale, from scale to iron, from iron to scale, and from scale to water, then it would be seen how the whole thing would be changed, and how much a laboratory formula, for iron alone, would do for them. Incidentally, M. Normand told them in his paper that petroleum could only be properly consumed in a separate refractory chamber. Mr Rowan suggested that the furnace should be separate from the tubes, and that full combustion should take place before the hot gases were allowed to touch the tubes. A separate refractory furnace into which could be introduced petroleum might be productive of further economy.

Mr C. H. Wingfield—As the author spoke of his paper of 1878 as if it were an epoch-making one, he (Mr Wingfield) had referred to the reprint in *Engineering* (Vol. xxvi., pp. 164 and 183) with some interest, but found in it absolutely nothing but what was already public property at the time, unless, indeed—which he doubted—the author's proposal to allow a slight scale to form on the plates, etc., as a protection against corrosion, was then new. The following was a *précis* of the paper:—In it Mr Rowan copied Professor Osborne Reynold's advocacy of high pressure steam; recommended forced draught, and quoted experiments showing increased efficiency; proposed to lead the furnace gases downwards, and gave reasons for doing so (this plan, and the reasons, being at the time well known); assumed *(quite wrongly*)* that the flow of heat from gas to water through a boiler plate varied directly as the difference of their temperatures; insisted on the importance of circulation, and on the necessity of *separate* down-take passages, to get best results, (these had been included in patented boilers over and over again); considered vertical tubes the correct ideal, and said the cause of circulation was that "heated portions of water, and the steam when generated, sought a directly upward means of movement or escape;" pointed out that his father advocated fresh filtered feed-water for marine boilers; and, lastly, that he himself proposed to deposit a thin soluble scale on the heating surfaces, in 1876. What part of that paper it could have been the desire of the Institution of Naval Architects to suppress as "revolutionary or disturbing," as the author fondly imagined, did not appear; but it was to his credit that, before writing it, he had so evidently read up what had been done, although—doubtless by accident—no mention was made of his revolutionary and disturbing facts having all been patented, or otherwise published, long before. Water specially distilled for boilers, for instance, was advocated at least as early as 1834 (see Hall's patent of that year, No. 6556). Condensed water from the surface condenser was used much earlier. The author referred to some historical points as not having been correctly stated by Mr Thornycroft. Of course, Mr Thornycroft did not attempt in his paper of 1889 to give the history of water-tube boilers, but

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* "Engineering, LX., p. 50, and Rankine's "Steam Engine," p. 260.

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merely selected some half-dozen typical examples of the points in design which he desired to illustrate. He should like, however, to know, to which of these historical illustrations Mr Rowan referred as not being "correctly stated." Water-tube boilers were among the earliest steam generators known; but, sometimes from faulty design as in the "Propontis," or sometimes from bad management, they became discredited; and it was a matter of common knowledge that the modern "boom" in water-tube boilers, to use an American expression, took its rise from the date of Mr Thornycroft's paper, of 1889, describing the successful application of his own boiler to torpedo-boat purposes and the economical results obtained with it. Mr Rowan thought the view that the water-tube boiler was "only a modern outgrowth designed to meet the defects and evils of the Scotch or cylindrical boiler" was wrong. There could be little doubt that that was one cause of its adoption in modern vessels, but, of course, no one said water-tube boilers were a modern idea. The evils referred to had long been patent to many, and naval engineers abreast of the times had only been waiting for a suitable design to appear, before condemning the Scotch boiler. Sir A. J. Durston, the Engineer-in-Chief of the British navy, speaking of the high pressures now common in the navy, said it was "necessary to turn to some type of boiler that contained less flat and thickly stayed surfaces."* Perhaps, however, Mr Rowan knew better! He thought the author had attempted to class water-tube boilers under too few heads, and he would venture to correct a few of his historical points. In the first place, Woolf's was by no means the first water-tube boiler. Rumsey patented one in 1788, and Blakey made a boiler in 1774. The latter, which was illustrated in Clarke's "Steam Engine," was possibly the first water-tube boiler, unless, indeed, the steam gun which Bourgeois exhibited before Louis XIII., prior to 1605, could be called one!

In Class I., he thought, the "Howard" marine boiler should be omitted, as it had inclined tubes.

Class II. should, he thought, be further subdivided into, say—

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*Minutes of Proceedings Inst. C. E., CXIX., p. 86.

(*a*) Boilers in which the tubes were connected "in series," so as to form a zig-zag course for the steam bubbles to follow. This would include Blakey, 1774; Rumsey, 1788; Seaward, 1819; Griffith, 1821 (the boiler figured by the author did not agree with Griffith's patent); Pearson, Witty, and Gillman, 1826; Perkins, 1827; Poole, 1829; Perkins, 1855; Benson, 1858; Belleville, etc. (*b*) Boilers in which horizontal, or nearly horizontal, tubes were connected "in parallel" with two headers, so that a steam bubble could reach a header without traversing more than the length of one tube:—Stevens, 1805; Hill, 1840; Root, 1869; Watt, 1871; Babcock & Wilcox; Heine, 1881; Lagrefel d'Allest; Oriolle, etc. (*c*) Nearly horizontal tubes, closed at one end, and opening at the other into a header:—Alban, 1843; Howard (marine), 1871; Lane, 1885; Niclausse; Dürr, etc. With the exception of Alban's boiler, all these had internal return tubes somewhat like Field's.

Class III.—(*a*) Coil boilers appeared to have been introduced at least as early as 1824, by Paul. Others were those of Rawe & Boase, 1830; Dance, 1832; Morgan, 1838; James, 1838; Beale, 1840; Isoard, 1855; Herreshoff; Matheson; White, etc. (*b*) Non-continuous and semi-circular or incomplete coils:—Goldsworthy Gurney's boiler of 1825, was not of this class, each pair of tubes being S shaped; the one figured by the author was patented in 1827. Others included those of Brunton, 1831; Dance & Field, 1833; Ward, etc.

Class IV.—The author thought no boilers having leaves or cells had been attempted, except those of Rowan & Horton, since Hancock's boiler of 1831. He would only mention a few invented by—Teissier, 1825 (here the leaves are combined with tubes); Hancock, 1827; Hancock, 1833; Brunton, 1831; M'Curdy, 1835; Collier, 1836; Anderson, 1837; Gillman, 1837; and perhaps Church's boiler with embossed plates, somewhat like Hancock's joint cells, might be added, although complicated by fire tubes running through them. In connection with Hancock's boiler, it was not generally known that he at first used a boiler with horizontal tubes connected at their ends, Fig. 66. This he abandoned for his boiler of 1827, consisting of

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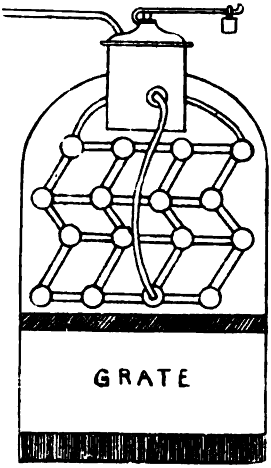

Fig. 66, Hancock.

flat leaves, stayed with partly countersunk rivets. These latter gave trouble by leakage, and he patented in 1833, the boiler shown in Fig. 20, in which the sides of the chambers were covered with bosses. These bosses were brought into contact so that each vessel supported its neighbour, while room was left for the passage of gases between the cells. He also patented a boiler the cells of which had corrugated iron sides.

Class V.—An earlier boiler than those given by the author, with depending tubes, was that of Trevithick, 1815. It had no internal circulating tubes, however, and in that respect resembled Allan's boiler of 1871. Perkins added these in 1831; and was followed by Prosser, 1839; Joly, 1857; Barrans, 1860; Howard, about 1867; the Field boiler, etc. The Niclausse tubes were so nearly horizontal that they properly belonged to Class II. (*c*). He was not acquainted with Mr Thom's boiler.

Class VI.—The author had included in this class slightly bent tubes and nearly vertical. That put the date back at least to 1822. (*a*) *Vertical* water tubes, or with top and bottom ends plumb with each other, their ends connected :—Clark, 1822; Moore, 1824; Eve,

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1825; Hall, 1828; Summers & Ogle, 1830; Trevithick, 1832; Maceroni & Squire, 1833; M'Dowall, 1834; Craddock, 1840; Ditto, 1846; Jordan; Rowan & Horton, Fig. 21; Rowan, Fig. 33,*b*. (*b*) Slightly sloping tubes, straight, or nearly so, connected top and bottom:—The boilers of the "Murillo," the "Propontis," etc.; boilers of Rowan & Horton, Fig. 29; Stirling, etc.

Class VII.—Boilers in which there was no reserve of water, the feed being brought in contact with hot metal surfaces in the form of spray or otherwise, so that it flashed into steam. The author thought Serpollet's the only boiler of that type, but the fact was, it was rather a favourite idea with inventors of early boilers. Possibly John Payne's boiler of 1736, was the first to work on that principle. With it he evaporated 90 gallons of water with 112 lbs. of coal. Others were invented by Pitts and Strode, 1792; Dale, 1793; Willcox, 1801; Congreve, 1821; M'Curdy, 1824; Howard, 1832; Schafhautl, 1836; etc.; and the same idea was revived (in a modified form) by Herreshoff, and in 1883 by Gill.

Class VIII.—The author claimed to have first proposed and illustrated, in 1876, the use of three horizontal chambers arranged like the points of an inverted V. He (Mr Wingfield) did not know when they were first introduced, but they appeared on the boilers of Clarke and Motley, 1849, Fig. 67, and Fryer, 1874. The boiler of Johnson, Fig. 68, 1855, was interesting, as it was practically a wet-bottom boiler of the Clarke & Motley, or Yarrow type. The author's attempt to claim all the modern boilers was more far-fetched than if, for instance, anyone suggested that the idea of the sections of the "Propontis'" boiler was taken from Newton's patent of 1849! There was about as much, or as little, in common He thought a wide distinction should be made between the Thornycroft boiler and its imitations, which discharged the steam and water above the water line, and those which delivered below water, on account of the great difference in the rate of circulation. He did not propose to deal with circulation on this occasion, although the author was, he thought, somewhat at sea on that subject, and he would not go further into historical matters.

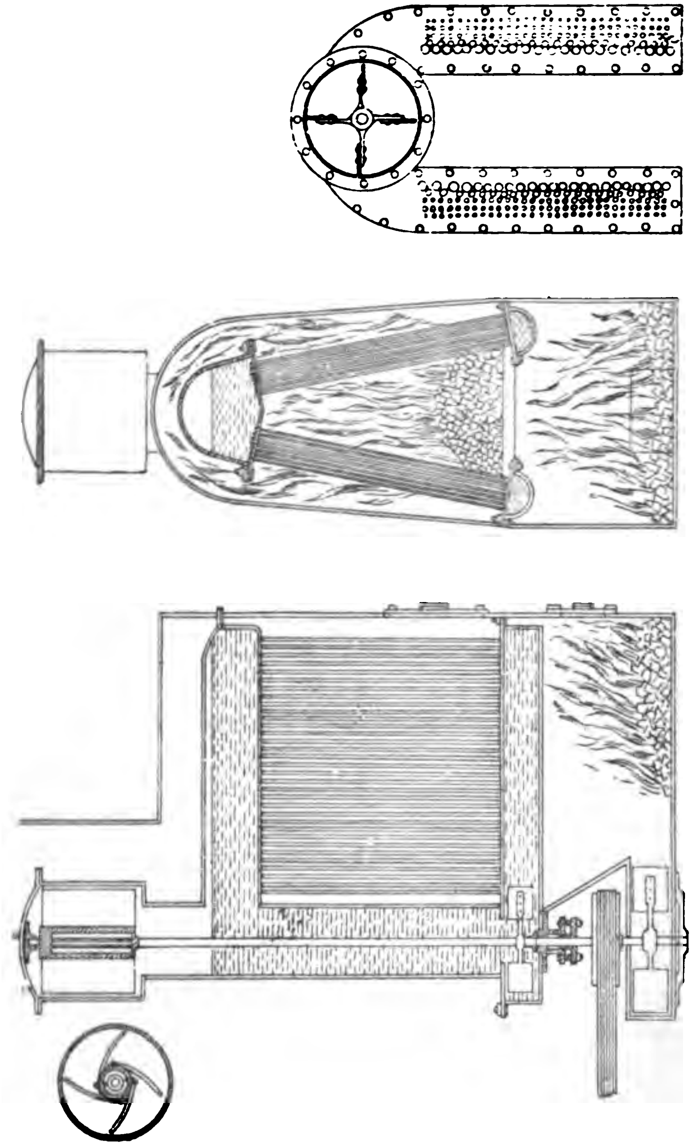

Fig. 67, Clarke and Motley.

The author considered Mr Thornycroft's statement inaccurate to the effect that Mr Flannery's paper and its discussion proved that "water-tube boilers *as then made* were unsuitable, because the tubes forming the heating surface were burnt owing to insufficient circulation." He further said "the reason then given by Mr Thornycroft is not borne out by the paper and discussion referred to, nor was Mr Thornycroft's account . . . . of the action of the Rowan and Horton boilers of the 'Propontis' correct in almost any particular.

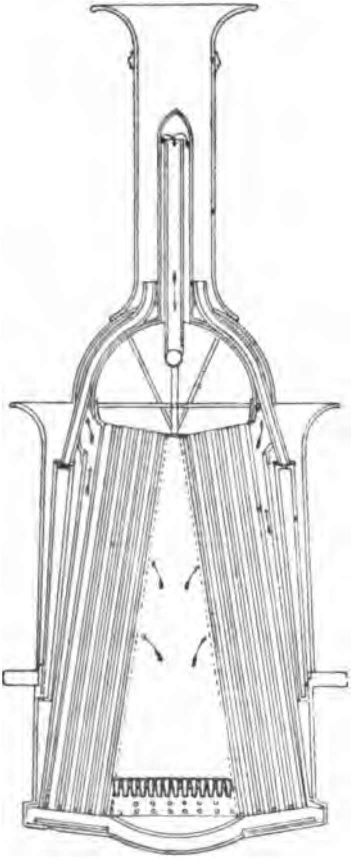

Fig. 68, Johnson.

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The failure of any of the 2½-inch vertical tubes . . . . was in no way connected with any fancied effects of insufficient circulation, nor occasioned by it, nor by the accumulation of impurities brought in with the feed-water, which was filtered. The salt-water scale found in some of the tubes . . . . was purposely made and with great difficulty." "That difficulty of formation was due to the rapid water circulation," and so forth. Now, to contradict a thing, as the author had done, was very easy, and sounded very well, but it was quite another thing to disprove it, and it would be interesting to know, not how positively the author could contradict, but how he could disprove the correctness of the following passages:—Mr Flannery's paper would be found in "Engineering" vol. XXI. pp. 318 and 349. It described the trial and failure of various water-tube boilers. (*a*) After describing the faults in the design of the "Montana's" boilers (in which the lower ends of the water chambers were connected, while the steam outlets from some of them were too small), Mr Flannery pointed out that "the natural action of the steam generated in these sections was therefore to rise to the top tubes, to accumulate there, and to depress the level of the water, driving it out through the bottom pipes from all that vertical section of tubes, and finally exposing to the direct action of the fire a bottom tube filled only with steam, or steam and a small quantity of water. This is exactly what did take place, and on the first trial passage of the vessel from the Tyne towards the Mersey five of the tubes burst." Did Mr Rowan consider there was good circulation here? If there had been, the lower tubes could not have been filled with steam as described. One would have thought that with that experience Mr Rowan would have done better another time, but, on the "Propontis," a similar error was made, and insufficient connection between the steam chambers caused the water level to fluctuate as much as five feet. With the water several feet below the tops of the down-take tubes* it would be interesting to know

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* In Figure 29 of the author's present paper there were shown what appeared to be gauge glasses well below the tops of the down-take tubes. The scale was so small, however, that it was difficult to say what they were. Perhaps Mr Rowan would kindly explain?

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how Mr Rowan conceived that circulation could exist at all. Mr Flannery said:—"Not only was the unprotected plate exposed to the fire, but the abnormal increase in the water level of one chamber held out every inducement to priming. This serious structural omission explains the bursting due to overheating, and at the same time the priming which occurred." "*It is very remarkable*," Mr Flannery pointedly added, "that the partial absence of a similar pipe contributed to the failure of the boilers of the 'Montana.' The longitudinal rents which caused the loss of life occurred in portions of the tubes practically uninjured by corrosion, and the uncorroded appearance of the fractured portions points to the conclusion that *defective circulation and overheating caused the explosions*." He admitted that "the 'small circular perforations' in the tubes did not arise *so much* from circulation as from corrosion, . . . but the same explanation . . . is not borne out by an examination into the character of the larger fractures." (*c*) Mr Flannery next described the failure of the "Root" boilers on the "Birkenhead," and said "the tubes in the bottom row were continually bulging, and giving out from overheating" . . . "The tendency of the water to forsake the bottom tubes was . . . *primarly due to imperfect circulation*." (*d*) On another ship—the "Malta"—fitted with "Root" boilers, "the *same defect as in the other cases* developed itself. *The circulation of the water was insufficient*; some of the bottom tubes nearest the fire bulged and gave way," etc., etc. (*e*) In the "Howard" boilers on other vessels "the lower tubes burst, others leaked, and very great priming took place. These results were traced to the same general causes that led to the difficulties with the 'Birkenhead' and 'Malta.'" During the discussion, as reported in "Engineering," Vol. XXI., page 350, not one dissentient voice was raised to the conclusions drawn by Mr Flannery. Mr Rowan said he joined in it, but, if so, his remarks did not appear, and were probably to be found in the "Correspondence" to which he (Mr Wingfield) was unable at the moment to refer. As to Mr Rowan's statement that on the "Propontis" "the salt-water scale was purposely made and with great difficulty," Mr Flannery, during the discussion of Mr Thorneycroft's paper, said—"Comparing

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the scale with some samples from the tubes of the 'Propontis, it would be found that the scale of the latter was $\frac{5}{16}$-inch thick after a very short period of work. That was an inadmissable amount of scale—no boiler could stand it." During the discussion of Mr Rowan's paper on "The Introduction of the Compound Engine," Mr Kirk, who had been employed by Messrs John Elder & Co. when they built the "Propontis'" boilers, said "a fluctuation of five feet in the water level was not uncommon," and he spoke of "the frequent replenishings of the boiler by sea-water" as a possible cause of the pittings which led to trouble. He referred to the "frequent blowing out when tubes pitted," and said, "the frequent blowings out of the main boilers as described above, and necessary refilling from the sea neutralised the action of the distilling boiler." Thus he agreed with Mr Flannery that the pittings were due principally to impure water. Mr Rowan, in his present paper, in "The Introduction of the Compound Engine," and elsewhere, had somewhat ungenerously attributed the failure of the "Propontis'" boilers to Messrs John Elder & Co., and pointed out that they constructed those boilers "without the external steam connection between the steam domes used in all the other examples, and that the *makers!* relied for the equalising of the internal pressure of the various sections upon an internal steam pipe which was substituted for the external coupling pipe." Mr J. L. K. Jamieson, who was connected with the firm of Messrs John Elder & Co. at the time, somewhat indignantly remarked that he "regretted the author of the paper said the firm were in error, for he was of opinion that everything was attended to most carefully to carry out his father's ideas as much as possible." Mr Alex. C. Kirk confirmed that, saying "Mr Jamieson's remark was quite correct. When the boilers were made, the late Mr Rowan brought the drawings of boilers of the same kind which had been worked with success in India, and, to get the power wanted in the 'Propontis,' two of them were to be simply grouped into one. *Mr Rowan had them grouped into one boiler* by connecting the large horizontal water pipes behind the furnaces, and *connecting the steam domes by the usual steam*

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pipes." Thus it appeared that no special pipe was proposed by Mr Rowan to connect the domes; they were simply to be severally connected to the main steam pipe. Mr Kirk proceeded to say that "in that unfortunate upper connection lay all the subsequent troubles and mishaps." (Of course he alluded to the unfortunate, or rather inadequate, *method* of upper connection, but the author, in his reply, twisted Mr Kirk's words to mean that Messrs Elder were responsible for the omission of an adequate connection, although Mr Kirk had said he agreed with Mr Jamieson!) "But he should be sorry to cast any reflection on the late Mr Rowan, for, on a three days' cruise, neither Mr F. Rowan nor he (Mr Kirk), nor an eminent engineering friend, nor three Surveyors of the Board of Trade, found that to this cause was due the excessive fluctuation of the water in the gauge-glasses. The result of this unfortunate connection was that, when one section of the boiler was harder fired than the other, the resistance of the increased volume of steam, as it passed out, depressed the water line in that boiler and forced the water through the lower connection into the other section." Could it be doubted that if Mr Rowan senior had had the least idea of the importance of a proper steam connection, he would have at once put his finger on the weak spot during that three days' cruise? In estimating the value of heating surface, the author made a vital mistake, by assuming (as he also did in his "revolutionary and disturbing paper") that the flow of heat from gas to water across the plates of a boiler varied directly as the difference of their temperatures. Rankine (p. 260 of his "Steam Engine") showed it varied as the *square* of that difference, and Mr Blechynden made a long series of experiments, completely confirming that.* Of course the whole of his remarks on that head, fell to the ground in consequence. The above remarks, on reading them over, appeared somewhat hostile; that appearance was unavoidable as there was so much to find fault with in history, theory and arrangement; but he wished to express his admiration of the author's industry in collecting

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* See "Engineer," Vol. LXXVI., pp. 98 and 127; also Vol. LXXXI., p. 509. See also "Engineering," Vol. LX., p. 50.

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together so many different boilers, and his feeling of obligation to him for illustrating so many of them in the plates accompanying his paper. He (Mr Wingfield) had not been able to find a suitable class for such boilers for instance as Goldsworthy Gurney's, of 1825, in which two sets of S shaped tubes crossed each other like the figure 8, and he was not acquainted with some of those mentioned in the paper. He trusted that his supplement to the author's list would prove useful.

Mr B. C. LAWS (Member)—The subject of circulation in water-tube boilers had evidently not yet been exhausted by those interested in the theory of its action; as was seen by the fact that, although that type of boiler had been in evidence for some 25 years, various arguments had been put forward to account for the real nature and origin of the circulation of the water. As far as the origin was concerned, it appeared unnecessary to go beyond the accepted laws of physics with regard to the action of heat upon liquids, wherein, by convection, the heated and lighter particles rose and were replaced by the colder particles from above. That was necessarily the first step towards the circulation which eventually ensued. Circulation was further augmented, not by the force of expansion of the liquid, which in itself had no effect on the mobility of the particles, as stated by the author, but rather that the liquid becoming less dense was replaced by the heavier liquid from above, at a lower temperature. That went on until practically a uniform temperature was established, when the circulation would be kept up by the rapid passage of the steam upwards. It was generally considered that a good circulation was necessary to the rapid formation of steam, and that therein lay the advantage of the water-tube boiler; apparently, however, the water would have a better chance of conversion into vapour were it to lie quietly above the source of heat, as in an ordinary cylinder. The chief function of circulation was to keep the water continually in contact with the heated surface of the tubes, so that they might not suffer through becoming overheated by continued contact with steam generated. By preventing the accumulation of steam, the tendency of the tubes to rupture, due to the expansive force of the steam, was avoided. Hence, any device which aimed at increasing the circulation would at the same time prevent the liability to failure of the boilers from this cause. That seemed to be brought about by the tubes being made to take a longer circuit to the steam drum, so that they entered the latter above the water level as shown in Fig. 1 of the author's paper. Mr Thornycroft, in his paper read before the Institution of Naval Architects, showed that that was the case by experiment.

Mr DAVID R. TODD (Member)—He should pass the first or historical portion of Mr Rowan's paper, which was only of minor interest. The matter of priority of invention in that as in other matters, as far as the practical purpose of an institution like theirs was concerned, was after all comparatively unimportant. What really concerned them was the development or improvement of such types of boilers or other apparatus as had given sufficient promise of success, or proved by performance their right to exist. Mr Rowan in his paper had raised the vexed question of the failure of the "Propontis'" boilers, and he (Mr Todd) observed, by inference at anyrate, that he blamed the makers for that failure. That responsibility was repudiated both by the late Mr J. L. K. Jamieson and Dr. Kirk in their remarks on Mr Rowan's former paper, on "The Economical Advantages of High-pressure Steam."* In the discussion on that paper, Dr. Kirk pointed out that the cause of the trouble was for a long time a matter of conjecture, alike to Mr Rowan's father, Dr. Kirk himself, and several other engineers, and was only discovered after the lapse of nearly two years, by an accident which then occured in connection with other boilers of a different construction. It was easy to be wise after the event, but in the light of their present knowledge, it was hardly likely that anyone now-a-days would make a water-tube boiler composed of such large units, and possessing such inadequate means of communication between the different sections as existed in the case of the "Propontis." On page 35 of his paper, Mr Rowan discussed the interesting problem of the circulation in water-tube boilers. It seemed to him that during the last few years a great deal had been

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* Transactions Inst. Engineers and Shipbuilders in Scotland, Volume XXIII., p. 51.

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said and written on this subject which had, after all, added very little to their real knowledge of it. He agreed with Mr Rowan's remarks on page 36, that "The only practicable way in which the water in any vessel can become heated is by *convection*, or the continual transference of heated portions." He was further of opinion that, notwithstanding all recent investigations and experiments, they had not got far beyond Clerk Maxwell's description of the phenomenon, which was as follows:—"When water is heated in the ordinary way, by applying heat to the bottom of the vessel, the lowest layer of the water becomes hot first, and by its expansion it becomes lighter than the cold water above, and gradually rises, so that a gentle circulation of water is kept up, and the whole water is gradually warmed, though the lowest layer is always the hottest. As the temperature increases, the absorbed air which is generally found in ordinary water, is expelled and rises in small bubbles without noise. At last the water in contact with the heated metal becomes so hot that, in spite of the pressure of the atmosphere on the surface of the water, the additional pressure due to the water in the vessel, and the cohesion of the water itself, some of the water at the bottom is transformed into steam, forming a bubble adhering to the bottom of the vessel. As soon as this bubble is formed, evaporation goes on rapidly from the water all round it, so that it soon grows large, and rises from the bottom. If the upper part of the water into which the bubble rises is still below the boiling temperature, the bubble is condensed, and its sides come together with a sharp rattling noise, called simmering. But the rise of the bubbles stirs the water about much more vigorously than the mere expansion of the water, so that the water is soon heated throughout and brought to the boil, and then the bubbles enlarge rapidly during their whole ascent, and burst into the air, throwing the water about, and making the well known softer and more rolling noise of boiling." Everyone who had watched water boiling in a Florence flask and noticed the ascending and descending currents would, he thought, recognise the correctness of that description of Maxwell's, and every steam boiler, and pre-eminently every well designed water-tube boiler, was constructed with a view to the separation of the ascending from the descending streams, under which conditions the circulation went on in obedience to the well-known law of Torricelli, with greater or less rapidity as the difference between the densities of the ascending and descending streams was great or small. He had not the pleasure of hearing any of Professor Watkinson's papers on that subject, but he thought he had read most of them, and he must confess that he could not understand his reasoning on what he described as the entraining action of bubbles, which he evidently considered to be a factor in promoting circulation altogether distinct from, and independent of, the difference in the density of the two columns. It would be observed that Maxwell stated that the lowest layer of water, or that nearest the heating surface, was always the hottest, and in this respect he was at variance with Prof. Watkinson, who assumed the water in the boiler to be of equal temperature (see the paper on water-tube boilers in Volume 38 of the Transactions, page 137). Mr Rowan had also referred to that point in his paper on page 38. He presumed that Professor Watkinson's remarks in that regard were only relative, as such a condition as the water being of equal temperature was impossible in any boiler, even when no water was being fed into it, and it was manifestly impossible in the case of a boiler under ordinary conditions when a constant, or nearly constant, stream of feed-water of relatively low temperature was being injected into it. Under such conditions in all well designed water-tube boilers, the cold feed-water was introduced into the boiler in such a way as to assist the descending column, and so promoted circulation. Mr Rowan's remarks on the value of heating surfaces were interesting chiefly as an illustration of what an ideal boiler ought to do, but they were of little value in enabling one to determine the relative value of heating surfaces. Most of them were no doubt convinced that a very large proportion of the heating surface of any boiler gave a very poor return for its cost; but, as far as he could learn, there was no reliable data published of the results of experiments on the performance of heating surfaces in the different parts of the boilers and under varying conditions. Mr J. Watt, in March of

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last year, read a paper on that subject before the Institution of Naval Architects, and, while his experiments were very interesting, they left considerable scope for further investigation of the matter. He (Mr Todd) was of opinion that a good deal might be done by some one who had the time, the patience, and who was not unwilling to spend some money experimenting on a moderate scale in that direction. It might be possible to make a model, say of a water-tube boiler, which could be enclosed in an envelope or hollow casing, the casing to have water at the boiling temperature constantly circulating through it; the boiler itself also being fed with water at 212° Fah. and evaporating it at atmospheric pressure. The heat could be supplied by gas through a Bunsen's burner, which, while giving a comparatively high temperature, would not occasion any soot deposit on the heating surface. The quantity of gas consumed per hour could be measured and its calorific power determined, and the water evaporated in a given time would be a measure of the value of the heating surface employed during the experiment. The apparatus might be so arranged that the heating surface could be increased or diminished at will, and the arrangement altered from time to time. Some such experiment as that would help to show the relative value of heating surface, and also indicate how it could be disposed to the best advantage. It might be remarked that in such a model the outer casing would ensure that the radiation losses were constant, while the temperature of the escaping gases and the temperature of the furnace could be measured at the same time as the readings of the gas consumed and water evaporated were taken. It was interesting to note that under ordinary conditions, say in a marine boiler, the heating surface on an average did not transmit more than 8000 B.T.U. per square foot per hour. If that was compared with the figures given on page 39 of Mr Rowan's paper they would readily see how inefficient it was; but after all, heating surface, even under the best conditions with thoroughly clean surfaces and free from the contamination of soot and scale, gave results a very long way below theoretical figures. For instance, Peclet himself in his

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experiments with copper tubes got a result which was only equal to 27 per cent. of the theoretical figures, and Messrs Weir, who claimed to have got better results than Peclet, only reached 32 per cent. of the theoretical value in their evaporative tests (see Mr Lang's paper on evaporation, Volume 32 of the *Transactions*, page 290). On the subject of forced combustion, he believed Mr Rowan was on the right lines in his suggested method. The particular difficulties in the matter of using producers on ship board were, he thought, space occupied, weight and upkeep, and facilities for repairs and durability. As far as the water-tube boiler was concerned, he might remark that, based on results obtained from boilers fired with blast furnace gases, waste gases from heating furnaces, coke ovens, etc., the efficiency of one boiler of that type which he knew very well was, at the very least, under ordinary working conditions, 30 per cent. above that of any Lancashire or Cornish type of boiler, and its construction lent itself much more favourably to the varying conditions of such service. In closing, he would express his surprise that among the numerous illustrations of water-tube boilers Mr Rowan had given them, there was not one of that in which he (Mr Todd) was specially interested, the Babcock and Wilcox. Perhaps that omission of Mr Rowan's was due to the fact that he considered the boiler in question to be so well known and so widely used that any comment or illustration was unnecessary.

Professor H. S. **Hele-Shaw** thought there was not much he could say upon the paper itself, as, beyond the historical portion and the most valuable tables that were given, the only point touched upon was in regard to circulation; but he quite agreed with the author in saying that the results obtained by simple glass models worked at atmospheric pressure could not afford a sure guide to what took place on board a steamer, where one of the most common occurrences was the state of topsy-turvydom, which would be difficult, not to say unpleasant, to imitate in a laboratory, and entirely altered the physical conditions of the problem.

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The discussion on this paper was resumed on 21st December 1897.

Mr F. E. **Rainey** (Member) considered that at the present moment when water-tube boilers were forcing themselves so much to the front, any data regarding them would prove interesting even though it might be open to criticism; it set the ball of discussion rolling. As far as the historial side of the question was concerned, the most interesting points at issue were the developments which from time to time had been made to enable them to work as satisfactorily under the varied and often most trying conditions which they had to face on land and sea, with equal if not better results as regarded maintained economy, efficiency, durability, and low up-keep, when compared with the various types which had been in more general use. As to who was the originator of the water-tube boiler, past records showed that it had been in existence in one form or another for not less than a century, so that the honour was not likely to fall to any gentleman present. Reviewing the numerous and varied designs which had been patented from time to time, it must strike every one as remarkable that, while it was admitted there were certain laws which regulated economical steam generation, so few had apparently followed them; indeed many inventors had actually defied them, and thus sealed the fate of their conceptions. One of the first of those laws which Mr Rowan had more or less correctly dealt with under the value of heating surface, was the law which related to the transmission of heat through metal surfaces, from a gas on the one side to a liquid on the other side. The author was, however, wrong in stating that those laws had not been realised, for in D. K. Clark's "Steam Engine," vol. I, a full account was given of experiments made, so far as he could remember, by Mr Isherwood, Mr Williams, and others, to show the relative value of the various surfaces in the boiler. One of those experiments was made with an old locomotive boiler. In that it was shown that about 60 per cent. of the work was done by the fire-box, while the evaporation from the tubes at the smoke-box end was almost imperceptible. Those experiments were made about thirty years ago. More recently the late Mr Blechynden read a paper before the Institution of Naval Architects, on July 12th, 1893, on the actual transmission of heat through plates of varying thicknesses, with varying temperatures of gases. That gentleman conducted his experiments with a vessel 10 inches in diameter by 12 inches deep, carefully lagged with non-conducting material, the fire consisting of asbestos lumps heated by gas jets supplied with ordinary lighting gas, and air from a smith's blast. The temperature of the gases was taken at from ¼ to ½ inch from the bottom of the plates, and as that method could be adopted much more reliably in practice than any attempt to gauge the actual temperature of the plate surface, those experiments became of special value. The variations in temperature were from 503° to 1318° Fah. above the temperature of the water, which was 212° Fah. The results obtained were of course very much higher than what occurred in an actual boiler. Mr Blechynden found that even a trace of grease reduced the rate of transmission nearly 50 per cent. He managed, however, to establish the following relations between differences of temperature and the rate of transmission for plates of a given thickness:—

(1) The total heat transmitted per square foot per hour was equal to the excess of temperature of gases above that of the water, squared, and multiplied by a constant. (2) The rate of transmission of the units of heat per square foot per hour, per degree difference of temperature, was directly proportional to the number of degrees of temperature. So that if the temperature of the escaping gases was 500° Fah. above that of the water, the total heat transmitted per square foot per hour would be 20,000 units, and the rate of transmission would be 20,000, divided by 500 = 10 units per degree difference; and if the temperature of the furnace was 1500° Fah. above that of the water, then the rate of transmission would be 1500 divided by 500, multiplied by 10 = 30 units per degree difference of temperature, and the total number of units transmitted would be 1500 multiplied by 30 = 45,000 units. In other words, the relative value of one square foot of surface next the furnace would be 2·25 times that of one square foot next the flue, and the rate of

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transmission would be three times as great. He had elaborated those experiments in Fig. 69, Plate X, relying chiefly on those made with Plate A, and had found that, so far as the experiments were concerned, for a given temperature, knowing the heat transmitted through a plate of a certain thickness, the heat transmitted through any thickness could be found with fair accuracy by the following formulæ :—

(1) If the plate be thicker, $N_2 = N_1 \left(1 - \frac{t_1 - t_2}{2}\right)$,

(2) „ „ thinner, $N_2 = N_1 \left(1 + \frac{t_1 - t_2}{2}\right)$,

Where N_1 = Total heat transmitted through plate t_1 thick,
N_2 = „ „ „ „ t_2 „

and $\left.\begin{matrix} t_1 \\ t_2 \end{matrix}\right\}$ = Thickness of plates in inches, and decimals of an inch.

The diagram clearly showed that the efficiency of the surfaces depended entirely on the temperature of the heating gases, so that to increase the efficiency of a boiler, the question of high furnace temperature played the most important part. In that respect the water-tube boiler had an advantage over the cylindrical, because it could be fitted to a furnace carefully lined with refractory material, which was the only method at present known of raising the furnace temperature. In the water-jacketted furnace the maximum heat obtainable rarely exceeded 2000° Fah., while with the other the temperature could be raised to 3000° Fah. Supposing the flue gases to be equal in each case, and taken at 500° Fah., then the range of temperature would be 1500° and 2500° Fah. respectively. The full realisation of the value of the heating surface therefore depended on adopting a furnace with the highest possible temperature, and applying that temperature in such a manner to the heating surfaces that they would have the opportunity of picking up the heat, as well as allowing the gases to escape at as low a temperature as possible. To do that it was necessary to have the circulation of the gases conducted in such a manner that they actually came in contact with every available particle of heating surface. If the internal arrangements were right then economy must result, and he would here draw attention to those internal arrangements. It had been found that water mechanically agitated would pick up heat more rapidly than when at rest. He referred, as an instance, to the economiser, a water-tube boiler that came into play when the cylindrical boiler ceased to be serviceable. In the economiser the agitation was set up by the pumps, which kept the water in motion, and by that means picked up the last units of heat. The velocity was just sufficient to prevent the tubes scaling, thereby diminishing the efficiency. On the question of circulation the author seemed to have preferred propounding theories rather than looking to facts, and it was somewhat strange that so many eminent engineers appeared to prefer that system to noting and accepting what they could see in every-day life, if they only took the pains to observe. If heat or cold were applied to the surface of a solid, liquid, or gas, its condition was at once changed as the temperature of the mass varied. With the exception of india-rubber and ice, all bodies expanded as the temperature rose, and consequently their density diminished; in liquids and in gases, by the ordinary laws of gravitation, the particles arranged themselves in layers according to their density. The rapidity with which that displacement proceeded was dependent on the variation in the density of the various particles. That agitation was only very slight as long as the particles maintained their liquid state, but when they burst into steam the force exerted had the same effect on all the particles which immediately surrounded the globules of steam, and, by the law of gravitation, the particles immediately above the globules naturally offered least resistance, and consequently gave way before them, while the weight of the particles surrounding the globules, with a force equal to that due to the head of water, pressed themselves, as well as the particles immediately below the globules, into the space they previously occupied. As the globule neared the surface, its volume increased as the pressure due to the head diminished. When it reached the surface it had for a moment to overcome the cohesive force of the particles, and formed what were known as bubbles. The rapidity with which those steam globules were formed was entirely propor-

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tional to the range of temperature as already explained, and if it was carried on with a due counter-balance of descending particles of water, the velocity of the ascending globules could be carried to a great range. If, however, the particles of water could not replace the globules of steam, then foaming took place, and the efficiency of the heating surface in contact with the foam at once fell, as steam, even in a moist state, did not absorb heat with the same rapidity that water did. It was obvious, therefore, that while a great variation must obtain in the temperature surrounding or impinging on the heating surfaces, it was necessary to adopt some method by which a proportional amount of steam would, as near as possible, be generated, that was if they were to have the boiler conducting itself in a natural and orderly manner as the author had put it. If means were adopted to do that, those tubes which were nearest the fire would not deteriorate more rapidly than those parts more remote, and the internal strains would be diminished. To insure that, the simplest method appeared to him to be to utilise the heating surfaces nearest the furnace for raising the temperature of the water up to boiling point, by introducing the feed-water inter-mixed with the water in the boiler in such a manner as to make it pass through those tubes. That would not reduce the rate of transmission of the heat in the tubes, but would reduce the proportion of steam present to the volume of water. With regard to the surfaces more remote, and in which the agitation of the water would be almost *nil*, he would propose to create a circulation in them by means of the steam which was present in the water, and which was formed on relieving the water of the pressure due to the head of water in the boiler. The agitation thus set up would have the effect of keeping the tubes clean, and of absorbing some of the heat which would otherwise be lost. He would describe this matter more fully in his remarks on the "Rainey" boiler. As a matter of fact, the circulation in all the boilers mentioned by Mr Rowan, with the exception of those boilers which came under the head of forced circulation, or boilers where the steam and water travelled together through coils or a continuous series of tubes, was purely a local one;

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and unless the greatest care was taken to have the feed-water absolutely pure, there was a great liability of the tubes affected by the lower temperatures of gases becoming heavily scaled. Those tubes where the heat was most intense were also liable to loss of efficiency and pitting, due to the presence of steam in too great a proportion, so that while every care might have been taken to circulate the gases so that they would impinge on all the heating surface, the boiler might as a whole give a very low rate of evaporation per square foot of heating surface. In such types of boilers, the only method of producing a uniform velocity and rate of evaporation in all the tubes, was to have a uniform ratio between the heating surface of each tube and the volume of water it contained, directly proportional to the temperature of the gas surrounding it, so that the boiler would consist of large tubes next the fire and small tubes further from it. With regard to Mr Rowan's criticism on Mr Thornycroft's paper, he thought he had evidently not seriously studied the two designs as illustrated, otherwise he would not have made the remarks on the geyser action which he had done. In boilers discharging above the water level, a principle on which Mr Thornycroft deserved much honour as the pioneer, there was much less likelihood of this geyser action than with submerged tubes, because in boilers discharging above the water level, the steam and water rose above the level that the water would assume when the boiler was cold; and though the efficiency of the upper ends of the tubes was diminished, the steam had a better chance of separating itself from the water, and overcoming its cohesion, than when the steam was discharged immediately below a body of dormant water and made to pilot its way as best it could to the surface, and there release itself. The variation of the level of the water in the gauge and that in the boiler pointed, where the variation was greatest, to a very much larger percentage of steam being present, and as the velocity of the circulation depended on the difference in density of the ascending and descending columns, the circulation would be more rapid in the boiler which had the smallest percentage of steam present in the water contained in the drum. So long as there

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was a rapid circulation through all the tubes in the Thornycroft boiler, there would be no danger of the tubes silting up by reason

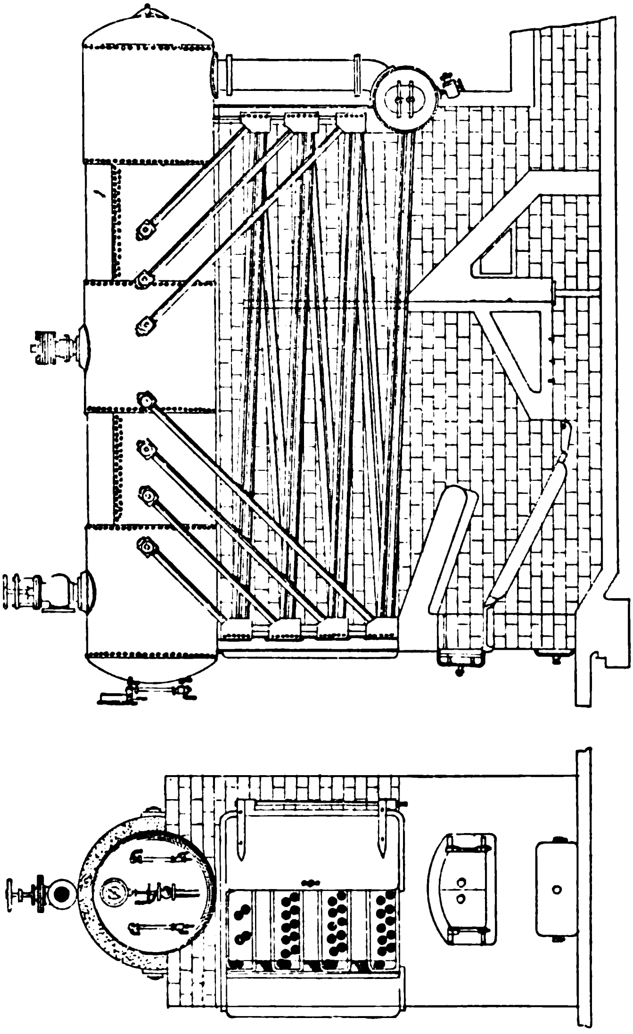

Fig. 70, Rainey.

of their sinuous form. The chief objection from a structural point was the tendency, in bending, of thinning the outer portion of

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the tube. The use of a glass model was to illustrate the nature and existence of circulation and the action of the steam on leaving the water. It also gave an idea of the per-centage of steam present in any one tube. In the model of his boiler, he could show it working at atmospheric pressure, and with a pressure of a few pounds. The chief differences between the model and the illustration, Fig. 70, were, that the down-comers were placed in the flame in the former, and outside in the latter, and that the headers were horizontal, so that there was plenty of come and go in the whole structure. The feed-water was introduced close to the head of the down-comer, so that it had a straight run to the mud drum. The water, which would thus be colder, entered the first series through header No. 1, which formed the suction header of the first series. The steam and water formed in that series were discharged into the second header, which formed the suction header of the second series. On entering it the steam separated, and travelled along the header to the riser pipes, which were steeply angled, and, passing along the riser pipes, discharged above the water level; the water rushed on through the next series, any steam generated being liberated in the same manner, and so on till it reached the last header, when it was discharged back into the steam drum to travel along the drum and back down the down-comers. It would be seen by the action of the model, that on entering each series the water was solid, and that in the upper series the water, being relieved by the pressure, burst into steam. Though it was apparent that the water could not flow fast enough down the down-comers, it would be seen that the flow through the evaporating tubes was continuous, and if one looked along the water-level, the only agitation seen was at the front, due to the discharge of steam and water in the last series and the vortex formed in the neighbourhood of the down-comers. It would also be seen that the steam was practically dry.

Mr JOHN THOM (Member) remarked that, when so many water-tube boilers had been illustrated, their old friend, the Haystack boiler, ought not to be left out. He did not see any difference

Mr John Thom.

between the Haystack water-tube boiler and any other water-tube boiler, except that it had a water envelope round it, which in itself was a good feature, although rather an expensive thing to make. He was not old enough to know who first proposed the Haystack boiler, but there had been a good deal of discussion in the technical press as to who first invented separate down-comers. In the Haystack boiler there were separate down-comers, so in that respect it was as complete as any pipe boiler, and settled the disputed point, that separate down-comers were best, as in the original boilers of that type separate down-comers were absent. The only objection to the Haystack boiler was that it had not a combustion chamber, and until water-tube boilers with combustion chambers were adopted, the Haystack boiler would hold its own, especially for paddle steamers. So far as he could gather, Mr Rowan was of opinion that the greater the drop of water in the gauge, the greater would be the circulation, but Mr Thornycroft's sketch inferred that the gauge showing the least drop showed the greatest circulation. Now, if that sketch was right, then Professor Watkinson's remarks referring to the use of a gauge to show the amount of circulation by the greatest drop, was just exactly what Mr Rowan contended; therefore, instead of Professor Watkinson proving that Mr Rowan was wrong, he had proved him right on that one point.

Professor WATKINSON—Mr Thom's reading of the paragraph showed how easy it was to make a mistake in interpreting these results. Mr Thornycroft was quite right, and it was right that the velocity varied as the square root of the depression of the column. The two did not seem to agree, but agreement would be seen if the matter was fully considered. It would take too long to go into the question, but he would strongly advise Mr Thom to read the paragraph, where he would see that it was quite easy to misinterpret the readings.

Mr THOM—That was exactly the point—that the greater the drop the greater the circulation.

Professor WATKINSON—Quite true.

Mr THOM—That was what Mr Rowan contended.

Professor WATKINSON—Mr Thornycroft interpreted the results quite correctly too.

Mr THOM—M. Normand, he believed, had drawn quite the opposite conclusion from the reading of the gauges, and if M. Normand had done so, either Mr Rowan or himself might be excused. There had been a great deal of talk about circulation, and it had been stated that the most perfect boiler was that which had the greatest circulation. He was led away with that theory at one time, and to prove it he had a 10 ton yacht built and put on the measured mile with the circulating tubes of the boiler acting satisfactorily in every respect. These tubes were then removed, and the vessel again put on the mile, when exactly the same speed was obtained. Now, what was to be gained by circulation ? Nothing, after sufficient had been gained to keep the boiler working satisfactorily. Any circulation above that was quite unnecessary. In reference to Mr Rainey's remark, that the part of the boiler which was surrounding the furnace was the most effective, he could bear that out, because one year he fitted out his little boat without examining the boiler furnace. After about two months steaming it was discovered that the back bridge was not built up, and the return tubes of the boiler were not being used to any extent, but only the large furnace, common in water-tube boilers. Still, when not forcing the fires, there was no perceptible difference in evaporation. There was nothing either in the paper or in the discussion which showed how to improve water-tube boilers. Belleville had made boilers a success, and was also the first to make it very prominent that a water-tube boiler required a combustion chamber. By putting an economiser on the top of a Belleville boiler a combustion chamber was formed between the economiser and the boiler. He (Mr Thom) had designed a pipe boiler with a combustion chamber, for Messrs Muir & Houston, which replaced a Scotch boiler having 20 square feet of grate surface, and the former was able to keep up a greater pressure than the latter with a less coal consumption. After two years' experience, without having had occasion to put a tool on the boiler, although it worked night and day, this firm had made another

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pipe boiler for the other half of their works. By forming a combustion chamber in this boiler, and keeping the heat in the furnace, the temperature of the funnel was reduced to 500° Fah., when burning 30 lbs. of coal per square foot of grate per hour. The Superintendent Engineer of the American line, Mr J. S. Doran, saw this boiler working, and thought a similar one might be successfully used for auxilliary purposes on board the s.s. "Noordland." He accordingly replaced a Scotch boiler, having 33 square feet of grate surface, by a pipe boiler with the same area of grate. The Scotch boiler was found inadequate to perform the necessary work, and one of the main boilers had to be kept working in port; but, when the pipe boiler was substituted, sufficient steam was generated to meet all requirements. He mentioned this instance, as in consequence of the great variation in the work demanded from an auxiliary boiler, it was more difficult to get it to work satisfactorily than it was a main boiler In the paper, the author distinguished between the marine type and land type of water-tube boiler. Personally he failed to see the reason why any difference should be made if the boiler was perfect of its type. He had fitted main boilers on shipboard of exactly the same character and type as he had on land.

Mr SINCLAIR COUPER (Member) said, although he had not had much experience in the actual working of water-tube boilers, he had made a few of different types, and considered it almost hopeless for Mr Rowan or anyone else to attempt to divide water-tube boilers into classes. Their features lent themselves to so many different designs, that those of one class—supposing they were divided—would almost certainly overlap or intermingle with those of another. Take for example Mr Rowan's second division, which he described as "boilers composed of horizontal or slightly inclined water-tubes leading into tubes, headers, or boxes of various forms"; among those he included Belleville's boiler. Now, many people were inclined to believe that each element of the Belleville boiler was simply a flattened spiral, and, if that view were accepted, it would be ranked as a coil boiler and should appear in the third class. Others had referred to Mr Rowan's divisions, and he would not therefore say anything more about them. It seemed to him that really the chief line of division among water-tube boilers, and one which would divide them naturally into two classes, would be got from considering where the contents of the water-tubes were discharged. In the one class would be those where the contents of the tubes were discharged at or above the water level, of which the Thornycroft boiler was an example; and, in the other, those where the contents of the tubes were discharged under the water-level, with more or less of a head of water over the ends of the tubes, according to the different types of boilers in existence. One was almost forced to conclude, however, that ten years after this a writer of a paper on the subject would divide them still more simply into two classes, first, water-tube boilers which came to stay, and, secondly, those which did not. There was not one of the present types which could be taken as a universal design. In our own Navy we had several different types adopted, and some of them were more or less still on their trial. No doubt water-tube boilers would come into general use, and if people would only have confidence and courage to go forward and introduce them into vessels, as had been done for some time in many situations on land, there was no doubt that a suitable boiler would ultimately be evolved. In the merchant service, water-tube boilers might have been adopted before now, if it had been proved that they were as economical in fuel as the ordinary return tubular boiler was. What Mr Thom described as a combustion chamber in the Belleville boiler was not really a combustion chamber. There was a defect, the existence of which was only too true in regard to most of the water-tube boilers, viz., that the gases passed away to the chimney at a very high temperature, and Belleville, and other water-tube boiler makers, were now taking advantage of that high temperature, and utilising it for heating the feed-water. He thought that the combustion chamber of a water-tube boiler should be—as it should be in every other boiler—in such a situation that the gases were thoroughly mixed in it before they came into contact with the bulk of the heating surface.

Mr George W. Thode (Member) wished to point out one thing

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in connection with the paper which he thought should not be overlooked. Mr Rowan had shown on the screen, at the last meeting, a very large number of illustrations of boilers, and he would particularly draw the attention of students, and engineers who were occupying themselves with water-tube boilers, to the various designs, inasmuch as they showed what was to be avoided in designing water-tube boilers, for, with a few exceptions, the boilers represented on the screen were found wanting, and were obsolete long ago. A careful study might keep them from re-inventing, and perhaps repatenting, old designs, thereby saving both time and money. Mr Thom mentioned that the paper told them a good deal, but it did not show them how to improve existing boilers. That was where the difficulty came in, and the very fact that there were so many hundreds or thousands of designs showed that the difficulty of making a really good water-tube boiler was great; but the fact remained that, while there were so many designs, there were at the same time a limited number which, as Mr Couper said, had come to stay. There were firms that manufactured to the extent of 2000 boilers a year, and that fact inferred that a boiler which was manufactured in such numbers was likely to stay.

The discussion on this paper was resumed on 25th January, 1898.

Mr F. J. ROWAN (Member), in reply, said he might safely assume that the discussion which had taken place afforded conclusive proof of the correctness of his opening statement as to the existence of diversity of opinion, on account of which he considered that he had no need to apologise for re-introducing that subject. Mr Thornycroft, however, tried to give another meaning to his (Mr Rowan's) words, and to imply that on other grounds he owed an apology for the paper, but he saw no necessity for shifting the ground, and Mr Thornycroft had not convinced him. The discussion, both spoken and written, had been most interesting, and there was no reason to regret the opportunity of receiving such communications as those of Prof. Thurston, Messrs Halliday, Todd, and Wingfield, not to speak

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of others. That of Mr Thornycroft, it was to be regretted, was not up to his reputation, as he could readily have drawn upon his experience for something more worthy of himself than mere querulous criticism; whilst Admiral Selwyn's communication was essentially *sui generis*, and showed a lofty disregard of facts—chemical, mechanical, and historical. In replying to the discussion, he might follow either of two courses, viz., that of taking up the contributors *seriatim*, or that of going through the paper and taking up in their order the points commented upon by the various speakers and writers. He preferred the latter.

Introductory.—In the introductory section (pp. 29 and 30) Mr Wingfield and Mr Thornycroft had misread two portions. He (Mr Rowan) stated the fact that the Council of the Institution of Naval Architects in 1877 refused his paper on "The Design and Use of Boilers" because it was, in the opinion of the Council, too revolutionary and disturbing in its views. This Mr Wingfield erroneously understood (or else he wilfully misrepresented the meaning) to convey that the paper was in *his* (Mr Rowan's) estimation "an epoch-making revolution." Mr Wingfield's *précis* of the paper did not reflect credit upon his ability to make an abstract of what he had read; but the secret of the erroneous idea which he had founded upon his (Mr Rowan's) remark, was to be found in the fact that he did not properly distinguish between what was known or published and what was practised or accepted at the time referred to. Although he (Mr Rowan) might have advanced nothing that was new in principle in that paper, yet the proper and logical conclusion from what he did press was in effect such an alteration from the then accepted practice that it was not welcome. Yet, if the information referred to was even so commonly known as Mr Wingfield imagined, it might be asked how it happened that neither he nor Mr Thornycroft acted upon it—as they were now doing—until ten years later. Both Mr Thornycroft and Mr Wingfield made some remarks about the last paragraph of the introductory section, which need not have been made if ordinary attention had been given to the language employed. There was more than one instance of this in

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the discussion, and it caused, on the part of the speakers, a waste of energy which might otherwise have been usefully employed. Mr Wingfield asked which of the historical illustrations given by Mr Thornycroft were not correctly stated, and Mr Thornycroft evidently understood his (Mr Rowan's) remarks in the same sense. They had not noticed that the historical section of his paper began at page 30, and extended to page 35, and in it he indicated, at page 33 (at foot) and page 34 the specific historical matters with which he maintained that Mr Thornycroft had dealt incorrectly. He did not allude to any "illustrations" or questions of dates or priority of invention, in referring to Mr Thornycroft's (as he did in referring to Mr Ward's) paper, but the other points noticed on pages 33 and 34 were equally matters of history.

Historical.—"Water-tube boilers," as Mr Wingfield correctly said, "were among the earliest steam generators known," though he did not tell them why the "boom" in these boilers could not have been started sooner than 1889; but he therein substantiated his (Mr Rowan's) remark that "the view that the water-tube boiler was only a modern outgrowth designed to meet the defects and evils of the Scotch or cylindrical boiler misrepresented the actual history." However, from not noticing his use of the word "only," Mr Wingfield tried to be sarcastic about that sentence. Yet he (Mr Wingfield) himself said "there could be little doubt this was *one* cause of its adoption in modern vessels, but, of course, no one said water-tube boilers were a modern idea." That was precisely the view which he (Mr Rowan) expressed otherwise, but Mr Wingfield had chosen to mix up the ideas of origin and adoption in dealing with his words, and so had the solitary pleasure of making merry at his own joke. When they came to the chronological arrangement of designs, Mr Wingfield, along with Prof. Thurston, made some remarks which were both useful and valuable. He (Mr Rowan) was pleased that in the main his arrangement of boiler designs into classes was accepted, but he noticed that Messrs Thornycroft, Wingfield, and Watkinson imagined that in making that arrangement he gave dates derived from the Patent Office

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records. That was not the case. He had in his mind, rather, the order of the introduction of different boilers in as far as he had learned of their use; but he was very glad that Mr Wingfield's and Prof. Thurston's acquaintance with historical records was made available for reference by the members and all who would possess the current volume of the Transactions of their Institution. The Howard marine boiler which he included in Class I. was the boiler of the steamer "Red Rose," which was of Messrs Howard's design. Their inclined tube boiler he mentioned and illustrated in Class II., and the original Howard boiler with hanging tubes was mentioned in Class V. In that class he regretted not having an illustration of Mr Thom's boiler, but he hoped it might yet be supplied.* Mr Todd complained that he did not illustrate the Babcock and Wilcox boiler, and had correctly forecasted one of his (Mr Rowan's) reasons for omitting it. It was in his recollection that Prof. Watkinson had illustrated that boiler in a paper read within the last two sessions, and although he (Mr Rowan) had many illustrations ready (the bulk of them having been prepared about six months before Professor Watkinson's paper, with a view to his making use of them during that session) a selection had to be made, and he had endeavoured to select those which had not been frequently published. Prof. Thurston had, however, supplied the omission referred to by Mr Todd, and had added several other designs of the same class. It was evident that some boilers possessed features which belonged to different classes, as for instance, the Niclausse boiler; but as he considered that the closed tube with internal circulating tube was perhaps the most distinctive feature of that boiler, he placed it in Class V. rather than in Class II., to which it might belong, as Mr Wingfield remarked, and the same course must be followed in other instances also. The Serpollet boiler was, as he remarked, recently introduced for steam motor cars. He did not imagine that was necessarily the origin of the use of that boiler, but motor cars were much older than was their

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* This illustration was subsequently supplied by Mr Thom, see Figs. 76 and 77, pages, 136-137.—Ed.

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use in this country, although the modern motor car was still "recent." He had been vehemently opposed on Class VIII., but did not feel that he had suffered much damage as yet. In reply, he should like to say, first of all, that Mr Thornycroft's sharp remark as to the dissimilarity between the Thornycroft boiler and the Rowan boiler was rather robbed of the point he intended it to have, by the fact that there were no published results from the latter boiler on which to found a comparison! However, on other grounds, Mr Thornycroft need not have distressed himself on that point, as he (Mr Rowan) did not say Mr Thornycroft had copied his boiler, but that Mr Thornycroft and others had copied the three-chamber plan, and of course, in that view, that design was entitled to the credit of Mr Thornycroft's results along with some others. In effect three designs had been advanced as having anticipated the Rowan boiler of 1876, viz., that of Clarke and Motley in 1849, that of Green in 1850, and that of Fryer in 1874. The Firminich boiler he had placed last in the list in Class VIII., because he was not quite satisfied that it belonged to that class, the illustration which he possessed rather indicating that each cluster of upright tubes came from a separate chamber above. But it was not possible to be certain of the design. Further examination had shown that it should not be in that class, but in Class VI., and as Johnson's design of 1855, Fig. 68, page 85, was not now advanced by Mr Wingfield as an anticipation, he had only to deal with the three mentioned. Clarke and Motley's, Fig. 67, page 84, was in no proper sense a three-chambered boiler. It consisted of a large vertical chamber, with two branches below and one above, so constructed as to be all of one piece with the vertical portion. It was easy to be wise after the event, and now that a three-chamber design was known, it was easy to say that a vertical cross-section of this boiler showed that design. But neither an elevation nor a plan of this boiler suggested the idea, but on the contrary these contradicted it. Some had tried to call the vertical chamber a return tube, but its size and the presence of a paddle in it for circulating the water from it into the branches upset that view, and showed that the inventor considered it the main chamber of the boiler. The drawings in Clarke and Motley's patent specification contained several errors, and it would be absolutely impossible to construct a boiler exactly as it was shown in them. He showed in Fig. 71 the cross section with some of the missing lines supplied, the effect of which was to show that this

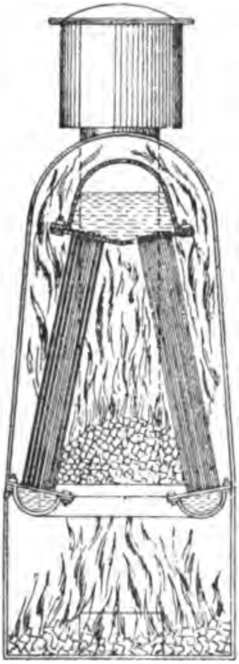

Fig. 71, Clarke & Motley.

boiler had no claim to be considered a three-chamber design. Mr Wingfield himself classified it along with Johnson's as one of the wet bottom class, which was shown very distinctly in Johnson's design, Fig. 68. The illustrations of the boiler of Fryer as patented, Fig. 72, and as published by Mr Druitt Halpin in the discussion on

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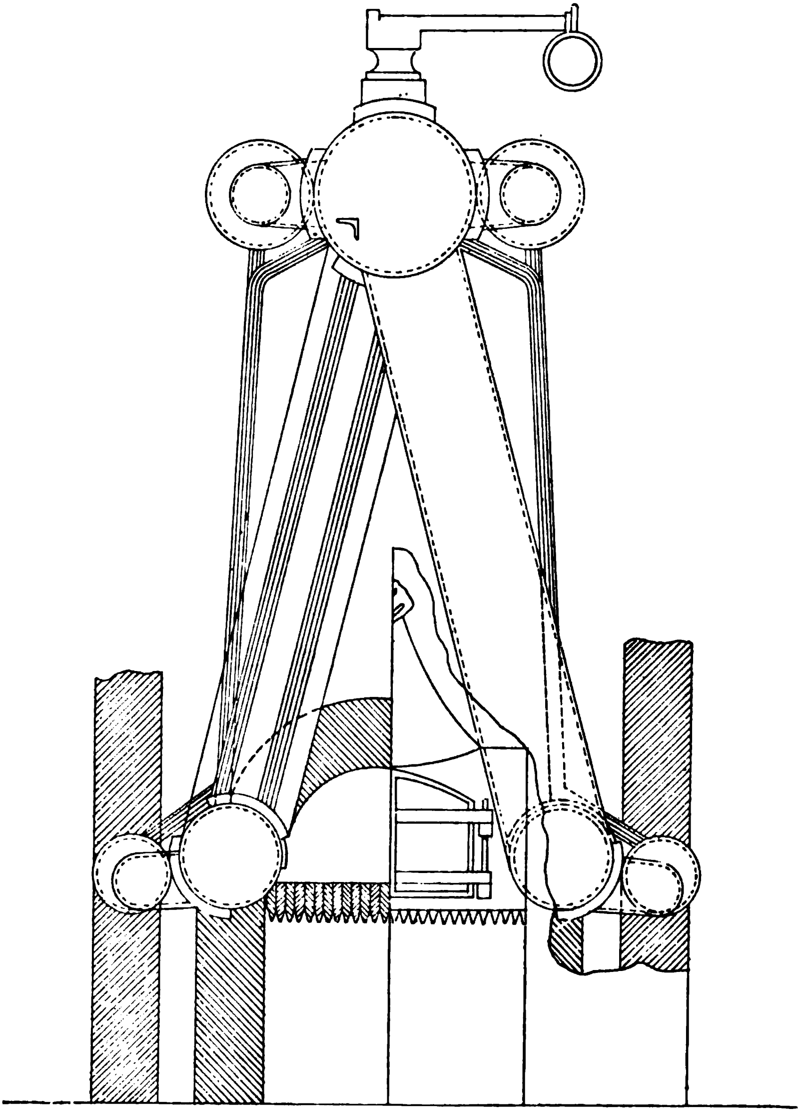

Fig. 72, Fryer.

"Torpedo-Boat Destroyers" (Min. Proc. Inst. C.E., Vol. cxxii., p. 81), see Fig. 73, for which he was indebted to the Council of the Institution of Civil Engineers, furnished a glaring proof of the same sort of wisdom; but it would be seen that the later illustration had improved the original design, which had seven chambers (three above and four below), out of all resemblance to its own likeness! Fryer did not patent in 1874 the boiler illustrated by Mr D. Halpin and quoted by Mr Wingfield. He came now to Green's design, Figs. 51 and 52, pp. 50-51, put forward by Prof. Watkinson. As far as those illustrations which he had given them showed, that *might* be a three-chamber design, but in the light of Clarke and Motley's they needed some more information before they could be certain even of that. But there was a graver objection to the claim made for that design.

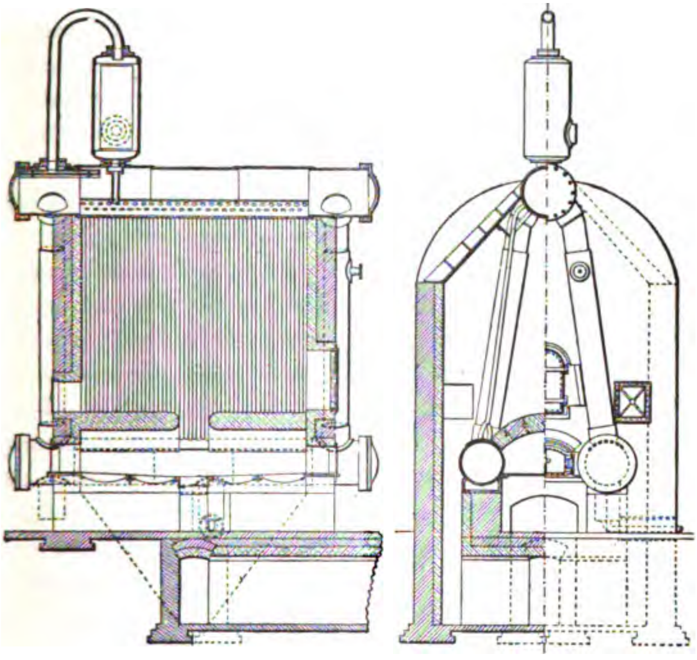

Fig. 73, Fryer.

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Prof. Watkinson had given them absolutely no evidence of its having ever been published before he himself produced it. It was quite easy for anyone to produce a design to-day and say that it was invented forty years ago, but, if so, where was it published then? He had personally searched through over 50 years of patent records, and there was no such design patented by Mr Green up till 1853. Moreover, in that year Mr Green had a patent with five sheets of drawings of boiler designs in it, every one of which proceeded on lines the exact opposite of Prof. Watkinson's illustrations. There were no engineering papers such as one was now familiar with in the days mentioned by Prof. Watkinson, and he must maintain that there was no satisfactory evidence of publication of Green's design before them. Under these circumstances, it was not to be expected that Scotland should at his bare demand yield the palm to Yorkshire. Now he came to the references made to historical points mentioned in Mr Thornycroft's paper, and curiously enough it was Mr Wingfield and not Mr Thornycroft who took up the cudgels principally here, although in one part Mr Todd joined in, and Prof. Watkinson made an essay at attack at the end of this section. First, with regard to Mr Flannery's paper of 1878 in the Min. Proc. Inst. C.E., he (Mr Rowan) had said that Mr Thornycroft's deduction was not borne out by that paper and the discussion on it. As he was present at the reading of that paper, and had sent a written contribution to the discussion, he thought he knew what it was about. But Mr Wingfield would not allow that he knew anything about it. He had merely made a rash and positive statement, and could not face his damnatory quotations. This sounded alarming, but, as Mr Wingfield said "it would be interesting to know, not how positively the author could contradict, but how he could disprove the correctness of the following passages," which he then quoted, he (Mr Rowan) had pleasure in giving the information. Not one quotation which Mr Wingfield here made, on pages 85, 86, and 87, had any reference to the paper to which he (Mr Rowan) alluded as having been misinterpreted by Mr Thornycroft. Mr Wingfield had fallen into the error of quoting largely

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from quite another paper, which was read by Mr Flannery to the Institution of Naval Architects two years before his Institution of Civil Engineers' paper. Perhaps Mr Thornycroft also intended to refer to that paper when he appeared before the Institution of Civil Engineers. Had he done so, of course his (Mr Rowan's) remarks would not have been made, as Mr Flannery's views about water-tube boilers underwent some change between 1876 and 1878, as his papers showed. On page 11 of his Institution of Civil Engineers' paper Mr Flannery had the following remarks—"Balancing these defects of the water-tube system against its admitted advantages there does not seem to be any insuperable objection to its general and satisfactory adoption. The difficulty of obtaining an equable circulation of the water may be met by a less tortuous and erratic disposition of the passages. The dangers arising from the smaller volume of heated water may be obviated by the use of more efficient safety valves, extra feed-pumps, and regular and careful firing," etc. The general purport of this paper was decidedly in favour of the introduction of water-tube boilers. Then as to the various references to the "Propontis," it appeared from Mr Thornycroft, Mr Wingfield, and Mr Todd, that he was to allow erroneous statements to be circulated, but was not to try and correct them. That he refused to do, and he would now proceed to put some facts on record. Up to the period of her voyage to Bombay (the vessel having been previously employed in the Black Sea trade) salt water had not been fed (unless on a rare occasion) into the boilers of the "Propontis," but a distilling boiler using sea water was employed to supply steam to the low pressure cylinder steam jacket. The area of surface in this jacket was so large that, if the steam pressure of the small boiler fell, from inattention, below a certain point, the jacket acting as a condenser produced a partial vacuum, and sucked both steam and some water out of the boiler. As the jackets were drained into the hot well, it frequently happened that the water there was brackish from the cause just mentioned, and he had no doubt that much of the corrosion was due to that cause, and there could be no formation of scale whilst corrosion was proceeding. On the voyage to Bombay, the

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vertical tubes gave so much trouble from pitting that instructions were wired out to try and stop it by using sea-water to form a scale in the tubes. He (Mr Rowan) was consulted by the owner, and agreed that that was the readiest method of stopping the corrosion and enabling the steamer to come home. The scale, therefore, which was exhibited at the meeting of Naval Architects, at which meeting neither the owner of the "Propontis" nor himself had an opportunity of attending, was made wholly during part of one voyage, and made for the purpose mentioned; so that all the learned remarks at that and other meetings as to the rate of formation of scale in those boilers, during the two years' working, were ignorant.

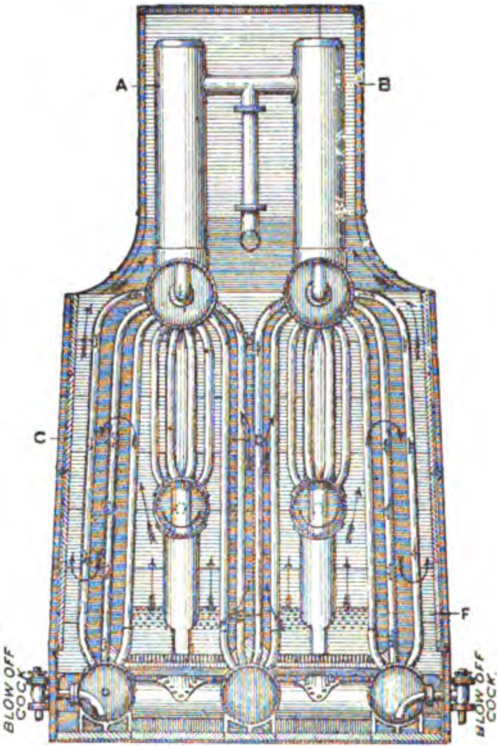

Fig. 74, Rowan & Horton.

It was intended only as a temporary remedy, and had no connection with the proper working of the boilers under ordinary conditions. Then as to the construction of those boilers, it was on record in his reply on the discussion of his paper in Volume XXIII. of their Transactions, p. 117, that Mr Kirk's remarks as printed in the Transactions were altered from his remarks as spoken, and as printed they were ambiguous at the best. Fig. 74 showed the design of boiler for the "Propontis" as given by his father to Messrs. John Elder & Co., and between the points A and B would be seen the usual connection between the vertical steam domes to which he had alluded. By comparing Fig. 75, which showed one of the "Propontis'"

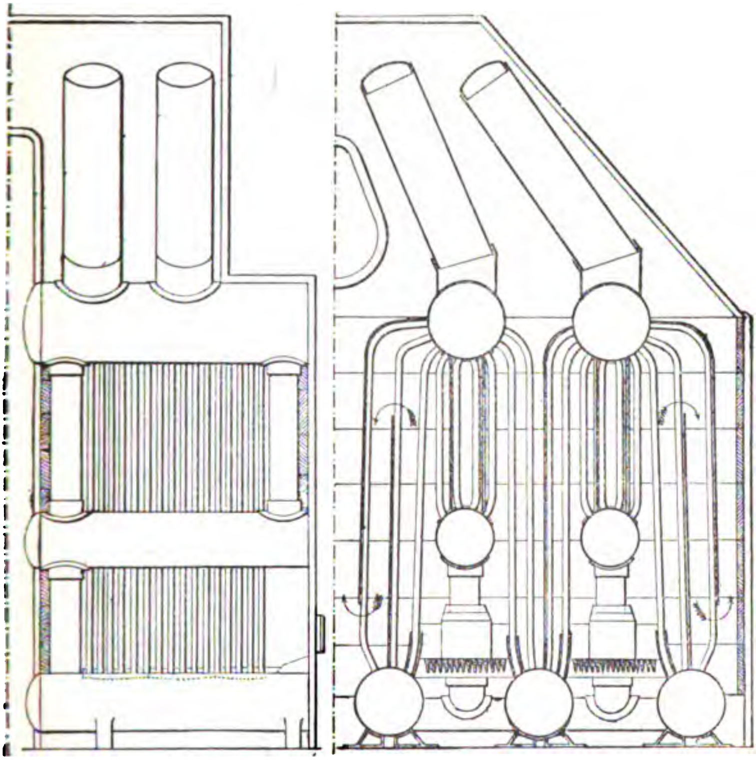

Fig. 75, Rowan & Horton. s.s. "Propontis."

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boilers as actually made, it would be seen that that connection was not supplied. It would thus be apparent that Mr Kirk's remarks in their printed form as quoted by Mr Wingfield, were incorrect, because it was a question not of a steam pipe to group the four boilers together—that was a necessity in any case—but of a steam pipe to connect the steam spaces of the two sections of each boiler together. These boilers had been made, as shown in Fig. 74, for the "Haco," two years before the "Propontis," and for Indian steamers, and, as the same design appeared in the Patent specification of 1869, it was no afterthought. Mr Kirk objected to cut the steam domes for the pipe between A and B so far up in the smoke box, and maintained that a steam pipe connecting the boilers across the front of the top horizontal chambers (having internal pipes coming down from the vertical domes to get dry steam) would be sufficient communication for the steam spaces in each boiler, as well as for coupling all the boilers together. His (Mr Rowan's) father died just before that question came up, and that was another fact which showed the incorrectness of the idea that he had proposed to let the outside steam connection between the boilers serve the purpose also of equalising the pressure between the sections, and it also showed the incorrectness of some remarks of Mr Todd and Mr Wingfield. It was absolutely false and misleading to say that he authorised the alteration from his plans. He (Mr F. J. Rowan) was suddenly called upon then to take a supervision of the work in the interest of the owner of the "Propontis," but had to do so without having any authority under the contract with Messrs. John Elder & Co. Nevertheless, he objected to the departure from their designs proposed by Mr Kirk, and notified his objection to the owner, but as the matter involved a question of experience he was overruled, and the owner, being satisfied with the quality of the work otherwise, and, with the evident desire to make a successful job, allowed Mr Kirk or Messrs. John Elder & Co. to have their own way. So long a time elapsed after that before the vessel went to sea that he (Mr Rowan) had completely forgotten the fact of the alteration, so that when the water level fluctuated considerably in some of the boilers on

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the trial run in the Irish Sea (which took place a year after his father's death) it did not occur to him that there was such a cause for it. It was not until after he had seen the model of the boilers prepared by Mr Samson, of the Board of Trade, for the inquiry at Liverpool, that he recollected the fact and circumstances of the omission of that steam connection. When his paper "On the Introduction of the Compound Engine,*" was discussed, the statement which he had made in it about this steam connection was corroborated by Mr Kirk, who was then not with Messrs John Elder & Co., and, in his reply, he said he "was much obliged to Mr Kirk for the frank admission which he gave about the unfortunately defective part of the Propontis' boilers, because no one else could have completely shown that his remark on page 73* merely recorded a fact, and did not impute any blame" as Mr Jamieson thought it did, and this because the alteration had been adopted by the owner, and then he went on to remark, "Mr Kirk's remarks as printed, however, read as if he meant that the existence of the upper steam connection was a mal-arrangement, and caused the trouble spoken of. The contrary was, of course, the fact; it was the want of that connection in the 'Propontis' boilers which was the secret of trouble." Mr Kirk's remarks as printed were so altered from his spoken remarks as to be really unintelligible. The boilers were not connected by "the usual steam pipe," for it was the one omitted, but if it be held from his language that they were, then "the upper connection" was left out. Yet Mr Kirk's remarks read as if both were there, and it was "the upper connection" which ought not to have been there, whereas the reverse was the case. Mr Wingfield had chosen to call his reference to this matter, "ungenerous," but he must pardon his saying that it was easy, but not wise, to pass judgment upon imperfect acquaintance with the facts. Before passing on to the section on circulation, he must notice Professor Watkinson's attack on his remark as to durability. He did not think it could be seriously meant. Prof. Watkinson pretended to think he (Mr Rowan) had advanced during the past twelve months in appreciation of the durability of

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* Trans. Inst. of Engineers and Shipbuilders in Scotland, Vol. XXIII. p. 51.

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water-tube boilers, though he gave no hint as to the probable cause of this advance. He could assure Professor Watkinson that he had known and studied water-tube boilers for thirty years, but that he had not learned anything during the past year, not even from Professor Watkinson's papers, to change or modify his views. In the discussion of Mr Couper's paper, he stated a fact in disproof of Professor Watkinson's somewhat fanciful idea of gases or acids settling down on boiler surfaces, as if they were flies that could be brushed off by the rush of circulating water. That fact was, that in the past there had been more trouble experienced with corrosion in water-tube boilers than in other boilers, in proportion to their number, on account, for one reason, of the thinness of the material. This showed that rapidity of circulation alone had not prevented corrosion, but he never said or indicated that corrosion could not be prevented in other ways. In fact, on the contrary, he had more than once referred to certain examples of their own boilers in which corrosive forces were overcome so that they worked at their original pressure of 120 lbs. per square inch for over ten years, under Board of Trade yearly survey. But in the latest edition of Prof. Watkinson's remarks he added that his (Mr Rowan's) was an incorrect statement because in it he "confused" "rate of corrosion" with "the time taken to corrode through a given thickness of metal." Well, what was the difference? Let them say that through $\frac{1}{16}$th of an inch per week was the *rate* of corrosion, then a week for the corrosion of $\frac{1}{16}$th of an inch was the *time* taken to corrode a given thickness; and he was quite unable to see the "confusion"! It stood to reason that, even with a slower rate of corrosion in its case as compared with another, a boiler with thinner material was likely to suffer serious damage sooner than one with thicker plates.

Circulation.—On the vexed question of circulation it was plain that even as yet the "doctors differ." Mr Todd had furnished them with an extract from Prof. Clerk Maxwell's writings, which was well worthy the attention of all, and was certainly clearer and more trustworthy than some more recent explanations of the action. In fact, no one

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could do better in connection with this subject than to read the paragraphs in Prof. Clerk Maxwell's "Theory of Heat" which dealt with Boiling (page 23) and Convection currents (page 230). Exception had been taken by Messrs Thornycroft and Watkinson to the terms in which he (Mr Rowan) described the action of circulation; but, whilst Mr Thornycroft asserted that gravity was the only force by means of which the water in a boiler could be circulated, Prof. Watkinson, by supposing the water to be all at the same temperature, eliminated any difference of density, except as between steam and water, and so far denied the action of gravity. Mr Thornycroft misrepresented him by inferring that he expressed any such view as that "expansion by heat, or even the formation of steam *without gravity*," would provide circulation; but, on the other hand, it was plain that gravity alone would not account for the comparatively large quantity of water which, in working, was continuously carried up some distance above the normal water level of the boiler, although gravity caused it, when freed from steam, to return to a lower level. In reply to Mr Thornycroft's question, a "mechanical entraining action of bubbles" was the only language which, it seemed to him, correctly stated the ideas of the action of steam bubbles set forth by Prof. Watkinson in his papers and illustrated by his experiment of beads on a string, which, by their mere movement, ignoring the vital element of temperature, could cause the water to move downwards as readily as upwards. Regarding the force exerted by the expansion of water by heat, Prof. Watkinson had attempted, as unsuccessfully as in other instances, to meet this by ridicule. He had only succeeded in expressing his own confusion of ideas regarding it. He (Mr Rowan) spoke of it as one of the forces which in the heating of water (not in steam-raising afterwards) tended to *commence* the movement of its particles, and, whether accepted or not, that was a physical fact. To talk of that as a measure of the circulating force in a boiler under steam was gratuitously absurd. Prof. Watkinson had omitted to notice that the 5 per cent. difference of volume mentioned, belonged only to the difference between the temperatures of 32° and 212° Fah. (boiling point). The temperature due to a

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pressure of 250 lbs. per square inch was almost 400 Fah., and the difference in the volume of water due to that temperature (as compared with it at 32°) was more nearly 15 per cent. Besides that, the moment steam was formed and able to escape upwards without being wholly condensed in its passage, there was a totally different cause of movement, and kind of movement, introduced, to which he made reference on pages 35 and 36. The variation in density of the water would then be reduced to that due to a comparatively small range of temperature. Then, as to the comparison between the hot and cold columns in the cases of a boiler and a chimney, Prof. Watkinson had uselessly expended a good deal of energy in trying to impale him on the horns of a dilemma. As two very different fluids were in question in those instances, viz., water and air, it was surely not too great a stretch of credulity to believe that ordinary intelligence could grasp the idea that in such a comparison a relative or proportionate difference must be meant. The difference of density, which was actually met with in wasteful cases where the chimney gases were discharged at a ridiculously high temperature, had absolutely nothing to do with the matter. The only questions to be considered were—What was the difference of density which was necessary to cause movement of the hot and cold air columns? and, Was a proportionate difference available in the case of a boiler? The velocity of the movement of air was also necessarily much greater than that of water. In the case of a chimney of 1 square metre in section, where the hot gases were at 400° Fah. and the external air at 32° Fah., that velocity would be about 50 feet per second. It was well for those who, like Prof. Watkinson, had to watch the progress of water "particles" whirling round glass models that they did not move at such a speed, for the only wonder would be how the observer could survive such gyrations. Talking of this astounding phenomenon, which Prof. Watkinson mentioned on page 55, it would be interesting to learn how he managed to observe it. Did he separately label "each particle" of water so that it might be distinguished, and then follow them all severally round in their wild career? Probably

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Prof. Watkinson's method of observation was to note how often some floating substance was carried round with the water whilst a given quantity was being evaporated, but it would be beyond the power of anyone but a Baron Munchausen to see that those floats kept company with the same "particles" of water throughout their whole voyage. Mr Thornycroft was at once more modest in his estimate of the rate of movement of the water, and more accurate in the language used in describing it; but, after all, his result (according to Prof. Watkinson) that the quantity of water carried round by the steam in a given time was about 50 times the quantity evaporated in that time was only a calculation from rather uncertain data. Mr Thornycroft said the flow of water was "measured," but that measurement amounted only to an estimation of the quantity flowing. In referring, on pages 37 and 38 of his paper, to Mr Thornycroft's Institution of Naval Architect's paper on "The Influence of Circulation," etc., he (Mr Rowan) did not do him the injustice of omitting to read his former papers on circulation. He could not see, however, anything in their conclusions to affect his reading of his (Mr Thornycroft's) gauge glass experiments. Mr Thornycroft said ("Circulation in the Thornycroft Water Tube Boiler," Proc. Inst. N.A., 1894)—"The method of measurement I adopted was to put a rectangular notch, similar to those usually employed in gauging small streams, across the separator, so that all the water that went down the downtakes had to pass over it; and I then observed the flow over the notch through a glass window in the end of the boiler, and thus knowing the size of the stream was able to calculate the circulation. I found that in the case of the above water delivery the circulation was 105 times the feed—that is to say, for every pound of steam brought up by the generating tubes, 105 pounds of water are also passed through them." It was evident from this that both the quantity of water flowing and the velocity of a varying current had to be estimated by the eye at some little distance in this method, and that neither factor could be thus determined with anything like the accuracy possible in dealing with small streams whose rate of flow was regular, and where actual measurement of the quantity could be carried out.

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He was pleased that Mr Thom called attention to the fact that he and Mr Normand had also taken the same view of these test column results as he (Mr Rowan) expressed, and he did not think that his remark was entitled to the unfair suggestion made by Mr Thornycroft at the close of his communication on page 76. It was of course absurd to argue, as Professor Watkinson did, that the test column could prove two opposing conclusions at one and the same time, or as Mr Rainey did, page 101, that the boiler making the largest quantity of steam had the slowest circulation! If Mr Rainey demurred to this, he must explain how a much larger percentage of steam could be present in the water in the ascending column and drum except by an increased rapidity of circulation. On the same page Mr Rainey said that he (Mr Rowan) would not have made his remarks as to geyser action, pages 36 and 37, had he seriously studied Mr Thornycroft's two diagrams, because there was less likelihood of the geyser action occurring with tubes discharging above the water level than with submerged tubes. Mr Thornycroft, although he was not (as it was claimed) the "pioneer" of boilers constructed with tubes discharging above the water level, had devoted much attention to that design, and was surely entitled to speak as to his own experiments. He announced the opposite opinion to that of Mr Rainey, and described what he (Mr Rowan) called the geyser-like action as occurring with tubes discharging above, not below, the water level, so that Mr Rainey's accusation of want of serious study was evidently misplaced. It was all very well to assert, as Prof. Watkinson did, that "the velocity of flow through the down-comer was proportional to the square root of the difference between the level of the water in the upper drum and that in the test column," but was this rule founded on Mr Thornycroft's 105 pounds or his 50 times velocity, or Prof. Watkinson's 240 times? Supposing both of these were wrong, what became of the rule? In any case if it were elastic enough to include such widely different velocities as 50 and 240 it was not much of a rule. In fact, those who talked so much about the "head" of water in a boiler as a measure of circulating power, apparently ignored the force exerted by the steam in

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continuously lifting a large quantity of the water from a lower to a higher level, and thus imparting velocity to the downward currents where there was freedom for them to flow. Taking the indications given by the action of Prof. Watkinson's glass models, the Belleville boiler ought to have, on Prof. Watkinson's basis of reasoning, the best circulation, because it showed the largest quantity of water forced up the greatest distance into the drum above the water level. But it really showed the worst circulation, because that water (the position of which really constituted Prof. Watkinson's gauge of the amount of circulation) was maintained there at the expense of the upper rows of tubes, which were kept nearly empty of water, and thus exposed to over-heating, and to easy distortion by strains, such as those caused by the pitching and rolling of steam vessels. That "way of regarding the matter enabled them to conclude at once" that they needed a considerable addition to the number of experimental results before any such rule could with safety be formulated. If it was on the basis of such so-called "facts" that Prof. Watkinson founded his idea that all the water in a boiler must be at the same temperature, it was no wonder that he was misled. Prof. Watkinson asked him which conclusions such an idea vitiated, and he replied, every conclusion as to circulation which was founded upon any difference of density in the boiler, except that as between steam and water. There was no room for difference of density in the water if it was all at the same temperature, and therefore no room for the action of gravity except as between steam and water; but the boiler and the furnace were not yet produced which would make such a result possible, and therefore it was utterly useless to argue from a chimerical basis. Prof. Clerk Maxwell's account of the distribution of temperature, referred to by Mr Todd, was much to be preferred. Mr Wingfield, at page 86, of his remarks and footnote, referred to Fig. 29, on Plate IV., to ask a question about the position of the gauge glasses in the Rowan and Horton boilers of 1869, and to suggest that if the water level were "several feet below the tops of the down-take tubes" circulation could not exist at all. In reply, he had to say that Fig. 29 showed the arrangement of boilers used

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in the Indian River Steamers, and the gauge glasses were placed for a nominal water level in the boilers of about one foot below the top of the down-take tubes or down-comers, so that Mr Wingfield was a little wide of the mark at "several feet." In the "Propontis'" original design, shown at Fig. 74, the water line was just level with the top of the down-comers, and in his own boiler of 1876 the water level was arranged as in this latter case, all the small vertical tubes discharging above that point. These facts showed that Mr Thornycroft was not the first to make a water-tube boiler with the tubes discharging above the water level. Before leaving this section he must say that he entirely dissented from the statement that, in order to observe the condition actually existing in a boiler when working at 150 lbs. pressure at a given rate of evaporation, it was only necessary to arrange the rate of evaporation in a model working at atmospheric pressure so that it was approximately one-tenth of the rate in the actual boiler, and so on, models being made to exhibit the conditions which obtain in actual boilers by merely making the rate of evaporation in them vary as the pressure in the actual boilers. This was suggested by Mr J. G. Hudson in *The Engineer* of December 5, 1890, but only with reference to the volume of the steam formed—not to the rate of evaporation. It would need much more than assertion to prove any true relation between such widely different results as those to which Professor Watkinson applied it. It was evident also that glass models were so utterly unlike actual boilers in material, strength, and weight, that it would be impossible to subject them to anything like the ordinary treatment which boilers underwent in practice, or that, as Prof. Hele-Shaw put it, the topsey turveydom of marine work could be imitated with them. It was, for instance, absurd to suppose that the gentle and regular motion imparted to a glass model mounted on the rockers of a rocking-horse, was in the slightest degree comparable to the violent disturbance produced by the combination of pitching and rolling experienced on board ship. One might as well compare the effects, on the average human specimen, of the soothing motion of a cradle, with those of the violent upheaval produced by the waves.

Transmission of heat.—He came now to the remarks made by Messrs Wingfield, Watkinson, and Rainey on the transmission of heat from gas to water, or from the fire to the water, as they put it, and here he must at the outset say that, the object of his remarks on page 39 of his paper had been missed by all these gentlemen. He did not pretend to give a calculation based upon actual results with boilers, but considering the heating surface *per se*, and "assuming the proper application of the heat to it" with thoroughly efficient circulation of water, he showed from Peclet's formula, on a modest estimate of fire temperature, what the heating surface was capable of doing. He assumed certain temperatures as those of the two sides of the iron, and said that each square foot of heating-surface exposed to these temperatures was capable of transmitting a certain amount of heat. It was no answer to say that results hitherto obtained from boilers showed that they had not succeeded, as yet, in maintaining such a difference of temperature between the two sides. His last sentence in this section on page 40 showed that it was on this very account that he drew attention to what could be done with the heating surface, provided heat was applied to it where water was kept at the other side of the metal. He utterly refused Professor Watkinson's statement that if 1500° Fah. were the temperature at the metal on the fire side, the heating surface would be burned through in a week or less, unless he added as a condition that no water should be on the other side. The gist of the matter lay in this, that in consequence of the rapidity with which heat was conducted through the metal of boilers, and of the capacity of water for heat, it was impossible, as long as water had free access to one surface, to burn the metal by the employment of any ordinary fire temperature. It was the same rapidity of conduction which caused the flame and hot gases to be robbed of their heat, where they came for a moment in contact with the heating surface, so quickly, that special means were needed to ensure the maintenance of a high temperature in contact with that surface· Prof. Watkinson's diagram, Fig. 54, was founded on the idea that a layer of cooled gases must be retained next the surface of the plate,

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and that practically nothing could be done to remove it, so that the difference between 2500°, and say 400° Fah. was uselessly employed. This, however, was fallacious, because with the same arrangement, only substituting steam for the water, the great difference between the temperature of the iron and that of the fire would disappear, and the metal would rapidly become over-heated and burnt—probably giving way under pressure owing to loss of tensile strength at a high temperature, even before it was badly oxidised. Moreover, a totally useless drop in temperature, such as he described, was no more true than was a useless drop in the supposed case of water, because if the heat energy did not directly reach the metal surface, it was employed in removing the cooled gases so that a fresh contact with heated gases might take place. He must say that the diagram Fig. 56 was, with the explanation of it, a most extraordinary one to be put forward. If water could fall from a height of 2500 feet to a height of 401 feet without doing any work, what was the object of placing the reservoir at that height? Why not at once place it at 401 feet level? What were we to understand by "head" of water? Fig. 56 really illustrated a result exactly the opposite of that to which Prof. Watkinson intended it to apply, for the water at 401 feet had the increase of energy due to its fall from 2500 feet (or more strictly its energy of position had become energy of action), and it was then capable of doing work which the same quantity could not do if maintained at the higher level, or if the reservoir were at 401 feet. The flame on the contrary lost energy by contact with conducting surfaces, and became less capable of doing work with a fall of its temperature. Turning to the calculation given by him (Mr Rowan) at page 39, Prof. Watkinson thought it was misleading, but he immediately gave an equation which expressed precisely the same view as to the rate of transmission of heat through iron. His (Prof. Watkinson's) second equation to some extent corroborated this view, because it was intended to show that they could transmit 20,000 British thermal units per square foot per hour through iron, with an increase of temperature of only 2·6° Fah. on the hot side, so that this went to prove that the iron could not be over-heated. Prof. Watkinson's figures differed from those given by Mr J. G. Hudson, in a series of articles on "Heat Transmission in Boilers," in *The Engineer*, Vol. LXX., 1890, and he did not inform them whence he derived the co-efficient or constant he ascribed to Angström. In his (Mr Rowan's) paper on "The Design and Use of Boilers," 1878, he quoted Angström's co-efficient of conductivity for iron; viz., 9·77, as given by Prof. G. Carey Foster in Watt's Dictionary of Chemistry, Vol. VI., p. 693, and the calculation embodying its use also gave a different result to that announced by Prof. Watkinson. Mr Wingfield had referred him to the late Prof. Rankine's formula on p. 258 of "The Steam Engine," etc., and he and Mr Rainey had alluded to the late Mr Blechynden's experiments; whilst Mr Halliday (who was the author of an interesting book on boilers) had also introduced some similar considerations. That subject was by no means so clearly defined as Mr Wingfield and Mr Rainey would have them believe. Prof. Rankine, considering the transmission of heat between two points on opposite sides of an iron plate, expressed the rate of conduction thus:—

$$q = k\frac{dT}{dx} \quad \text{or} \quad q = k\frac{T' - T}{x},$$

when q is the quantity of heat transmitted,
k, the coefficient of conductivity,
dT or $T' - T$, the difference of temperature between the two points,
and dx or x, the distance perpendicularly to the sectional plane through which heat is transferred between the two points, *i.e.*, the thickness of the plate.

The latter form was the equation used by Prof. Watkinson, with an added symbol for area of plate, and there was no practical difference between it and the one he (Mr Rowan) had quoted from Peclet. In fact, Prof. Rankine's reasoning was admittedly founded on Peclet's work. Strictly speaking, some deductions had to be made from this on account of the internal thermal resistance of the metal and the external resistance where the heat passed from

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one fluid to another across the plate. The internal resistance was extremely small for iron, being, according to Rankine, expressed by $\cdot 0096x$, when q is expressed in thermal units per hour per square foot of area, and x in inches. The full state of the case was thus expressed by Rankine:—

$$q = \frac{T' - T}{\sigma' + \sigma + \rho x}$$

T' and T being the temperatures of the two fluids in contact with the two faces of the plate respectively;
$\sigma' + \sigma$ being the coefficients of external resistance;
ρ being the co-efficient of internal resistance, as above;
x being the thickness of the plate.

It had been pointed out (Watt's Dict. of Chem., Vol. v. p. 69) that this could be written $Q = \frac{T' - T}{R}$.

R representing the sum of the resistances, and
$T' - T$ being the condition which determined the flow of heat, and comparable, therefore, with electromotive force in electrical matters.

In this form it was strictly analogous to the expression of Ohm's law for electric currents, and to the expression for magnetism also. Practically, the whole difficulty lay in determining the value of $\sigma' + \sigma$. It must not be forgotten that Rankine also said ("The Steam Engine," etc., p. 259)—"The rate of external conduction through the bounding surface between a solid body and a fluid is approximately proportional to the difference of temperature, when that is small; but, when that difference is considerable, the rate of conduction increases faster than in the simple ratio of that difference." So that there was merely the practical difficulty to meet which consisted in removing the gases, as they were cooled, from the heating surfaces, and in preventing the deposit of soot on those surfaces, besides that of governing the speed of the gases so that they came in contact with the heating surfaces at the most suitable velocity. Mr Rainey thought that Mr D. K. Clark's and Mr Blechynden's results showed that the theoretical transmission of heat had been realised in boilers, but therein he was much mistaken. Rankine added what he called the "approximate formula"—

$$q = \frac{(T' - T)^2}{a}$$

(which is quoted by Mr Wingfield to the exclusion of the others), as an expression compiled from results with some boilers with whose performances he dealt in another part of the same book, a being an empirical factor which, according to him, had the value of 160 to 200. Experiments by Mr Stromeyer, however, were said to have given a a value of 217, whilst those of Mr Blechynden made it equal to 40 or 50, so that they were still some distance from unanimity on this point. It had been said of Mr Blechynden's latest results that they "plotted so well that they might be taken as evidence that the rate of transmission varied as the square of the difference of temperature, or, in other words, that the rate of transmission, per degree of difference, was simply proportional directly to the difference between the temperature of the water and the furnace gases." But both Mr Blechynden's experiments, and previous experiments by Mr Fletcher and others, left something to be desired on the score of means to render the heating surface more efficient by better circulation of the hot gases, or by the removal of the cooled gases from them. Flat surfaces, such as they used, were not conducive to rapidity of circulation, and it was certainly not safe to draw general conclusions as to boilers from experiments carried out on small flat-bottomed cans or vessels of 10 or 12 inches diameter, such as those experimenters used. Mr Blechynden also used a copper-ball pyrometer for his temperature measurements—an apparatus, which, he (Mr Rowan) had satisfied himself by use, was only capable of giving rough approximations to the actual temperatures. Other experiments had been carried out by Neuman, Dr Kirk, Sir A. J. Durston, and by Messieurs Thomas & Laurens, Hirsch, and A. Witz, in France, but this question was far from being fully understood as yet. For instance, M. Witz obtained in his experiments an evaporation of 136 and 204 lbs. of water per square foot of heating surface per hour, (the feed-water having been at 57° and 194° Fah. respectively)

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where the plates were made red hot; and Mr C. Lang, in experiments with evaporators, had recorded* a rate of 140 lbs. per square foot with a difference of temperature of 106·7°, and a transmission of heat amounting to 1224 units per 1° of difference; whilst Mr Foster (author of a large work on "Evaporation by the Multiple System") informed him that an evaporation of 14 and 16 lbs. of water per lb. of coal was constantly obtained from cold liquor in double-effect apparatus. It had been claimed for multiple-effect evaporators that a triple-effect apparatus would evaporate 23½ lbs., but he did not know if such a result had been realised. These results, compared with the best rates obtained in steam boilers, which rarely reached 20 lbs. per sq. ft., with a much greater range of difference in temperature, showed that there must be much still to learn regarding the subject, and that Mr Rainey and others were rash in thinking that anything approaching to perfection had been attained as yet in boiler practice, or that such experiments as those of Mr Blechynden had "established" anything more than that certain results were true in as far as they related to the apparatus he used. The experiments referred to, however, indicated a direction which investigation might usefully take with a view to arriving at means for more effectively applying the heat of fuel to the heating surfaces of boilers, and he (Mr Rowan) would be glad if his paper was the means of stirring up an increased interest in that matter. He believed that in it, and in that of the means of applying forced combustion in a complete way—which was itself a prime factor in increased efficiency of boilers—he had indicated directions in which improvements might be made in boilers, in spite of the complaints of some of his critics.

Forced Combustion.—Mr Todd approved generally of his views as to improvement in boiler firing, but erred in thinking that he (Mr Rowan) proposed to import gas producers *simpliciter* on board ship. Prof. Watkinson's remarks on that head aroused the desire to know what kind of boiler and gas producer he could possibly have in his mind, which would enable them to witness the

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* Trans. Inst. Engineers and Shipbuilders in Scotland, Vol. XXXII., page 287.

remarkable design of a gas producer placed inside of a boiler. A gas producer (except apparatus for gasifying oil) was generally employed to gasify fuel at a comparatively low temperature, whilst a boiler required the combustion of fuel at the highest economical temperature, and if Prof. Watkinson saw his way to combine these two opposing elements in the manner he indicated, and to "secure many advantages" from such a combination, he would be entitled to the credit of great ingenuity. In conclusion, he would ask Mr Couper and Mr Thode to remember that, as to the particular boilers which might be largely manufactured and sold, and which thus might be said to "come to stay," such a question was not always settled by scientific merit or correctness of design. There were many considerations, financial and personal, which entered into such a problem, and the ultimate issue was one that could scarcely be foretold. Of course his own opinion was that the boiler which he introduced in 1876 was second to none in point of design, as compared with any hitherto introduced. He believed, however that in the future, great changes would be introduced in methods of generating steam by means of the heat derived from combustion, so that probably an entirely new type of boiler might appear. M. Chasseloup-Laubat summed up his elaborate treatise on "Marine Boilers and their Circulation" in these words:—"This account of the subject shows that the ideal boiler does not yet exist, perhaps even it will never exist," but he (Mr Rowan) was inclined to take a more hopeful view.

On the motion of the President Mr Rowan was awarded a vote of thanks for his paper.

Correspondence.

Mr W. M. McFarland (Passed Assistant Engineer, U.S. Navy) —As the Secretary of the Institution had invited him to take part in the discussion of Mr Rowan's paper, he gladly availed himself of the compliment, but both the paper itself and the discussion were on lines which he had not the time or inclination to follow closely. As a naval engineer, his interest had been rather in the practical merits of the water-tube boiler as warranting

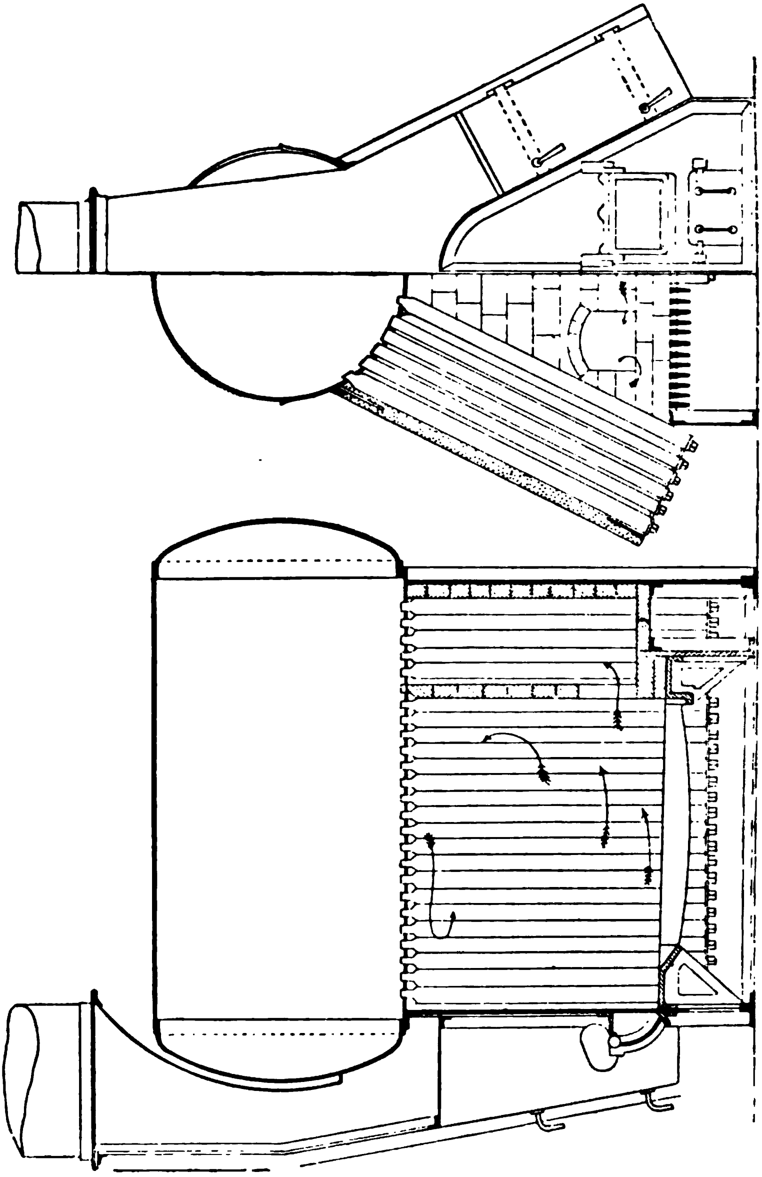

Fig. 76, Thom.

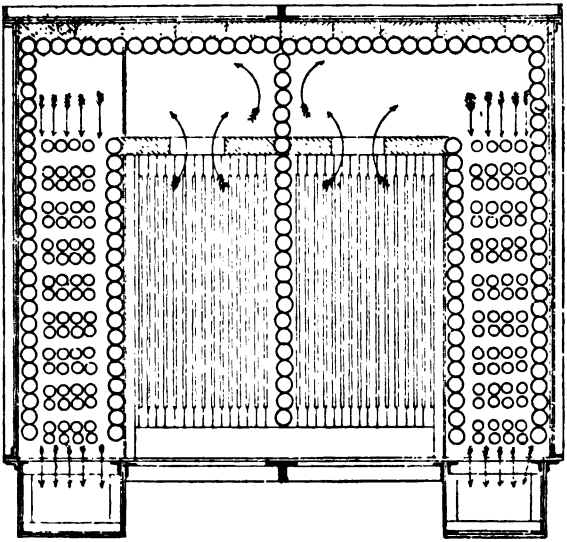

Fig. 77, Thom.

its use in naval vessels to the replacement of the shell boiler (often called the Scotch boiler in America) and the study of correcting its defects so as to disarm the prejudice against its use. He might say, however, that the paper and discussion would undoubtedly exhaust the historical side of the question, so that future students could find a complete account of the subject there. It might be remarked (as he had done elsewhere) that Mr Charles Ward, in his paper at Chicago, in 1893, referred to the *renaissance* of the water-tube boiler as occurring about twenty years ago, *not* its inception, especially for marine purposes. It appeared to the writer that the main reason for the rapid progress with marine water-tube boilers in recent years, was the reduction of weight, and that explained why they had been adopted so much more readily in the naval service than in the merchant marine. That was certainly the case in steam launch work in the United States Navy, where the Herreshoffs were the pioneers, and a recent cruise from which he had just returned, and during which he had had an opportunity of seeing the steam launches of almost every naval

Mr W. M. McFarland.

power, showed that the United States was the only country using water-tube boilers exclusively for that work, while he did not remember a single one used by any other country. The merits of the water-tube boiler were so well known that to mention them again would be tiresome, but it was perhaps worth noting that, while they possessed the very great advantage of safety from disastrous explosion, that had had little weight in their introduction, owing to the fact that well-built shell boilers had not exploded. In preparing an article on the subject about two years ago, the only instance he could find was one in which a fire-box had collapsed from low water. In discussing circulation as affected by the design of the boiler, it was a curious and interesting fact that it seemed almost impossible to make any combination of tubes that would not do fair work. The designer and manufacturer of an American boiler that had a very extensive sale, which he believed had never had an accident, and which had replaced other boilers of apparently better design which had suffered from accident, had told him that he was not prepared himself to demonstrate that his boiler was designed scientifically for good circulation, but that it certainly did well, and that he had been too busy building them to worry about experiments to show why they worked so well. In discussing the necessity for external "downcomer" tubes, Mr Ward said, "I have not found them necessary. As a matter of necessity some tubes will be cooler than the others, and if the water goes up in some, it must come down in others." Mr Yarrow's famous experiments demonstrated the truth of Mr Ward's remarks, made some years before. To his mind, the eventual supplanting of the cylindrical by the water-tube boiler was as certain as anything in the future could be. The apparent failures in particular instances would usually, on investigation, be found to be due to bad workmanship, carelessness or indifference (strange as it might seem), or personal interest. A recent occurrence in the United States was an illustration of this last point. A large steamer was built by a prominent firm who preferred to use cylindrical boilers, but the owners insisted on a particular make of water-tube boiler and made a separate contract for them, specifying a certain horse power. On trial, and in service, a very much greater horse power was found necessary, and the boilers were forced to such an extent as to be beyond the capacity of the feed-pumps, and, as a result of this and some accidents resulting from a stampede when the first trouble occurred, the boilers were ruined. Impartial judges, who saw the boilers working before the forcing was so hard, said they worked admirably. By those who simply knew that the boilers gave out, without hearing the reason, this would doubtless be cited as showing that water-tube boilers were unreliable, while the facts were just the opposite. When they were thoroughly understood, and especially when the fire-room *personnel* had become well trained in their use, water-tube boilers would give as great satisfaction in regular service as the older type.

Mr James Foster (Member)—He had been much interested in the paper and discussion on water-tube boilers, especially as regarded the question of evaporation and circulation, and it appeared to him that a few particulars concerning evaporation in vacuum might be of interest to the members of the Institution, as throwing some light on evaporation and transmission of heat. He would direct attention particularly to the "Film" tube single evaporator, with which the following average results had been obtained, not by special tests and trials with working models, but in actual daily work of 12 hours. The liquor concentrated when these results were obtained was a solution of calcium and soda salts:—

Vacuum,	26·5 ins.
Steam pressure per square inch,	6·5 lbs.
Temperature of the steam at 6·5 lbs. per square inch,	232° Fah.
„ in the evaporator during evaporation,	110° „
„ of liquor supplied to the evaporator,	49° „
Specific gravity of the liquor supplied to the evaporator,	1·050
„ „ „ discharged or concentrated liquor,	1·152
Temperature „ „ „ „	102° Fah.
„ „ condensed steam at outlet,	96° „
Water evaporated per sq. ft. of heating surface per hour,	13·65 lbs.

Mr James Foster.

In order that this apparatus might be understood, he showed a section of a working tube in Fig. 78. The working heating tubes were 4 ft. 1½ ins. long over the tube plates, by 1⅞ ins. internal diameter, and fitted internally with the patent "Film" tube. Each tube was supplied separately with liquor, which was concentrated during the time it took in running from the top to the bottom of the tube, and was drawn off at the bottom by a pump. During the time the liquor was running down the tubes, each tube evaporated 26·77 lbs. of water per hour from the liquor, at a temperature of 49° Fah. Each tube had a heating surface of 1·96 square feet—viz., 48 ins. × 1⅞ ins. internal diameter = 1·96, × 40 tubes = 78·4 total square feet of heating surface in the apparatus; 48 inches was the length of the tubes between the tube plates. The tubes were arranged in the evaporator in parallel rows, each branch supply pipe supplying two rows of tubes. These supply pipes were connected to a main trunk supply chamber on the side of the evaporator from which they took their supply, and were easily disconnected when the "Film" tubes required to be taken out for cleaning purposes. As would be seen from Fig. 78, the top of each "Film" tube was fitted with a liquor spreader or distributor chamber with bayonet catch attachment to the tube. This chamber, as would be seen, had three legs or ribs with open spaces between, which rested on the top tube plates, and from which the "Film" tube was suspended. The liquor to be concentrated was fed into those chambers, and ran down the annular openings in each of the three legs or ribs, and was then distributed by the shields and ran down the inner surface of the heating tube in a thin film. The annular space between the shields and the heating tube was larger at the top than at the lower end, as there was less water to be evaporated as the liquor got to the bottom of the tube. Each "Film" tube was fitted with five distributing shields. As the water was evaporated the vapour passed under the distributing shields and through the openings under the shields, and up through the centre of the "Film" tube to the top vapour chamber, and from there to the condenser. By this arrangement the vapour was got rid of as it was generated, and the

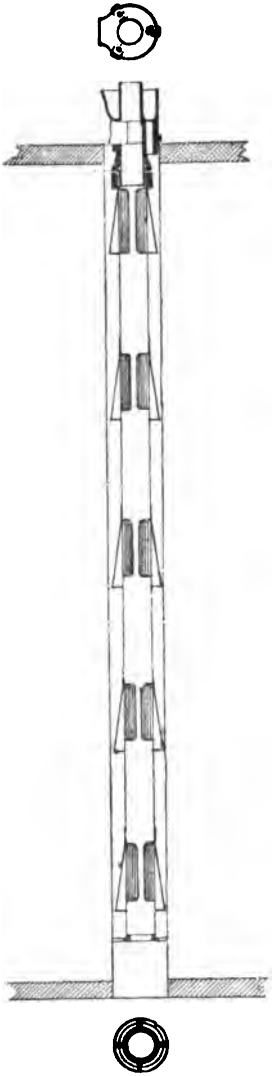

Fig. 78.

Mr James Foster.

whole evaporating surface of the heating tube was covered with liquor, which did not run down in rivulets. In order that the vacuum should be the same at the bottom of the tubes as in the top vapour chamber, a large vapour connection was made in the side of the apparatus from the underside of the bottom tube plate to above the top tube plate. That also took away any vapour which would be carried down with the liquor and might accumulate at the bottom of the apparatus. In a patent vertical double effect evaporator for concentrating caustic liquor, it was evaporating 16 lbs. of water per lb. of coal, with steam at 6 lbs. pressure per square inch. The heating tubes were made of steel in this case. The specific gravity of the liquor supplied was 1·125, and concentrated to 1.450. He regretted that he could not at present lay before the Institution the complete results of the working of the apparatus, but hoped to do so at some future time.

Mr G. W. THODE (Member)—Upon the subject of rapidity of circulation he thought the following information, being based on facts, might be useful and interesting. In an edition of the German book, "Handbuch über Vollständige Dampfkessel Anlangen," by Mr Thielmann in 1881, an experiment was described for the purpose of answering the following questions with respect to water-tube boilers:—

First—"Is the circulation of a water-tube boiler continuous and always in the same direction?"

Second—"What quantity of water circulates through a boiler?"

To answer these questions, the following experiments were made. One element or section of a boiler was placed inclined, and provided with the necessary connections at front and rear. A continuous fire beneath the elements showed a regular equal flow of water at the uptake end, and consequently perfect circulation. In order to establish the quantity or amount of water circulated, a propeller wheel was fixed within the rear circulating tube or downcomer. This propeller was carefully watched, and by means of a large number of observations, it was ascertained that an equal quantity of water passed with a certain number of revolutions of the propeller.

Thereafter the whole element, together with its propeller wheel, was placed (without any alteration whatever) between other elements of a complete boiler of about 220 square feet of heating surface. The boiler was set to work, and it was then found that the propeller always turned in the same direction, and that its velocity varied with the rate of evaporation. Taking into account the amount of water contained in the boiler, it was proved that the total contents of the boiler passed a given point every three minutes. A further test was made with a boiler described as of 50 nominal horse power, and it was found that approximately one-third of the total contents of the boiler circulated per minute; or, to put it differently, that approximately 50 times the weight of the feed-water required per hour circulated past a given point within one hour. It was stated that the absolute correctness of the above figures was of little interest. It was, however, of more importance that during observations extending over several months it had been proved that the propeller wheel always, without exception, revolved in the same direction, and that the revolutions were very regular, which proved that the circulation was always in the same direction. It was further proved that the circulation commenced very shortly after the kindling of the fires, that it continued (although slower) during the meal hours, and that it stopped only a long time after the fires had been put out.

Translation of a Letter received by the Secretary from the Marquis de Chasseloup-Laubat.

DEAR MR PARKER,

In reply to your kind letter of 8th inst., I send you, by book-post, a copy of the essay published in April, 1897, in the "Memoirs of the Society of Civil Engineers of France," on the subject of water-tube boilers, and on the general theory of circulation in these apparatus.

You will find therein :—

(1) Some remarks upon the principal types of boilers presently in use.

Marquis de Chasseloup-Laubat.

(2) A summary of the principal experiments, including my own.

(3) The general theory of circulation.

(4) Some considerations upon water-tube boilers or generators.

As regards the first and fourth sections, I shall not say anything at present, but I shall give you a short summary of the principal ideas embodied in the second and third.

Before expounding them to you, allow me to take the liberty of reminding you that the theory in question is strictly and completely in accordance with the results of all the experiments known to this day, and particularly with those of Thornycroft, Yarrow, Bellens, Solignac, and Watkinson. I desire above all to make special mention of these last, for they are by far the most complete and the most scientific. Last of all, I draw your attention to the fact that my theory enabled me to foresee all the results of the experiments, of which, so far, I did not know the details.

This theory may be summed up in the following manner:—

(1) In a liquid of known specific weight, a bubble of steam of known specific weight and volume, occupying a position situated at a known distance from the free surface of the liquid, corresponds to a determined potential energy.

(2) The yield of this potential energy in circulating work when the bubble rises to the surface—*i.e.*, the useful work resulting (from the point of view of the circulation) from the transformation of this potential energy—is not constant. It is, on the contrary, variable. It is equal to the theoretic work multiplied by a coefficient varying between 0 and 1. This coefficient is itself given by a very complex function of numerous elements, such as absolute diameter of the tubes, absolute diameter of the bubbles, quality of the water, intensity of the heating, etc., etc. I have only been able to show the existence of this complex function, without managing to determine the relative value of its constituent elements.

(3) I have divided the water-tube generators into two principal classes, which I have named "reversible" cycle and "non-reversible," according as the tubes heated have their outlet below or above the free surface of the water in the upper collector.

(4) I have shown that for the reversible cycles the normal circulation was always continuous, whilst for the non-reversible cycles it was generally pulsatory.

(5) I have shown that, leaving out of account the friction, and in supposing the case of plug bubbles almost completely closing the tube, the maximum weight of fluid—steam and water—discharged in a given time per unit of section of heated tube, was attained. That is a new argument in favour of the use of very high working pressures, and a means of calculating the maximum of specific heating compatible with the security of the apparatus. If this maximum volume of steam be exceeded in the tube heated, the circulation may become irregular and pulsatory, and diminish in intensity, in which case the apparatus may be endangered.

(6) For the non-reversible cycles, the theory and the experiments together show that continuous circulation can hardly exist except with certain qualities of water — brackish, for example — which facilitate the formation of a sort of emulsion or close mixture of water with a very great number of very persistent little bubbles. More generally, with ordinary water, the circulation is pulsatory —that is, it is effected by alternate discharges of plugs of water and of steam, or, more correctly, by plugs of steam separated by a mixture of water and steam. In this case I have not been able to calculate the maximum of circulation.

(7) The conclusion is that—(*a*) The first cause of all circulation is evidently the potential energy of gravity resulting from the formation of bubbles of steam in the midst of the liquid mass. (*b*) The rule of mean specific weights—which evidently gives the work available to produce the circulation—*does not* give the effective work which produces this circulation. The second is equal to the first multiplied by a coefficient varying between 0 and 1. It is this which explains why in certain water-tube apparatus of faulty construction the general circulation is almost *nil*, all the available work being absorbed by local eddies, and not by general circulation.

Such are the few observations and reflections which I take the liberty of addressing for your great Institution. I need not say that if certain points do not appear clear to you, I shall consider it a duty and a pleasure to try to explain them to you. I must, however, decline to reply to all questions which may be put to me as to the relative advantages and defects of the different styles of boilers in use. Engaging in scientific research for the love of it, I cannot either extol or depreciate the property of any maker whatever. It is for those who are good enough to read my work to draw therefrom, for their own behoof, the practical conclusion.

I remain, etc.,

(Signed) CHASSELOUP-LAUBAT.

Note.—Referring to paragraph 7 of the preceding letter, the author writes:—

"I wish also to say that this part of my theory has just received an important experimental confirmation. Mr Bellens, whose studies upon circulation are well-known, has published in the *Revue Technique*, of January 10th, January 25th, and February 25th of this year, three articles, in which are given the results of a great number of experiments made with vertical glass tubes, in which circulation is produced by the ascension of air bubbles.

"In the conditions, which I have stated, the maximum discharge of water always took place when the volume of air was practically equal to the volume of water. I say 'practically,' as Mr Bellens found only about ten per cent. difference between the results of theory and practice.

"This I consider a most important fact, which ought to be made widely known.

"As I have stated in the *Bulletin des Ingenieurs Civils de France*, of April, 1897, if we call Q the maximum weight of water—calculated by the formulæ I have given—which a tube is capable of discharging during the unit of time, T the temperature of the steam, and N_s the total number of caloric units received by the tube during the same unit of time, there will be a serious danger each time, that:—

$$N_s > Q\ (606{\cdot}5 - 0{\cdot}695\ T).$$

"This shows for 'reversible cycles,' that is to say for the majority of boilers, a maximum of specific working beyond which, contrarily to the general opinion, *things no more adjust themselves.* The specific discharge diminishes; the column of mixed water and steam travels slower and slower; the circulation becomes pulsatory; long plug bubbles drive the water completely out of the heated tube through both ends at once; and finally the tube melts and bursts."

The PRESIDENT stated, at the meeting held on the 22nd February, 1898, that Mr Matthey had prepared apparatus in order to show some experiments, but having been abroad he could not get back in time to attend the last meeting. Mr Matthey would now conduct his experiments, and briefly explain them.

Mr C. A. MATTHEY (Member) considered there was one point which was at the bottom of the whole question of circulation of water in water-tube boilers, which seemed to be still undetermined, and that was—Did the presence of a bubble of gas, or of a solid body lighter than water, immersed in a column of water and rising through it, diminish the hydrostatic pressure at the bottom of the column, or did it not? Water at rest only began to move from one place toward another, if the pressure at the first place was greater than that at the second. Therefore, in seeking the explanation of the motion of water, we should look for the static forces which caused that motion. He had recently been making experiments in which he purposely avoided circulation, and measured the hydrostatic forces which would produce circulation when the necessary conditions were present. He anchored a glass bubble, much lighter than water, at the bottom of a column of water, and measured the hydrostatic pressure there by means of a pressure gauge. The bubble was then released, and the pressure of water observed in the column while the bubble was rising to the top. Fig. 79 illustrated the manner in which the experiment was carried out:—A vertical glass tube, 2 inches in diameter and 5 feet high, connected at the bottom with another glass tube of the same height and $\frac{1}{8}$th of an inch in

Mr C. A. Matthey.

diameter, rested upon an electro-magnet D. The tubes were nearly filled with water, and a glass bubble C, a little smaller than the large tube, floated within it, with the water level at BB. To the bottom of the bubble was attached a small piece of soft iron, and when the bubble was pushed to the bottom of its tube it was held there by the attraction of the electro-magnet. The water level then rose, by the displacement of the bubble, to AA. The pressure on the bottom was registered by the level of the water in the small

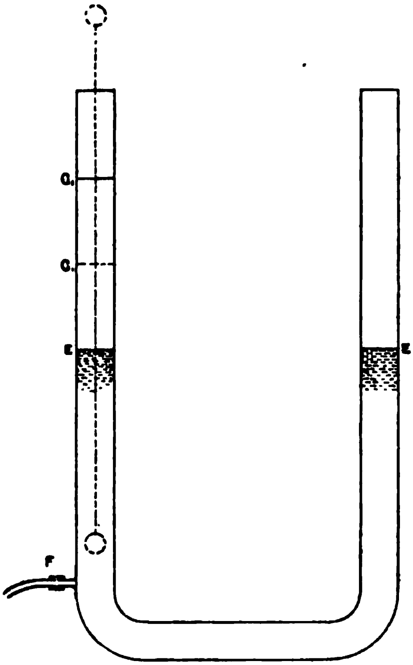

Fig. 80.

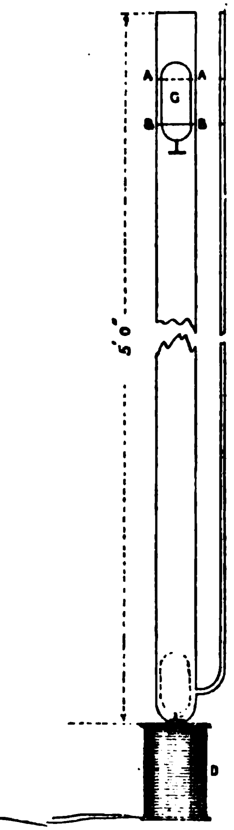

Fig. 79.

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tube. When the bubble was anchored down, the pressure was greater than when floating at the top, by an amount represented by the distance AB. On interrupting the current which flowed through the electro-magnet, it would be found that while the bubble rose, the water in the gauge tube dropped to B, which showed that the presence of the free bubble in the large tube made the pressure on its bottom less than that which corresponded to the height of water in it. This could also be shown by the U tube, Fig. 80, which was filled with water to the level EE. On blowing gas into the left-hand leg by the nozzle F, the level in that leg rose to G or G_1, but the level in the right-hand leg remained at E; and this was so whether much or little gas was forced into the tube, which demonstrated that the pressure at the bottom was the same as if the gas were absent. This disposed of the distinction which had been drawn between the case where there was continuity of water round the bubbles, and where the bubbles made plugs of gas and water alternately, completely occupying the section of the tube. It was sometimes said that the water was entrained by the bubbles; or that the bubbles rose in virtue of their lightness, and dragged the water with them. Such expressions were loose and unscientific. The bubbles which rose in the left-hand leg, in Fig. 80, did not drag any water out of the other leg. But if instead of the bubbles a solid ball, attached to a fine wire, was placed at the bottom of the left-hand leg, and drawn upwards by means of the wire, the level in the right-hand leg became depressed, while in the left-hand leg it rose. That might be called entrainment, but it was produced by an external force, not by the mutual action of the water and the immersed body. There was an unfortunate word often used in that connection; viz., "head" of water. It had two distinct meanings, which lead to confusion. One was a vertical linear dimension, the other a hydrostatic pressure. Until recently these meanings were held to be interchangeable, "a pressure of so many feet of water" having been a common expression. In his experiments, when the bubbles rose in one leg of a U tube, what he might call the pressure-

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head was the same for both legs, while the linear head was not, being less for the unbroken water than for that with bubbles in it. On the other hand, in two contiguous drowned tubes of a Yarrow boiler, one with bubbles in it and the other without, the linear-head was the same, but by what was described above as the pressure-head was not; hence motion took place from the greater to the lesser pressure. The fact of the matter was, we were dealing, not with a hydrostatic, but a hydrodynamic problem. The water in the column where the bubbles were present was not at rest, but was a complex system of stream-lines flowing round each bubble; and although he had shown that the net result of all this modification of pressure in stream-lines was to produce the same hydrostatic pressure at the bottom of the column, as if all the gas were absent, the head correspondingly lower, and the water quiescent, it was far beyond his ability to follow out the pressures in detail.

On the motion of the PRESIDENT Mr Matthey was awarded a vote of thanks for exhibiting his apparatus.

Mr ROWAN, in reply to the correspondence printed since the Meeting on 25th January, wrote that Mr McFarland's remarks, as to the part played by personal interest in the question of the introduction of certain boilers, quite bore out what he (Mr Rowan) had said, on page 135, in reply to Mr Couper and Mr Thode. Mr Foster's remarks opened up a very interesting question in connection with boiler design and working, on which he (Mr Rowan) had touched in his reply, on page 134. If such results were obtained with multiple evaporating apparatus, with so small a difference of temperature between the heating medium and the liquor, we must endeavour to realize approximately their conditions in boilers. The method of observation noted in the German work of Mr Thielmann, as quoted by Mr Thode, seemed capable of giving more accurate indications of the rate of movement and of the quantity of circulating water, than any of the other methods proposed or attempted. The remarks of Mr McFarland and others, on the subject of downcomers, showed, however, that even such a method might fail to record what was going on in a

Mr F. J. Rowan.

boiler, unless where the heat was always steadily applied to the same parts, which was practically impossible except with gas firing. Mr Matthey's experiments were extremely interesting and instructive, whilst nothing could be neater or more free from causes of error than his method of anchoring and releasing the glass bubbles. He had certainly emphasized very opportunely the necessity for distinguishing between static and dynamic ideas in connection with the subject of steam raising, and he (Mr Rowan) quite agreed with Mr Matthey that the ideas of "head" of water, and of "entraining" action of steam bubbles, had been too loosely employed in connection with this subject. He had no doubt that Mr Matthey's experiments might render it necessary to modify even such elaborate calculations as those given by M. Chasseloup-Laubat, in the work to which he referred in his letter. The paper recently contributed by Mr Gretchin showed that results obtained with Belleville boilers at sea justified the remarks which he (Mr Rowan) had made on page 127, as to the probable effect of the absence of water in some of the tubes, and the strains produced by pitching and rolling. His remarks on that page, with reference to the level of water in the Belleville model boiler, also showed that Prof. Watkinson's added communication on his rule for calculating the velocity of circulation of the water in boilers required some correction. Professor Watkinson in that later communication introduced some additional terms, which, it seemed, were now necessary for the statement of the "rule" for velocity of flow of circulating water, which he gave on page 54. Formerly "the velocity of flow through the downcomer was proportional," simply "to the square root of the difference between the level of the water in the upper drum and that in the test column," and "the height of the test column was proportional," simply "to the average density of the water and steam in the upcomers." Now he had introduced as factors in the calculation the area of the downcomer, and its co-efficient of discharge, and discarding the average density of the water *in the upcomer*, he made the velocity vary from 50 to 1 to 250 to 1, *according to the area of the downcomer*. It was evident that these alterations had been introduced in order to endeavour to meet the objections which he (Mr Rowan) raised in his reply, on page 126, to the rule in its original form. In fact, as the matter stood, it would appear either that the rate of evaporation in a boiler was governed by the quantity of water allowed to flow through the downcomer, or that if a velocity of 50 to 1, for a given evaporation, were sufficient for the working of a boiler, there was no object in increasing it to 250 to 1 beyond that of having a larger downcomer. He (Mr Rowan) did not believe that Professor Watkinson's explanation of the reason for variation of level in the two gauge glasses was the right one, or that the case described in the experiment, shown on the 25th January, 1898, with the plugged upcomer and water syphoned into the upper drum, was at all parallel to that of a boiler under normal conditions. The experiment was practically a hydrostatic one where the various parts were duly proportioned. In the experiment as described there was no upward current within the system, and the water simply flowed down the downcomer and out at the orifice marked *d*, in Professor Watkinson's illustration, by virtue of gravity. In such a case no variation of water level, more than a mere oscillation, should be produced in two gauge glasses, connected practically with the top and bottom ends of the same system or reservoir. If the area of the discharge orifice were greater than that of the downcomer, the level in the guage glass connected with the bottom chamber would necessarily fall, but that would show inadequacy of supply to the bottom chamber. Where that chamber had, however, a sufficient capacity, such a result could be prevented in great part, if not wholly. In fact, it was apparent that the capacity of that lower chamber must exercise the greatest influence on the level in the said guage. If the end of one guage pipe were in still water, and the other had its lower end parallel to the direction of flow, the second pipe would form a Piezometer, and the difference in head would enable the velocity of flow to be calculated according to the formula (which was given in text books on hydraulics) $h = \frac{v^2}{2g} \therefore v = \sqrt{2gh}$. The fact that bubbles of gas or steam could be

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made to join in the direction of an already established flow of water in a model, did not demonstrate anything more as to boilers than an exceptional phenomenon under certain conditions. The ease with which the flow was arrested in the first experiment with the U tube, made at the Meeting on 25th January, showed that the movement even at the best was in a state of unstable equilibrium, which would be quickly found out and upset in actual practice. Heating by means of Bunsen flames was perfectly steady and under command, and bore no sort of comparison to the sudden and often violent fluctuations in direction and intensity of the flames from a coal-fed furnace. Consequently the results obtained by means of the first system of heating could prove little or nothing as to what might be expected with the second.

SHIP CARPENTRY AND SHIP JOINERY.

Mr F. P. Purvis, on the 26th October, 1897, showed several models of work in ship carpentry and ship joinery, including the complete frame of a wood ship, portions of the outside planking, etc., of a composite ship, a deck-house, and skylights of different designs. These models, he said, had been executed by students working for the annual examination of the City and Guilds of London Institute, and in most cases evinced very skilful execution. He had for the current year been examiner in the above subjects for the City and Guilds of London Institute, and the models formed part of the work of the examination. He thought they would be interesting to the members of the Institution of Engineers and Shipbuilders. They had apparently been executed at night schools and technical schools, in connection with the City and Guilds of London Institute, most of them at Hull; and the point of chief interest was that, in England at least, there were technical schools where attempts were being made to supplement the manual work done by an apprentice in the workshop, by teaching the principles of construction in a practical way, in such subjects as ship carpentry and ship joinery.

A GRAPHIC LOG.

By Mr ROBERT CAIRD, F.R.S.E., Member.

SEE PLATE VI.

Read 23rd November, 1897.

Mr NISBET SINCLAIR stated in his paper on "Notes on the Estimation of the Power of Steamships at Sea, and of Feed and Circulating Water at Sea," read last session, "My purpose has been to show that the owner, by providing proper instruments, by insisting on having observations carefully made and recorded on board, and by having curve analyses of the observations regularly made and used in his intelligence department as complementary to his balance sheet, would render the conduct of his business easier and more certain."

And again, "I am aware that shipowners, or their superintendents, have various ways of analysing the performances of their ships."

"It would be interesting to know what plan is found generally most convenient and useful."

I now propose to present a plan which I hope may be found a useful and convenient one. Had I been able to be present at the discussion of Mr Sinclair's paper, I should probably then have communicated what I now put before you in separate form, and so have spared you the infliction of this paper.

The subject is really one of considerable importance, and I do not know that members of this Institution can be more profitably employed than in analysing the efficiencies of ships and their machinery. The data necessary for such analyses are to be had, for sea-going conditions, and these are, of course, the ruling conditions, from owners only; and Mr Sinclair's appeal for carefully compiled records on shipboard deserves our heartiest support.

I present the following analysis of one voyage of a mail steamer made for the purpose of discovering the cause of a loss of efficiency In this case the remedy was easily applied, and we are not in any way concerned with it in this paper, which merely suggests and exhibits a form of graphic log, and explains what deductions can be drawn from such simple data as could easily and without labour be recorded in ordinary ships' and engineers' logs.

The procedure in this analysis has been as follows:—

The whole of the outward voyage from Amsterdam to Batavia, and from Batavia back to Suez, has been divided into seven runs, as shown on the diagrams; the only runs for which indicator cards were given.

The mean revolutions for each run being given, the I.H.P. corresponding to these mean revolutions was deduced from that given on the cards, by assuming the I.H.P. to vary as the cube of the number of revolutions. When, on any run, there was more than one set of cards, the means were taken.

The mean displacement during each run was obtained from the mean of the mean draughts on leaving and arriving.

From the mean I.H.P. and displacement, as thus obtained, and the given mean speed, values of the Admiralty or $D^{\frac{2}{3}}$ constant were deduced. The diagram shows how these "constants" vary for the several runs. On the run from Amsterdam to Genoa the "constant" is 12 per cent. lower than the trial value, the only data on hand to account for this difference being a small balance (8 per cent. of the total) of the wind velocity against the ship. As for currents, the chart does not show anything unfavourable in this respect.

The revolutions taken are the daily means from log.

The condition of the hull relatively to the trial condition must also be taken into account. The vessel was fresh painted in dry dock, in May. She sailed in June, about a month later, and lay in port most of the intervening time. Some allowance must therefore be made in I.H.P. for the state of the bottom.

From Genoa to Port Said the wind is favourable, as also are the drift currents, though small, the result being that the "constant" is about ¼ per cent. higher than on trial.

Between Suez and Padang both wind and currents are favourable, the latter varying from 1½ to 2 miles an hour, according to the wind and current charts published by the Hydrographic Office. The "constant" on this run is about 4 per cent. higher than on trial.

On the run from Padang to Batavia, and from Batavia back to Padang, the "constant" is again lower than trial value—about 15 per cent. on the former, and about 12½ per cent. on the latter run, there being nothing to show against this but a little unfavourable wind.

From Padang back to Perim the "constant" shows about 22 per cent. less value than on trial. A small balance (9½ per cent. of the total) of the wind is favourable, but the mean retarding current is at the rate of 2 miles an hour, according to chart. When with this the foulness of the ship's bottom on her return home is considered, the lowness of her co-efficient of performance will not appear anomalous. The foul bottom might easily account for 10 per cent. of the difference, and, reasoning from the accelerating effects shown on her performance on the outward journey over the same course, one would expect a fair proportion of the remaining 12 per cent. to be due to the retarding action of the currents.

It is of course impossible to state with any accuracy the precise retarding effect due to the condition of the bottom without actually observing the conditions, measuring the surfaces affected, and estimating the properties of the deposits. But 10 per cent. is certainly not an exaggerated appreciation. That is to say, the foulness of the bottom accounts for 210 I.H.P. and for a fall in the $D^{\frac{2}{3}}$ "constant" from 307 to 276·8.

On the remaining run from Perim to Suez there is a small balance of unfavourable wind, but the currents, although unfavourable, are not so strong as on the previous run. The result is a slight improvement on the co-efficient of performance, the "constant" in this case being about 18 per cent. lower than on trial.

Turning now to the coal consumption, we find that, after deducting the constant amount of 2 tons per day for ship's use, the mean daily consumption, as debited to the main engines, varies from 43 to 46½ tons. The diagram does not show a proportionate variation in the mean I.H.P.; clearly, then, there is a loss of efficiency either in the furnace as a steam producer, or in the engine as a steam user, or in both.

The coal burnt per hour per I.H.P. may be taken as a true measure of the combined furnace and engine efficiency, but, to be of any use for purposes of comparison, some standard of thermal value must be fixed upon. In the present examples, the thermal value of Cardiff coal of average quality (14,300 B.T.U. per lb.) has been taken. The weight of coal per hour per I.H.P. given on the diagram is not therefore the actual weight consumed, but is the weight of Cardiff coal of equivalent total heat value. In reducing the actual coal consumption to its Cardiff equivalent, the following are the ratios of heat value which have been taken:—Scotch and German coal 95 per cent., and Ombilien coal 90 per cent. These values have been obtained from various published sources for the first two, and for the Ombilien coal from certain results reported by Mr Croll. It should be borne in mind that furnaces and grates suited to one quality of coal may be very unsuitable for another: indeed, in this case, it would appear as if the excessive draught were favourable to the Ombilien in comparison with Cardiff coal, the former showing a relative efficiency of 90 per cent., instead of 80 per cent., the value given by another authority. The total heat value of the coal used on each run, as compared with that of Cardiff, is shown on the diagram. The general relation between these two sets of lines—the one showing the variation of the total furnace and engine efficiency, and the other showing the quality of the fuel used—is of the greatest importance. This relation, which is clearly marked, goes to show that the higher the quality of the coal, the higher is the rate of consumption, and, consequently, the lower is the combined furnace and engine efficiency.

The part played by the engine in this loss of efficiency was estimated as follows:—

The weight of steam per hour per I.H.P., as shown on the H.P. cards, was ascertained. The method adopted was the usual one of deducting from the weight of steam calculated for a point on the card during expansion, the weight calculated for a point during compression. Speaking generally, the steam consumption as measured in this way, showed higher the more throttling and linking; but throttling appeared to have a greater effect than linking.

As compared with an estimate made in the same way of the steam shown on the cards taken on trial with I.H.P. and revolutions much about the same, but with no throttling or linking, the differences due to these causes, though marked, were not very great. In fact, no inference of any importance could be drawn from these measurements of steam on the cards, further than that the efficiency of the steam, as there shown, was not very different from that due to normal condition. Reasoning from established principles, one would expect a certain reduction of efficiency, due both to throttling and linking, but the quantitative value of these losses can only be ascertained by measuring the feed-water and testing the quality of the steam.

From an examination of a considerable amount of experimental data, published and unpublished, derived from trials with engines and boilers similar to those under consideration, it was found that under normal conditions of working, the steam shown on the indicator card averages about 82 per cent. of the feed-water. From this ratio and the steam given on the cards were plotted the lines of steam consumption as shown on the diagram.

By thus fixing the engine efficiency, the whole loss of efficiency practically becomes debited to the furnace.

Under ordinary working conditions this engine should use about 14½ lbs. of steam, and the furnace burn about 1·6 lbs. of Cardiff coal per hour per I.H.P. This would give an engine efficiency of about 16 per cent. and a furnace efficiency of about 70 per cent., which, combined, gives 11 per cent. total efficiency. Having provisionally fixed the engine efficiency, it was easy, from the data supplied, to deduce the efficiency of the furnace. The lines representing the values of the furnace efficiency on the various runs, show a steady falling away from about 65 per cent. on the first run to 53 per cent. on the last. The remarkable relation connecting the quality of the coal used and its rate of consumption has already been pointed out, and, as affecting this, there is an element—the human one—which must not be overlooked. The nature of this element, and the extent to which it is likely to affect results, are strikingly illustrated by the lines on the diagram showing the temperatures in the stokehold.

It may not be without interest as bearing upon the quantities of coal logged as consumed, to quote from an article in the "Engineer" of 19th February, 1892, on "Triple-Expansion Engines in the Mercantile Marine," by Mr Alex. Dalrymple, himself a chief engineer, who says :—

"It is an unfortunate peculiarity that the engineer's log book cannot be made to show such a low rate of consumption of coal per day as has been obtained during these trials. The discrepancy increases as the number of coaling ports abroad at which the vessel calls during the voyage."

Mr Sinclair's investigation was originally, he tells us, intended to show comparative propeller efficiencies. Mine is more particularly directed to furnace efficiency. Both, however, require a consideration of all the phenomena that enter into the problem of the economical propulsion of steamships at sea.

From a number of logs worked up in the manner I suggest, a standard set of lines might be constructed for a given ship, and, by simple inspection, an owner would be able, in most cases, to put his finger upon the cause of any deviation from the normal on subsequent voyages.

Mr Robert Caird explained that Mr Gretchin, of the Russian Volunteer Fleet, had kept the logs of the T.S.S. "Kherson" in a graphic form, which possessed some advantages in that the data had been taken watch by watch, so that there were four different points for every day. Those who had read his paper would see that his diagram was simply a diagram of means, while Mr Gretchin's was an absolute diagram of every watch of the day. For that reason he would like very much to have the logs of the "Kherson" placed before the members so that they might see a more convenient and better form.

Correspondence.

Mr G. GRETCHIN (Member)—The object of the diagrams on Plates X., XI., and XII. was to illustrate the official log of the T.S.S. "Kherson," prepared for the Committee of the Russian Volunteer Fleet. He took means of the six following items during every day (or 24 hours − or + a certain number of minutes according to the course of the steamer to the east or west):—

(1) *Number of revolutions.*—The revolutions per minute were taken from the counters, which worked continuously.

(2) *Speed in knots.*—The distances were obtained from the log book, and, to avoid doubt, he did not make diagrams for spaces of time of less than 24 hours, starting each day at noon.

(3) *Slip of Screw.*—Formula for obtaining slip:—

$$S = \text{Slip.} = 100 - \frac{R \times 6080}{n \times H}.$$

R = Distance in knots from noon to noon.
6080 = Number of feet in a knot.
n = Number of revolutions from noon to noon.
P = Pitch of screw = 25 feet.

(4) *Indicated Horse-Power.*—Cards were taken on the first and last day of every run, and every time the weather changed.

(5) *Coal Consumption per day.*—That was found by weighing the coal, and by measuring the bunkers, which were very convenient for the purpose, being quite square. These figures were not absolutely correct, as it was a very difficult matter to obtain records at regular intervals every day.

(6) *Lbs. of Coal per I.H.P. per hour.*

Mr G. Gretchin.

The displacement was obtained from the mean draughts on leaving and arriving at ports. The arrows, with the figures in brackets on the speed curves, showed the direction and force, in miles per day, of the current. The arrows, with figures on the slip curves, showed the direction and force of the wind according to the British Admiralty scale, considering the direction of the steamer to be always parallel to the respective ordinates of the diagrams.

The discussion on this paper took place on 22nd February, 1898.

Mr F. P. PURVIS (Member) said that they ought all to thank Mr Caird and Mr Gretchin for not only giving them the particulars which were before them, but also for the very frank way in which they had put down their difficulties, showing the variations they had to deal with in the logs they had been analysing. He thought that if some seagoing engineers would speak, it would be very desirable to hear their views as to what data it was really possible to give without the process of cooking. Most of them who had had experience of logs, had analysed them in some rude way to ascertain, say, the coal consumption, and after arriving at it they had perhaps received the further information that the sum total of the coal did not agree with the coal bill; or perhaps, after deducting results which appeared highly satisfactory, they had found that the rival engineer in the next ship had managed to go one better. Mr Caird's subject seemed to point out that there was a big field for the exercise of the inventive faculty, and if some one would design an apparatus to give a continuous record—such as a barograph gave—of such matters as (1) speed got from a thoroughly perfect recording log, (2) coal burned per hour, (3) work done, as measured by a continuous indicator, or better still a dynamometer or ergometer, and some half-a-dozen things besides, he would deserve the very best thanks of Mr Caird, Mr Gretchin, Mr Sinclair, and everybody else who had tried to grapple with these difficulties.

Mr ROBERT T. NAPIER (Member) thought the Institution was the gainer through Mr Caird having given a separate paper, rather than having supplemented the discussion of last session, as his method was on different lines. A continuously recording dynamometer was still in the future, but surely the time was not far distant when superintending engineers would find it worth while to keep a record of power exerted. It would be very satisfactory if Mr Caird could get the log of some large steamer, for a round voyage, with sets of indicator cards taken at least once in the twenty-four hours, and samples of coal from each coaling station. Furnished with that, the calorific value of the coal could be confidently fixed, the too rough assumption that the I.H.P. varied as the cube of the revolutions could be dropped, and the comparison of ship performance on the basis of the $D^{\frac{2}{3}}$-coefficient could give place to a comparison more after Froude's method. As pointed out by Mr Caird, the consumption of coal per I.H.P. seemed to increase with the number of coaling stations visited. Was it possible that this was due to the growth of weeds, consequent on the steamer lying longer in quiet water?

Mr ROBERT CAIRD, in reply, said he quite agreed with Mr Purvis that they would be all delighted if they could get anything coming near a continuous record. He thought they were very far from a good continuous patent log, and still further from any means of getting a continuous indicator. So far as Mr Napier's remarks were concerned, he quite agreed with him. He did not know why the coal bill should increase with the multiplication of coaling ports, but it was an undoubted fact.

On the motion of the President a vote of thanks was then passed to Mr Caird for his paper, and to Mr Gretchin for his contribution.

THE THEORY AND PRACTICE OF MECHANICAL REFRIGERATION.

By Mr T. R. MURRAY, Wh. Sc., Member.

SEE PLATES VII., VIII., AND IX.

Read 21st December, 1897.

THE establishment of free trade, the improved methods of rapid transport, and increasing wealth and population having of late years brought to our door enormous food supplies, practical science found a new problem in devising some means of efficiently preserving meat.

Engineering skill has solved that problem by the invention of refrigerating machinery, and to-day we find that in almost every town or city of importance cold storage and ice-making installations have been erected; and, in addition to these, chemical factories, breweries, and many other industries find it desirable to have a means of providing a low temperature; so that no excuse need be given for the consideration by this Institution of a subject of such great present interest and of probable vast extension in the not distant future. I propose, therefore, to give a brief description and analysis, from an engineering point of view, of the theory of the subject, and of the application of that theory to practice.

In the first place it is well to have a clear idea as to what has really to be done by any refrigerating machine. If two bodies of different temperatures are in contact or near each other, and no special means are provided to maintain this difference, it is only a matter of time till their temperatures equalise. Refrigeration demands that a reduction of temperature should be not only originated but maintained. It may be well here to recall the first law of thermodynamics, which declares that heat and mechanical energy are mutually convertible; and the second law, which states that heat cannot pass from a cold to a hot body, unless by the aid of some external agent. On these two laws all refrigerating theory and practice are based.

The theoretical cycle of a perfect refrigerating machine is exactly the reverse of that of a perfect heat engine. In the latter, heat is taken in from an external source at a high temperature, and given out at a lower temperature; in its falldoing a certain amount of mechanical work. In the former, heat is taken in at a low temperature and given out at a higher temperature, and to render this possible, work has to be done on it.

The efficiency E_1 of the heat engine is expressed by the equation $E_1 = \frac{T_2 - T_1}{T_2}$, T_1 being the absolute lower temperature, and T_2 the absolute higher temperature. By efficiency we here mean the quantity of heat units expended in producing work, divided by the quantity of heat units taken in at the higher temperature.

The efficiency E_2 of the refrigerating machine is expressed by the equation $E_2 = \frac{T_1}{T_2 - T_1}$. Efficiency here means the quantity of heat units removed, *i.e.*, the refrigeration done, divided by the quantity of heat units representing the work done.

The most perfect refrigerating machine theoretically possible, is the combination of such a heat engine with such a heat remover, the engine being used to provide the work necessary to raise the temperature from T_1 to T_2.

You will observe that, whereas in the heat engine the efficiency becomes greater as the difference between the temperatures T_1 and T_2 increases, the reverse obtains with the refrigerating machine. This is a most important point which bears directly upon various questions of practical refrigeration.

I have calculated the efficiencies for temperatures T_1 from $-15°$ Fah. to $+45°$ Fah., and for T_2 from 50° Fah. to 110° Fah., and also plotted them as curves, see Fig. 1.

This covers the whole range of practical refrigeration, and will be found useful for many comparisons and calculations when considering working cycles. We may then say that what a refrigerating machine has really to do is to pump out heat from a cold body—from the air in a chamber for instance—and by the expenditure of mechanical energy, raise the temperature of this heat to a point which will enable it to be carried away by some external agent. This agent is, in practice, invariably water.

Time does not permit our going into the history of refrigeration, so we may at once proceed to a consideration of the various types of machines now to be found at work. These may be divided broadly into two classes—(1) air machines, and (2) machines which depend for their action on the alternate liquefaction and vaporisation of some volatile liquid. Class 2 may again be subdivided into compression machines and absorption machines.

In the first class we have now practically only the cold air machine of the type still in use to some extent on board ship, and for special applications. This is an open cycle machine, that is to say, a machine where the air is not confined in closed vessels or pipes, as was the case with Kirk's, Allen's, and some other obsolete forms, but is drawn direct from the chamber to be cooled, and, after being brought to a low temperature, is again ejected into it.

Fig. 2 shows this type in a diagrammatic form. The compressing cylinder draws air from the cold chamber and compresses it up to about 50 or 60 lbs. per square inch. The heat of compression is removed by discharging the air through a cooler, where a circulation of cold water reduces the temperature to nearly that of itself, and from this the air passes to the expansion cylinder, where it expands and does work, helping to drive the machine.

The result of this expansion is that the temperature falls to something like -70° Fah. or -80° Fah., and the air is then discharged into the chamber to be cooled. It will readily be seen that any moisture in the air passing through these operations will be frozen and discharged from the expansion cylinder in the form of snow. This caused serious difficulties in earlier types of machines, principally by choking the valves and outlets of cylinders, and it was found desirable to get rid of this moisture before expanding, either by a mechanical separation of the particles of water, or, as in the case of the Haslam machine, by further cooling the air, after leaving the cooler, to nearly freezing point. This causes the moisture to condense, and enables it to be drawn off as water, before reaching the expansion cylinder. This extra cooling is effected by passing the air through a series of pipes surrounded by cold air returning from the cold chamber to the compressor.

With regard to the efficiency of cold air machines, Professor Ewing, of Cambridge, in his very interesting Howard lectures of this year, states that, as the result of an examination of a number of independently recorded tests, he was in no case able to find a co-efficient of performance greater than ¾. If then, we consider an ordinary case where heat is being removed from a temperature of 18° Fah. and discharged at a temperature of 70° Fah., we find that theoretically we ought to get an efficiency of 9·19.

That is to say, with a perfect refrigerating machine we ought to remove 9·19 thermal units for each thermal unit required to work the machine, whereas, with the cold air machine in practice we only remove about ¾ of a heat unit. It is thus very far from perfect.

The reasons for this are not far to seek. In the first place, the air machine rejects heat at a much higher temperature than the cooling water, the heat in the compression cylinder rising to as high as 270° Fah., and it also cools its air to a much lower temperature than the room to be cooled, in some instances to below −100° Fah. Thus the difference between T_1 and T_2 becomes excessive, and is fatal to a high efficiency; but unfortunately this cannot be got over, as air has such a low specific heat and is such a bad conductor of heat that it is necessary to cool down to this low point before discharging, otherwise the amount of air circulated would require to be enormously increased, which would of course mean larger machinery and greater expenditure of energy. Losses by friction and the presence of moisture are also considerable.

The relative proportion of work done to refrigerating effect produced, is shown with great clearness for any refrigerating cycle by means of an entropy diagram, that is, a diagram in which the absolute temperatures are laid out as ordinates, and the abscissæ are the quotients found by dividing the quantity of heat by its absolute temperature.

These abscissæ represent what is known in thermo-dynamics as entropy. It is plain that if the change of temperature of a body is carried out adiabatically, *i.e.*, without either gain or loss of quantity of heat, then it will show on the diagram as a straight vertical line, and any isothermal change, *i.e*, without change of temperature, will show as a straight horizontal line.

Cotteril, in his book on the steam engine, refers to the use of these diagrams in connection with the thermo-dynamics of steam, and Mr George Richmond, an eminent American engineer, in a paper read before the American Society of Mechanical Engineers in 1892, demonstrated their special applicability to refrigerating problems. Professor Linde of Munich, a very high authority on theoretical refrigerating matters, has also used this method to a considerable extent.

Let us now apply this to the example of a cold air machine already given; viz., air taken in at a temperature t_1 of 18° Fah., being the temperature of the refrigerated chamber, and rejected at a temperature t_2 of 70° Fah., which is the temperature of the air after being cooled by the cooling water—the temperature at which the cold air is discharged into the chamber to be taken at $-85°$ Fah., and the highest temperature to which it is heated in compression to be taken as 250° Fah.

We will assume that compression and expansion are carried out adiabatically, which is theoretically the case, and, as in the meantime we do not need to trouble ourselves about the absolute quantities of heat, but only desire to know the relative amount of heat expended in work to the amount removed, *i.e.*, to the refrigeration done, it will answer our purpose to take any convenient length for the abscissæ, as the proportions will in any case remain the same. If we were to apply this to any particular size of machine, and required to have the diagram areas representing to scale the actual quantities of heat dealt with, then we should find our abscissæ by dividing the quantity of heat at any part of the cycle by its absolute temperature.

Consider, in the first place, that the machine is theoretically perfect; then we get the diagram ABCD, Fig. 3, in which D to C is the rise of temperature of the air during compression from 18° Fah. to 70° Fah. CB represents the removal of heat in the cooler, B to A represents the cooling in the expansion cylinder, and A to D the collection of heat in the refrigerated chamber The proportions of the areas ABCD and ADEF represent the proportion of work done to the refrigeration produced. The rectangle AE will be found to be 9·19 times the rectangle BD.

Coming now to the working cycle where the air is raised to 250° Fah. in the compressor, this will be represented on the diagram by point H, and the fall in temperature during cooling by HB. The temperature being again lowered in the expansion cylinder to − 85° Fah. is represented by the vertical line BG, and the collection of heat in the chamber by GD. The diagram of work is now BHDG, which is about 3·75 times the theoretical amount, and when compared with the refrigeration done, now represented by area GDEF, gives an efficiency of only a little over 2. As before stated, losses by friction, moisture, etc., reduce this in practice to about $\frac{3}{4}$.

We can thus more clearly grasp the comparative inefficiency of this class of machine, and when we come to make a comparison with the vapour compression machines now in use, we can readily understand why the cold air machine has practically died out for general application.

I do not, therefore, think it necessary to occupy your time with the practical matters of constructive detail of this type.

We now come to class 2, where the action depends on the alternate liquefaction and vaporisation of a volatile liquid.

We all know that no matter can change from a solid to a liquid form, or from a liquid to a gaseous form, without absorbing a definite quantity of latent heat, and in the reversal of this process the same amount of latent heat must be given up. This latent heat varies in amount for different bodies, but given a suitable liquid and a means of causing it to vaporise in such a situation that it can only draw the latent heat to enable it to do so from the material that it is desired to refrigerate, and given some process whereby this heat can be removed from the gas, and the gas again liquefied, a continuous refrigerating cycle is the result.

The compression refrigerating machine, which is by far the most important and the most commonly used type nowadays, is the favourite method of carrying this cycle into practice.

The diagram Fig. 4 shows the elements of such a machine.

The compressor discharges the gas into a condenser, where a water circulation carries off the heat of compression and of liquefaction. The pressure and the cooling action of this water together cause the gas to liquefy and collect at the bottom of the condenser.

This liquid then passes through a small orifice, or expansion-valve as it is termed, which can be regulated to a nicety, into the refrigerating coils, where the suction of the compressor keeps the pressure much lower than on the condenser side. This pressure must be sufficiently low to cause the liquid to vaporise, and in doing so it of necessity absorbs the requisite amount of latent heat. This heat is taken primarily from the medium itself, which becomes intensely cold, the actual temperature depending on the pressure under which it is vaporised; and this cold vapour circulating through the refrigerating coils on its way back to the compressor collects heat from its surroundings. This heat enables a little more of the liquid to vaporise, and thus the expansion process is going on right through the coils back to the compressor. Here the gas is further heated up by compression to a point at which it can discharge its heat to the cooling water, and so the cycle goes on. The expansion-valve must be so regulated, that no more liquid can pass than the amount requisite to keep up the same supply of vapour in a given time, that the compressor removes, at a pressure corresponding to the temperature desired in the coils. You will note that here the expansion-valve takes the place of the expansion-cylinder in the cold air cycle.

We will now consider which liquid is the best and most economical to use in such a machine as above described. Theoretically this is a matter of indifference, but practically we are limited by certain physical considerations, and the choice of the best medium becomes a matter of great importance. The points chiefly to be considered in determining the liquid to be used are as follow:—

It must have a large capacity for heat, *i.e.*, its bulk must be small for the work it has to do, and its latent heat of vaporisation must be as great as possible.

It must be able to stand the temperatures and the pressures to which it will be subjected without deterioration.

It must work within practical and suitable pressure limits.

It must be cheap and readily obtained.

It should be of such a nature that leakage is readily detected.

It should, in the cycle of operations, approach as nearly as possible to the theoretically perfect standard, and it should be practically safe in working, or even in the case of moderate leakage.

Various liquids have been tried, but the only ones that have come into commercial use to any extent are sulphuric ether, sulphur di-oxide, carbonic acid, and anhydrous ammonia.

The ether machine was the first compression machine to come into use, but the advance of scientific and engineering knowledge has replaced it with the others as being more efficient, and it is now practically obsolete. This is owing to the fact that the compressor requires to be about 17 times larger than for ammonia; the pressure during expansion also falls considerably below that of the atmosphere, which is objectionable as tending to draw air into the system, and finally, the vapour is so inflammable as to constitute a grave source of danger.

This leaves the other three liquids to consider, and I have made out diagrams, Figs. 5 and 6, showing the latent heat of vaporisation and the vapour pressures in each case, between the limits of − 40° Fah. and + 100° Fah.

The particulars for these were taken from the tables of Ledoux for ammonia, Zeuner for sulphur di-oxide, and Professor Schröter for carbonic acid. From these we find that, at −22° Fah.,

Sulphur di-oxide has a latent heat of vaporisation of } 172·6 B. T. U.
Carbonic acid = 136·15 B. T. U.
Anhydrous ammonia = 594·86 B. T. U.

Again, at 86° Fah.,

Sulphur di-oxide = 144·79 B. T. U.
Carbonic acid = 19·28 B. T. U.
Ammonia = 527·36 B. T. U.

(1 lb. of saturated vapour being considered in each case.)

Thus ammonia has a much higher latent heat than either of the others, and, in addition, the specific heat at constant pressure of ammonia gas is 0·508, against 0·190 for carbonic acid, and 0·154 for sulphur di-oxide, so that in both of these respects it is the best agent to use. Against this has to be placed the fact that the increase of volume during evaporation is much less with carbonic acid than with either of the others. This means that the compressor does not require to be so large, but on the other hand an examination of diagram, Fig 6, will show at a glance the very much higher pressures that have to be dealt with in the case of carbonic acid. Thus, at 86° Fah.,

Ammonia has an absolute pressure of 170·83 lbs.
Sulphur di-oxide = 66·37 lbs.
Carbonic acid = 1080·00 lbs.

This means that, in the latter case, very excessive pressures have to be provided for with consequent greater danger of trouble from leakage. Sulphur di-oxide has the objection that, at low temperatures, its pressure falls below that of the atmosphere, with the danger of allowing air to leak into the system, which, in this case, causes a chemical change in the gas, producing sulphuric acid, with consequent troubles through corrosion. We may also consider the fact that, in case of a leakage from any part of the system, carbonic acid, having no smell, allows the probability of it going on for a long time before it is detected, the efficiency of the machine being impaired in the meantime; while in the case of ammonia or sulphur di-oxide the slightest leakage can at once be located and put right. On considering all these points, it is not to be wondered at that ammonia is by far and away the principal and favourite agent at present in use throughout the world for refrigerating purposes. Sulphur di-oxide has been employed to some extent abroad, but its use is practically unknown in this country. Carbonic acid, however, has met with a fair amount of favour, especially for ship work, owing to the small bulk of the machinery required and the absence of possibility of smell.

I have made out entropy diagrams for 1 lb. of saturated ammonia vapour, and 1 lb. of saturated carbonic acid vapour, from the temperatures of $-40°$ Fah. to $+100°$ Fah., Figs. 7 and 8. This range practically covers all the temperatures required in ordinary practice, and, by means of these diagrams, almost any problem regarding efficiency between any temperatures T_1 and T_2 can be solved. I have not produced a diagram for sulphur di-oxide, as it would not be of much practical interest.

We will first consider the ammonia diagram. FE is the basis line, the temperature at this point being the absolute zero $= -460°$ Fah.

A the absolute temperature at $-40°$ Fah. $= 420°$ Fah. $= T_1$.
B „ „ $+100°$ Fah. $= 560°$ Fah. $= T_2$.

AD = the entropy at T_1, and if we consider that we deal with a unit weight of ammonia, say 1 lb., we can determine the length AD by taking $\frac{L_1}{T_1} = \frac{603 \cdot 45}{420} = 1 \cdot 436$. In the same way $BC = \frac{L_2}{T_2} = \cdot 922$. We have still the point G to determine in order to find the position of point B, but if we consider that DC represents the compression in compressor, CB the giving out of heat to the condenser, BA the expansion through the orifice of the expansion-valve, and A D the taking in of heat in the refrigerator, we can understand that AG really represents the entropy of the liquid heat carried into the refrigerator; and its length may be found by the expression $AG = c \log_e \frac{T_2}{T_1}$, where $c =$

mean specific heat of liquid between T_1 and T_2. A simpler formula is $AG = \frac{h}{\frac{T_1+T_2}{2}}$ where h = liquid heat T_2 - liquid heat T_1.

By calculating these values for various temperatures between T_1 and T_2, I obtained points through which to draw the line BA. For ammonia it will be found to be practically a straight line, so that it is quite near enough to find the point B only and draw a straight line between A and B.

By plotting, as abscissæ, the values of the entropy of the latent heat at the same temperatures, the curve CD will be formed.

The same construction applies to the diagram for carbonic acid, but it will be noticed that this forms a continuous curve with rounded top, the reason of which will be referred to later on.

Suppose now we wish to find the efficiency, by means of these diagrams, of a machine working with the same temperatures T_1 and T_2 as we took with air, and considering, in the first place, the cycle as being the Carnot or perfect one, compression and expansion will both be adiabatic, therefore they will be represented by vertical lines, and the giving up of heat to the condenser, as well as the collection of same in the refrigerator, being isothermal, will then be shown as horizontal lines. Draw horizontals *ad* and *bc*, and verticals *bgf* and *che*. Then the area *bh* will represent the work of the compressor, and the area *ge* the refrigeration done. These equal respectively $bc \times T_2 - T_1$, and $bc \times T_1$. The efficiency will therefore $= \frac{bc \times T_1}{bc \times (T_2 - T_1)}$ $= 9{\cdot}19$, as before.

Let us now consider how nearly in practice the actual working cycle approaches the above, in the case of the ammonia compression machine, and of the carbonic acid machine. In the first place, we must remember that our cooling agent simply circulates in pipes through the chambers being cooled, and must of necessity be colder in order to secure a transference of heat. The difference in temperature depends on the cooling surface, or length of piping, as compared with the cubic capacity of the chamber, and may be in practice from 10° to 25° Fah. Suppose we allow for a difference of 18° Fah., then our lower temperature T_1 will correspond to 0° Fah. Again, the working cycle falls away from the Carnot cycle in not being reversible, owing to expansion taking place through a small orifice instead of by means of an expansion cylinder. Thus the liquid carries a certain amount of heat into the refrigerator, which goes to heat up the expanded gas, rendering part of it unavailable for refrigeration. The amount of this liquid heat varies for each agent, and I have prepared entropy diagrams Figs. 9 and 10 to a larger scale, showing the working cycle in each case. In these, the areas *agb* represent the additional work that the use of an expansion cycle would have obviated.

The heat which ought to have been spent in producing this work is carried by the liquid into the refrigerator, and this therefore falls to be deducted from the refrigeration done, so that the latter is now represented by the area g_1hef_1, being less than before by the rectangle gf_1, which is equal to area *agb*. A comparsion of the respective diagrams of ammonia and carbonic acid will show at once what a large percentage of loss there is in the latter as compared with the former. For ammonia the actual efficiency is now 6·1, and for carbonic acid 4. In practice, under favourable conditions, and after allowing for friction, loss by heat stored in walls of compressor, etc., about $\frac{3}{4}$ of this efficiency is actually obtained, which is a very satisfactory result.

Diagram Fig. 11, which I have prepared for the two gases at various temperatures T_1 and T_2, shows the loss owing to the introduction of liquid heat.

Diagram Fig. 12 shows the relative efficiencies of ammonia and carbonic acid with limits T_1 (corresponding to − 15° Fah. and + 25° Fah.) and T_2 (corresponding to temperatures from 50° Fah. to 80° Fah.). The curves for temperatures T_1, between − 15° Fah. and + 25° Fah., will fall between the curves shown in the diagram. From this you will see that, at a lower limit of − 15° Fah., and a higher limit of, say, 70° Fah., the efficiency of carbonic acid is only about 65 per cent. of that of ammonia; and, at a lower limit of + 25°

Fah., and higher limit as before, the efficiency, as compared with ammonia, is about 69 per cent.

Thus again ammonia asserts its superiority. This loss could, of course, be overcome by the addition of an expansion cylinder, where the agent could do work, as in the cold air machine, but the additional complication necessary to carry this out in practice has hitherto prevented it being done.

Another important point is that ammonia does not reach its critical temperature—that is, the temperature beyond which it will no longer liquefy—until 256° Fah., which is far beyond the possible temperature of condensation in actual work, while the critical temperature of carbonic acid is reached at 88° Fah., a temperature of condensing water that is often exceeded in tropical countries. This is clearly shown in the entropy diagrams, where the carbonic acid curve ceases its upward course at about 88° Fah. When worked beyond that temperature, the volume of saturated vapour and that of the liquid become alike. Consequently, there is no latent heat; and, to produce refrigeration, the vapours must be expanded below the temperature T_1 otherwise required. The superheating of these vapours in the refrigerating coils allows a fair amount of cooling work to be done, but, of course, at the expense of economy.

This point has been referred to at some length in papers by Prof. Linde, and also by Prof. Ewing, and, as the results of actual tests, it is stated that, with a condenser temperature of 95° Fah., the carbonic acid machine only gave half the efficiency of the ammonia machine. Thus practice bears out theory.

With ammonia compression machines there are two systems of working, known as "wet compression" and "dry compression," and about the respective merits of these much controversy has taken place. The former consists in the regulating-valve being so adjusted that the vapour returns to the compressor in a supersaturated state, analogous to the priming of a steam boiler. This surplus of liquid evaporates during compression, and absorbs the requisite amount of heat, with the result that the temperature in the compressor is kept correspondingly low, and the gas at the end of the stroke is still saturated. In attempting to follow this closely out, there is great danger of allowing too much liquid to pass into the compressor, with the result that at the end of the stroke the clearance space may be filled with liquid ammonia, which re-expands on the return stroke, and occupies space that ought to be filled with entering gas. When we consider that ammonia, in expanding from liquid at, say, 120 lbs. pressure to gas at 20 lbs. pressure, increases in volume 216 times, it is evident that a compressor with 20-inch stroke and clearance of only $\frac{1}{32}$-inch would lose 66 per cent. of its capacity.

In practice, therefore, wet compression machines are always run with such a supply of liquid ammonia as will permit of a certain amount of superheating taking place during compression.

Dry compression consists in so regulating the expansion-valve that only as much liquid is admitted to the refrigerating pipes as will entirely vaporise there. Thus the gas comes to the compressor in a perfectly dry state, and is superheated during compression. This enables the full value of the liquid to be used for refrigerating work, but the pressure during compression is higher, and the heat greater. A water jacket or oil injection is used to carry away as much of the heat as possible.

As a matter of fact, in actual work, dry compression machines generally work partly wet, and the efficiency, so far as this goes, may be said to be alike in both cases.

We may now glance at some of the actual details of construction of a modern type of ammonia compression machine, and, as time is limited, I will confine myself to the De La Vergne system as made by the firm with which I am connected—Messrs L. Sterne & Co., Ltd., of this city. As the compressor is the principal part of the apparatus, I will first endeavour to make its construction (as shown in section in Fig. 13) clear. I may state that in a perfect compressor it is essential—

To discharge the whole volume of gas entering the compressor.

To extract as much heat as possible from the gas during compression.

To prevent all leakages past the stuffing box, piston, and valves.

To thoroughly lubricate all working parts.

The satisfactory carrying out of all these requirements is insured in the De La Vergne compressor by a very simple device; viz., the injection during each compression stroke of a certain definite quantity of special oil or liquid base. The composition of this is such that it is entirely unaffected by intermixture with ammonia.

The compressor is vertical and double-acting, and one suction and one discharge passage connect it with the pipe system. On the up stroke gas enters through the lower suction valve behind the moving piston, and, at the same time, the charge of oil is injected into the space above the piston. Thus the oil does not in any way reduce the compressor capacity, entering as it does, after the full charge of gas. The compressed gas is entirely discharged through the upper valve, followed by a portion of the oil, leaving only enough of the latter to entirely fill the small clearance space. On the return stroke a similar action takes place through the two bottom discharge valves.

When the piston passes over the upper one, the gas is still being discharged from that below, and, when this in its turn is covered, communication is made with the top one through the valves in under part of piston and annular space, thus ensuring the discharge of the gas before the oil.

The indicator diagrams, Fig. 14, are interesting as showing the effect of this oil injection in doing away with clearance spaces. The top diagram was taken from a De La Vergne compressor of 12 inch bore × 24 inch stroke, built by L. Sterne & Co, and at work in London. The diagram was taken after the machine had been in daily work for several years, and without the slightest alteration or repair of any kind having been done on it since its erection. It represents, in every respect, the normal working of the compressor as it was erected and as it is working to-day. You will note the utter absence of clearance or any indication of re-expansion. The centre diagram is copied from an exhaustive report by Prof. Schröter on a Linde machine of German manufacture, specially tested at Munich. This is an ammonia compression machine, having a horizontal compressor without oil injection, and requiring to work with wet compression. As this machine was specially sent in for testing, the diagram may fairly be taken to represent this type of machine working at its best, and the rounded corners at the bottom of diagram show the loss through clearance and re-expansion. The lower diagram is copied from the same report, and represents the working of a Pictet machine using sulphur di-oxide. This is a French type of machine, with a horizontal compressor, which was also specially prepared for this test. Here the evils of clearance space are still more marked.

A common source of trouble with ammonia compressors is leakage past the gland, and very long lantern glands are generally used to overcome this. Such an arrangement means great increase of friction, whereas with the oil seal a short gland of ordinary type is all that is required, and this can be kept comfortably loose. Should any leakage take place it is only oil that passes, and this can be collected and returned to the system.

The construction of this form of double-acting compressor being somewhat costly and complex for very small compressors, the demand for these led me to design a modification, which has proved very satisfactory in practice. This retains the oil injection and seal, but in a considerably simplified form, as will be seen from Fig. 15. The double discharge valves at the bottom, and also the valves in the piston, are done away with, and the gas and oil pass up through holes in the latter to an annular recess, and thence out at the discharge valve. A small portion of the piston block immediately opposite the valve is cut away, so that the piston never entirely shuts off the discharge passage.

It has been objected that, with oil injection, a quantity of ammonia is absorbed by the oil and given out during the return stroke of the piston, but this is not so, as shown clearly by the indicator diagrams.

This point was also the subject of an exhaustive series of experiments by an American scientist, Dr Hans Von Strombeck, whose results were presented, in the form of a paper, to the chemical section of the Franklin Institute in April, 1892. He found that in the double acting De La Vergne compressor, the loss of capacity due to oil injection was nil.

Fig. 16 indicates in a diagrammatic form the complete system, from the point where the expanded ammonia returns from the expansion or cooling coils, to the point where the main supply of liquid ammonia passes to the expansion valves. After the gas leaves the compressor it passes to the fore cooler, where the oil is cooled and deposited in the pressure tank. The gas goes on to the condenser, where it enters at the bottom and is drawn off at different levels as it liquefies, and collects in the storage tank. From this it falls to the separating tank, where any remaining oil is trapped, and the liquid ammonia passes to the expansion coils by way of the main liquid pipe.

The cooled oil returns from the pressure tank, through an oil strainer, to the injector on machine—this injector being really a measuring device for allowing the required quantity of oil to pass into the compressor at the correct time. The oil being at the condenser pressure enables it to readily do so.

It will be noted that, this being a closed cycle with the same ammonia and oil being used over and over again, the only possible loss is by leakage. It thus becomes a very important matter to have everything so mechanically perfect that the possibility of such leakage is reduced to a minimum. In fact, when one considers that refrigerating machines are often situated abroad, at places far from any efficient help in case of break-down, and under conditions necessitating their constant working from one year's end to another, day and night, and also very often under conditions where a stoppage would mean a very serious monetary loss, it is apparent that very special precautions must be taken to render such a stoppage practically impossible. The machine, pipes, and fittings of all kinds should be made in the strongest, safest, and best possible manner. In this, more than in most things, it pays the purchaser to get the very best article he can possibly procure.

To return to the diagram. The condenser is of the open-air or evaporative form, and is generally placed on the roof of the engine house. This form secures maximum condensing power with minimum supply of water, and has the additional advantage of being always open for inspection and cleaning. We saw that it is of the utmost importance to keep the condensing pressure and temperature as low as possible, so that it is advisable to allow abundance of condensing surface, and to use a sufficient supply of water.

Where water is scarce or dear, it becomos a question of deciding whether it is cheaper to use less water and more coal, as any reduction of the one means increase of the other. In such cases it is very often possible to greatly economise by putting down a water-cooling arrangement, whereby the same water can be constantly circulated with only a small make-up for loss by evaporation.

The steam engine forms part of the complete machine, and is of the horizontal type, being high-pressure or compound condensing, according to circumstances. Generally speaking, our practice is to make the engines of large machines compound surface-condensing, with Corliss valve gear on the high-pressure cylinder, and a double-ported slide valve on the low-pressure cylinder.

Small machines have the connections much reduced and simplified, and are often made for belt driving.

All machines, with the exception of the small sizes, have two compressors. These are so arranged that either can be shut off if required, and one only worked. Fig. 17 shows a pair of 11″ x 20″ machines with a compound condensing Corliss steam engine. Each of these machines is quite separate and independent, being only connected by the platform round the compressors. Fig. 17*a* shows a 12″ x 24″ machine with similar engine.

Fig. 18 shows a pair of machines with a single high-pressure steam cylinder fitted with variable expansion-gear. The compressors of these machines are 8″ x 16″.

Fig. 19 is one of the small compressor machines, with steam engine; and Fig. 20 shows a small machine for belt driving.

All parts in connection with the ammonia system have to be made of iron or steel, as brass or copper are corroded by contact with ammonia. Every pipe connection or part of machine under pressure is tested by water pressure to 1000 lbs. per square inch; and, in addition, the cocks are tested under air pressure. After a plant is erected, the compressors are run as air-pumps, and a pressure of 300 lbs. per square inch pumped on the entire system. This pressure must stand for twenty-four hours without appreciable loss; then the air is discharged and a vacuum pumped, and the plant charged with ammonia. If any loss of pressure is noticeable, then the leaks have to be found and put right; and, when I state that in large plants there are sometimes over ten miles of 2-inch expansion piping, in addition to the engine-house connections and condensers, you will understand that careless erection may mean a very considerable amount of after work and trouble. As a matter of fact, with the system of testing everything before being sent out, we have very little trouble from this cause.

You will now appreciate the importance of having all fittings carefully designed and made, and Fig. 21 shows a group of some of those in use with the De La Vergne system.

All flanges, bends, elbows, etc., are made of malleable cast-iron, and with machined male and female joints, the packing being a soft lead ring. The expansion-valve or cock is made with a wedge-shaped opening which permits of very minute adjustment. This adjustment is effected by means of a worm and worm wheel. By this the supply of liquid to the coils can be exactly controlled. The cooling pipes in the chamber, or ice tank as the case may be, are 2-inch lapwelded wrought-iron pipes, fitted with special flanges as shown. These flanges are made a very exact fit on the screw, and the recess at the back filled with solder is simply an additional precaution. The result is a pipe that can be readily coupled up, and can always be depended on for tightness.

The amount of this expansion-piping for any installation depends entirely on the class of work to be done, and the temperature required. In the case of cold chambers it may be placed on the roof, on the walls, or wherever most convenient.

Much controversy has taken place at various times as to the relative merits of cooling by direct expansion, and by brine circulation. The former consists in causing the ammonia to evaporate in pipes placed directly in the chamber to be cooled, as already described; the latter consists in having these expansion-coils placed in an insulated tank, full of a non-congealable liquid or brine, generally a strong solution of calcium chloride. This refrigerated brine is then pumped through coils of piping into the chamber to be cooled, and back to the tank to be again cooled, and so on. This, you will observe, means the introduction of a secondary medium as heat collector, and entails corresponding loss. Suppose we consider the case already given, of ammonia at 0° Fah. as t_1, and 70° Fah. as t_2. In order to circulate brine at the same temperature, namely 0° Fah., we must have the ammonia expanding in the coils for cooling the brine at a temperature, say 10° lower. This is necessary to effect the interchange of heat, and means that we must reduce t_1 in the brine system to $-10°$ Fah. This means a loss of efficiency of about 16 per cent., and an additional loss in compressor capacity of about 18 per cent.

I have shown these losses graphically in diagrams, Figs. 22 and 23, for various temperatures. In addition, a considerable waste of power is generally entailed in circulating the brine. When direct-acting steam pumps are used, as is often the case, this loss is considerable. Brine circulation is understandable where joints and fittings are so imperfect that ammonia cannot be circulated in the cold chambers without leakage and smell, but under proper conditions direct expansion is not only much more economical, but much more satisfactory. The argument that a store of cold is obtained is often used by advocates of the former system, so that by circulating the brine, even with the machine standing, refrigeration can be carried on for a time. When we look into this, it is clear that to store cold to any extent, it is necessary to have the brine at a very much lower temperature than would otherwise be required. This entails a still further lowering of the temperature of the expanding ammonia, and consequent largely increased cost for the refrigeration actually obtained, accompanied by further reduction of compressor capacity.

Our own practice is to supply direct expansion in all cases, unless brine circulation is specially demanded by the user, and, as a matter of fact, we have erected many hundred miles of direct expansion-piping without one single case of trouble by leakage.

The limits of this paper present more than a passing reference to compression machines using carbonic acid, but the principle is similar in all respects to those using ammonia. The practical details of construction are different, as pressures so much higher have to be dealt with, and very special means have to be adopted to ensure safety and prevent leakage. Fig. 24 shows a small ice-making plant with machine of this class, by a German maker.

The other subdivision of class 2, the absorption machine, is of some importance theoretically, but time does not permit my entering into a full consideration of its action. Briefly, it may be stated that in this type two elements are used—one a volatile liquid, and the other some different liquid which has the power of readily absorbing the vapours of the first. The liquids that have been practically used are water, with sulphuric acid as absorber, and ammonia with water as absorber. With the first pair the action consists in volatilising the water under a very perfect vacuum, produced by means of a special air-pump, and causing the air and water vapour on its way to the pump to come into intimate contact with strong sulphuric acid, by which the water vapour is absorbed, leaving only the air to be discharged by the pump. The rapid boiling of the water by thus reducing the pressure, causes so much heat to be withdrawn to provide that necessary for vaporisation, that the water itself soon crystallises into a mass of spongy ice. Such machines are generally known as vacuum machines, but have not come into use to any extent. Fig. 25 shows one of the more modern attempts—the Lange machine. The air-pump here is of a special and ingenious form, consisting of three barrels, with an oil seal in each. The upward stroke draws air into the bottom cylinder, and at same time compresses the air above the piston in each cylinder, until by a repetition of strokes air of the utmost rarefaction can be eventually discharged. An almost perfect vacuum can be readily obtained by this means.

The ammonia absorption machine is one of the oldest types of refrigerating appliances, and is shown diagrammatically in Fig. 26. Here the generator contains a solution of ammonia in water. On heat being applied by means of a steam coil, ammonia gas is driven over to the condenser where it liquefies and passes through an expansion-valve to the refrigerating coils, where the cooling effect is produced. These coils are in communication with the absorber, a vessel containing water, or rather the weak solution of ammonia left over after gas has been driven from it in the generator, and, as the vapours form in the refrigerator coils, they pass over to this weak solution and are absorbed. The resulting strong solution is then pumped through the interchanger to the generator, to recommence the cycle of operations. This interchanger serves to take up the heat of the weak solution when being passed over to the absorber, and returns a considerable portion of it to the strong solution passing from the absorber to the generator.

This type is of very much less commercial importance than the compression type, and the actual efficiency is in practice only about one-third of a good compression machine.

It is usual, in comparing refrigerating machines, to speak of them as being of so many tons ice-melting capacity. This means that they remove the same amount of heat per 24 hours, that would be required to melt the stated number of tons of ice at 32° Fah. into water of the same temperature.

This must not be confounded with the ice-making capacity, which is a variable quantity depending on circumstances and the system of ice-making employed, but may range from one-half to two-thirds of the ice-melting capacity.

A most interesting method of producing excessively low temperatures is what is known as self-intensive refrigeration. This depends for its action on the fact that any gas, in expanding through a small orifice, does an amount of work on itself which causes a reduction in temperature. In the case of air, for instance, the reduction is small but still appreciable. Dr William Hampson, of London, in May, 1895, patented a process for using the whole of this expanded gas to cool the gas coming to the expansion orifice, and thus reducing its temperature slightly. The gas expanded from this cooled gas is slightly lower in temperature than that preceding it, and cools the next-coming gas still lower; and so on, until the critical temperature of the gas is reached and liquefaction commences, or until the access of heat from without counterbalances the removal of heat within the apparatus. Fig. 27 shows a section of this arrangement. It consists essentially of a fine copper tube, wound in a series of helices, which conveys the gas to the expansion-valve. It is so arranged as to be most carefully insulated, and also so that the expanded gas is compelled to follow the whole length of the tube externally before escaping, thus taking up all the heat possible from the entering gas. The expansion-valve is shown to a larger scale, and can be regulated by means of a hand-wheel at the top of the apparatus. By this means Dr Hampson has readily liquefied oxygen and air, and his latest results are, I believe, unique in their way. He informs me that, with a copper coil in the exchanger, weighing 16¾ lbs., and air supplied at a pressure of 87 atmospheres, he has been able to obtain liquid air in 27 minutes from the start. This was without external cooling of any kind, and with everything at atmospheric temperature when the start was made. When we consider that in these 27 minutes the temperature at the expansion end of coil was reduced from that of the atmosphere to – 377° Fah., it is clearly a very satisfactory result. The temperature of the entering air was 50° Fah., and, when liquid was forming, the return air was issuing from the apparatus at a temperature of 47·4° Fah.; *i.e.*, the exchange of temperature was effected over a range of 427° Fah. within 2·6 degrees. Dr Linde had also been working independently on the same lines, and applied for an English patent a month or two after Dr Hampson.

This self-intensive process, whilst not of use for ordinary commercial refrigeration, is still of great scientific value, and may yet be applied to industrial purposes.

One of the most important points in connection with refrigeration is the providing of a satisfactory insulation, and in all cases it is cheapest in the end to carry this out in a thoroughly satisfactory manner. Defective insulation may mean a little less outlay to begin with, but it means extra cost daily and hourly thereafter. Many materials have been used or tried—sawdust, charcoal, silicate, wool, hair-felt, and others—but all depend for their efficiency on the presence of a number of still air spaces, and practice shows that the best insulation is simply a sufficient number of air layers surrounding the space to be cooled, made so as to be quite air-tight, and sufficiently subdivided to prevent trouble from convection currents. There are several methods of carrying this out in practice.

The various applications of refrigeration and the methods and arrangements in connection therewith, are outside the scope of this paper, but it is not too much to say that the comforts and luxuries of modern life are considerably increased by this agency. What were known as the delicacies of the season are now familiar all the year round. Our tables at Christmas may have the strawberries of summer; our Easter days may see the grouse of the preceding autumn; and our friends of the Izaak Walton type may store their salmon catches and enjoy them in full freshness many days thereafter.

Such applications as these are already commonplace, but it requires no strong imagination to predict the likelihood of further extensions leading to still greater benefits and advantages.

Correspondence.

Mr J. WEMYSS ANDERSON—He would like to congratulate the Institution on obtaining such a valuable addition to its proceedings. The graphical diagrams were exceedingly important and interesting, and no doubt they had entailed considerable labour on the part of the author. He agreed generally with the theory as set forth in the paper, with one or two exceptions, which he would now mention. On page 166 they found the expression "Efficiency here means the quantity of heat units removed, *i.e.*, the refrigeration done, divided by the quantity of heat units representing the work done." He thought the word "efficiency" was now generally accepted as a term having unity as a maximum, and therefore it was not applicable in the case of $\frac{T_2}{T_2 - T_1}$, which should be called the

Mr J. Wemyss Anderson.

"co-efficient of performance." The author used that term on page 168 without, however, explaining what it meant. He would take very strong exception to the position which the author had taken up on the question of "wet *v.* dry compression." After using every argument in favour of keeping down the range of temperature in a refrigerating machine, as on page 166, for instance, "You will observe that, whereas in the heat engine the efficiency becomes greater as the difference between the temperatures T_1 and T_2 increases, the reverse obtains with the refrigerating machine. This is a most important point," etc. Also on page 182 "We saw that it is of the utmost importance to keep the condensing pressure and temperature as *low* as possible." How could that be reconciled with the statement on page 178, "Thus the gas comes to the compressor in a perfectly dry state, and is *superheated* during compression. This enables the full value of the liquid to be used for refrigerating work, but the *pressure* during compression is *higher* and the *heat greater*." As a matter of fact, under such conditions, the full value of the liquid was not used for refrigerating purposes—taking a complete cycle,—which was of course the only correct way to deal with the subject. He could not understand the author when he said, "As a matter of fact in actual work dry compression machines generally work partly wet, and the efficiency, so far as this goes, may be said to be alike in both cases." He could quite understand that a "wet" machine might be worked so dry, and a "dry" machine might be worked so wet as to practically come out the same—but, generally speaking (*e.g.* for temperatures of 35° Fah. and below) the greatest co-efficient of performance—taking practical considerations into account — would be obtained with a "wet compression" machine having the discharge ammonia pipe such that it could be grasped with the hand, or say 100° Fah. On no account would he fit a compressor with a water jacket or an oil injection; both were unnecessary. In conclusion he would like to bear out what the author said respecting "still air spaces" in insulation. Dr Howard and himself, of the University College, Liverpool, had recently carried out a series of tests on different forms of insulation, and they had come to the conclusion that the question of "still air" required more consideration in practice than was at present given to it. The outcome, as far as he was concerned, was that, whereas in a large cold store in Liverpool, where he had some time ago proposed the use of silicate cotton, he now proposed to use "still air," the only question now being the best means to obtain that end.

Professor J. A. Ewing—Observed that Mr Murray was to be congratulated on the success with which he had carried out the difficult task of giving, in a short paper, a lucid and systematic account of a large subject. The paper was interesting and comprehensive, and did not appear to give much opening for criticism. On one point of phraseology he was inclined to differ from the author, who spoke of the ratio of the heat extracted to the work spent as the "efficiency" of a refrigerating machine. He (Professor Ewing) preferred to call this ratio the "co-efficient of performance." The word "efficiency" was already rather overloaded with meanings. As applied to a machine it was used to designate what was always a fractional quantity—a ratio between energy that the machine gave out, and energy that was given to it, whether as heat or work. But the co-efficient of performance of a refrigerating machine might be, and often was, many times greater than unity. Taking a perfect heat-engine, the efficiency was $\frac{T_1 - T_2}{T_1}$; but when such a machine was thermo-dynamically reversed, and turned into a perfect refrigerating machine, the co-efficient of performance was not the reciprocal of this, but was $\frac{T_2}{T_1 - T_2}$, T_1 being the upper limit, and T_2 the lower limit of temperature in both cases. There was, in fact, no strict correspondence between the two ideas, and to express them both by the same word "efficiency" was, he thought, undesirable and likely to be misleading to beginners in the subject. In regard to the entropy temperature for carbonic acid, it appeared from the researches of Dr. Mollier that the diagram should have had a rounded top, much more nearly

Prof. J. A. Ewing.

symmetrical to left and right than was the diagram given by the author in Fig. 10. The form should be more like that shown on a small scale in Fig. 8. It was scarcely correct to say when the upper limit of temperature exceeds the critical point, that to produce refrigeration the vapour must be expanded below the desired temperature. The author appeared in this passage to imply that it was to super-heating of the vaporised substance in the brine coils that the refrigerating effect of carbonic acid was, under these conditions, to be ascribed. But it was possible enough to get refrigerating effect without allowing any super-heating to take place prior to the super-heating which occurred during compression. Thus the temperature of evaporation need not be sensibly lower than the temperature at which refrigeration was intended to be effected It would have added much to the interest of the paper, if the author had been in a position to bring forward any experimental data relating to the type of machine described by him in detail. Much information of this kind had been published regarding ammonia machines of other kinds, namely those working on the "wet" system without oil injection and without, or nearly without, super-heating of the gas during compression. But it was less easy to find the results of tests of machines using dry compression and oil injection. From the point of view of thermo-dynamic theory there was but little to choose between wet and dry working as regarded ideal of efficiency. The difference, such as it was, was in favour of wet compression. He had not been able to satisfy himself that there was practically any sufficient advantage in oil injection to compensate for the additional complication which it involved. The regenerative method of producing extreme cold, briefly referred to by the author at the end of his paper, was first actually carried out by Dr. Linde of Munich. This was perhaps not quite clear from the author's remarks.

Mr HERBERT BIRKETT—Mr Murray went so thoroughly into the theory of mechanical refrigeration that very little was to be added by way of amplification or criticism. He would therefore

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confine his remarks to a few practical details which were the results of his own personal experience. Mr Murray called attention, on page 173, to an objection to the use of sulphurous acid as a refrigerating agent. He could corroborate this objection by a case that was some time ago brought under his notice. The machine in question had been erected by the makers and left in complete working order, but after the lapse of a few weeks it was found to have very materially fallen off in its refrigerating effect. Examination proved that some of the pipe joints in the engine room and surroundings had been badly made and leaks had occurred, with the result that the spigots of the joints were corroded away, the leaks became worse, and almost the entire charge of the refrigerating agent was lost. After serious delay and inconvenience had been caused, the machine having been installed in a brewery at the commencement of the hot season, a fresh charge of acid was obtained and the defects remedied. It was only just to the makers to say that the machine afterwards gave great satisfaction and did excellent work. He would now say a few words about the De La Vergne system of refrigeration, and more especially with regard to the pipes and fittings used for the direct expansion of ammonia, in coils placed in the chambers where the cold temperature was required to be produced. Three large machines on this system were now working in the Meat Freezing Works of the Sansinena Co. at Buenos Aires, and all the freezing and cooling was done by direct expansion. There were in all about three miles of 2-inch pipes in the chambers, and during the four years of his daily presence in the works, which were arranged by him and built under his personal supervision, he never knew a case of a leak occurring after the pipes had been thoroughly tested in their place and set to work. It was essential, as was stated on page 183, that the screw threads of the pipes and flanges should be a very exact fit. The solder joint, as the author said, was simply an additional precaution, and could not be relied on to remedy an imperfect screw thread. Should the thread be imperfect, and leave the slightest room for movement to even an imperceptible degree, it was found that the flange when bolted up to another would spring sufficiently to pull the solder away from the metal and cause a leak, so small, however, that it could not be detected till ammonia under pressure was let into the pipes. He had the highest possible opinion of the efficiency and convenience of the direct-expansion system. There were special cases in which it was preferable to work with an intermediary such as brine, but that could only be done at the expense of a larger quantity of fuel. One very essential feature in his opinion of the De La Vergne machine had been omitted by the author. That was that the ammonia receivers were fitted with glass gauges by which one could tell at any moment the amount of refrigerating liquid in the system, so that the plant could always be worked up to its highest efficiency, and shortness of ammonia was impossible under ordinary supervision. As far as he knew this item in the apparatus, which seemed to him so very necessary, was not fitted in any other system.

Mr JAMES D. MACKINNON (Member)—Wished to record his protest against the continued use of the efficiency of the Carnot cycle as a standard of efficiency for heat engines of any description. Based as it was on the assumption that "heat could be transferred to, or abstracted from, one body by another at the same temperature," it seemed only slightly less incongruous than to assume that "heat could pass from one body to another at a higher temperature without the aid of an external agency." Yet, while the latter statement was considered of sufficient importance to be directly negatived by the second law of thermodynamics, the former, which was equally a violation of the laws of thermodynamics, was actually embodied as a fundamental principle in that so-called "perfect heat engine." Whatever advantages physicists might derive from the conception of the Carnot engine, engineers ought not to countenance any such visionary standard of efficiency.

Dr W. HAMPSON (Associate)—Thought the following remarks ought to be introduced by a recognition of the appreciative way in which the author of the paper had referred to the process of self-intensive refrigeration. Since the information quoted by him

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was supplied, a new model of the apparatus, with further improvements and better results, had been constructed; and the particulars in connection with this were given below in the column headed H. For comparison, the corresponding particulars were given in column L for a machine constructed by Professor Linde. His apparatus was the only other machine capable of liquefying air without the use of auxiliary refrigerants, and the following particulars of his most successful attempt at reducing the size of the apparatus, and the time required for liquefaction, appear near the end of an article by him in *The Engineer* of 20th November, 1896:—

	L.	H.
Weight of coils, in pounds, - - - -	132	14⅓
Time required to liquefy air, - - - -	2 hrs.	16 min.
Quantity of liquid air per hour, litres, -	·9	1·2
Air compressed per hour, cub. metres, -	22	16⅔
Percentage liquefied, - - - - -	3·8	6·6
Compression of air, in atmospheres, -	190	120
Time for liquefaction with 130 atmospheres,	—	10 min.
Time for liquefaction, with preliminary cooling by carbonic acid, - -	nearly 1 hour	1 min.

The apparatus referred to in column H could also be worked without a compresser, from oxygen or air obtained ready compressed to 120 atmospheres in an iron cylinder. In that case the preliminary cooling of the apparatus was effected by carbonic acid from another cylinder, and 125 cub. centimetres of liquefied gas could be obtained from a single cylinder of oxygen. The leading feature, which was also the chief novelty, in this apparatus was a process which was not always clearly understood. Confusion had been introduced by a growing abuse of the word "regenerator," which it might be well here to examine. In processes involving currents of fluid with changes of temperature, it was sometimes desirable to keep within an apparatus heat or cold developed there. This was done by taking from the fluid, before it left the apparatus, the heat or cold to be retained, so that the fluid might leave at the starting temperature; that was, in many cases, the temperature of the air. It was plain that this was a process of intercepting heat; and all varieties of such processes might fairly be called interceptive, and the appliances to carry them out interceptors, as a generic term. Such heat-interceptors, whose business it was to intercept heat—to catch it on its way in a current of fluid and turn it back—must not be confused with insulators, whose business it was merely to retard the passage of heat by interposing bad conductors, a device which might be used where there were no currents of fluid at all. Heat-interceptors then, as a genus, included two distinct species as follows:—(1) The heat might be intercepted by causing the fluid, as it left, to follow passages composed of massive materials, such as fire-brick, metal sheets, or wire gauze, which took up the heat and afterwards gave it out to a current of the fluid returning through the same passages, when the flow had been reversed; the massive passages alternately rising and falling in temperature, according to the direction of the current. Such appliances were very properly called regenerators, and the process might be clearly and simply exhibited in such a diagram as that of Fig. 28.

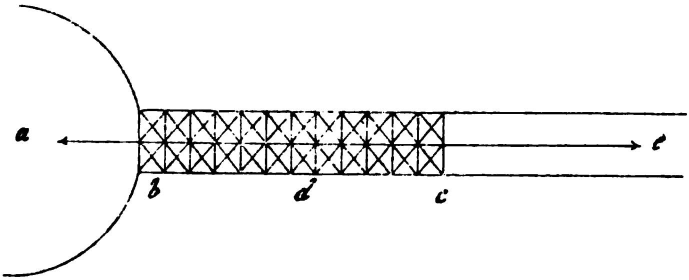

Fig. 28.

a, being the source of heat or cold; *bc*, the regenerator; *b*, the inner portion, near temperature of source; *c*, the outer portion, near starting temperature; *d*, the intermediate portion, alternately heated and cooled; and *ae*, alternate currents. Such an interceptor plainly answered in every way to Professor Ewing's admirable definition:—See "The Steam Engine and other heat

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engines," p. 59. "For the present purpose it will suffice to describe the regenerator as a passage through which the working fluid can travel in either direction, whose walls have a very large capacity for heat, so that the amount alternately given to or taken from them by the working fluid causes no more than an insensible rise or fall in their temperature." He further explained that by these walls the heat was "stored and restored," thus bringing out the true meaning of the word regeneration. So Wood, Thermodynamics, p. 166, said:—"Regenerators consist of a chamber well filled with thin plates of metal. During the flow of air from the cylinder the plates act as a refrigerator, by abstracting heat from the gas; but during the return of the gas they act in the opposite sense, and hence become regenerators." With these definitions Peabody and Rankine exactly agreed, and the latter also said that the heat was "stored and restored." Regenerators, thus defined, included Stirling's hot-air engine, Siemens' furnace, Kirk's refrigerator with gauze or sheet metal, and Solvay's refrigerator with long massive piston and cylinder. (2) The second species of interceptors included those in which the heat in a current of fluid was intercepted, not by a fixed mass, but by a counter-current of fluid; the passages having as little mass and specific heat as possible, the currents not being stopped and reversed, and the fluid, or the passages at any point, not being alternately heated and cooled. The arrangement in its simplest form was shown in Fig. 29.

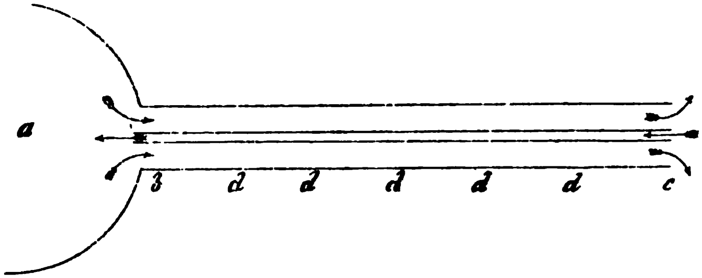

Fig. 29.

a, being the source of heat or cold; *bc*, the constant current interchanger; *b*, the inner portion, near temperature of source;

c, the outer portion, near starting temperature; *dd*, the intermediate points, each having currents of constant direction, and a temperature progressive and finally constant. Interceptors of that second class had also been called regenerators, but inaccurately so, whether from a scientific, historical, or etymological point of view. Scientifically, it was wrong to include under the same name processes which possessed such opposite features as were shown in the columns below, when authoritative definitions, such as those given above, showed that the essential features denoted by the name were those which were found in only one of these processes:—

I. Regenerative Interceptors, or *Regenerators.*	II. Constant current Interceptors, or *Interchangers.*
1. Massive passages, with great specific heat.	1. Lightest possible passages, with lowest specific heat.
2. Currents continually stopped and restarted in opposite direction.	2. Currents of unchanged direction.
3. Currents passing only in one direction at a time.	3. Currents passing in opposite directions at the same time.
4. Temperature of regenerator alternately rising and falling in middle portion.	4. Temperature of interchanger not alternating at any point.
5. Heat "stored and restored" by passage walls.	5. Heat constantly in motion through passage walls, and stored only in currents of fluid.

When a new variety was added to the species represented by Column II., it was unscientific to give it the name already appropriated to Column I., and then justify the misnomer by using the name generically to include both columns. That was what was done when the new self-intensive refrigerator was called a regenerative apparatus, and regenerators were made to include constant-current interchangers. It was as if a naturalist, on discovering a new variety of horse, called it an ass, and then used ass generically to signify both asses proper and horses of

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all kinds. Such nomenclature introduced gratuitous confusion. Historically the true regenerator, on the one hand, already by universal consent possessed that name, and the constant-current interchanger, on the other hand, was also by universal consent, both in scientific and practical works, named exchanger or economiser long before this method of liquefying air was thought of; and if this process must receive a name already appropriated, it should have that which had been used for the apparatus most like it. To find which this was, it was only necessary to look out the references under the word regenerator in the indexes of books on heat or engines.

Etymologically, regeneration, or bringing to life again, implied a period of suspended existence, and while very suitable to a massive regenerator, where the heat alternately died and revived, disappeared and reappeared, or was "stored and restored," it was quite unfitted for an apparatus in which every point kept first a progressive and then a constant temperature. This second kind of interceptor was seen fairly well realised for liquids in such appliances as the economiser or exchanger of an ammonia absorption machine; and for liquid and vapour, in a still, or in the condenser of an ammonia refrigerator. But for gases in both currents, only the very rudest attempts to interchange the temperature had until lately been made; in suggestions by Siemens, by Laidlaw and Robertson, and by Solvay, as an addition to his regenerative interceptor; in practice by Windhaüsen in a refrigerating machine, as well as in heating feed-water by condensation-heat or in heating air for combustion by means of combustion-gases. But the apparatus had been so rudimentary for gases, on such ill-conceived principles, and with results so poor, that no one appeared to have understood the powerful effects obtainable by thoroughly carrying out the constant-current interchange for gases, unencumbered by other arrangements; and the cascade method, through intermediate agents, such as nitrous oxide and ethylene, was the only available means of obtaining intensely low temperatures. The crude apparatus referred to, in which the elements of constant-current interchange imperfectly appeared, bore much the same relation to the invention of the self-intensive refrigerator as a common baker's oven, where the bricks stored heat taken from combustion-gases and restored it to bread, bore to the invention of Siemens' regenerative furnace.

If now, changing the plan of the diagram in Fig. 29 to that in Fig. 30, the source of cold at *a* were the expansion of compressed gas from the inner tube *c* into the outer tube *d*, it would be seen

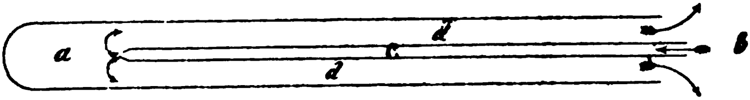

Fig. 30.

that the expanded, and therefore cooled, gas, in returning along *d*, would give up its cold to the compressed gas passing in the opposite direction along *c*; or, to put it otherwise, the compressed gas in *c* would give up its heat to the expanded gas in *d*. Thus the compressed gas would arrive at the *a* end of its tube in a cooler condition, would therefore be cooler than before when expanded, and would again on its return as expanded gas cool the arriving compressed gas to a still lower point. If now the tubes were long enough, and sufficiently well arranged in suitable coils, the expanded gas might be made to leave at *b* not perceptibly cooler than the compressed gas entered at the same end. Thus the whole of the cooling produced by expansion would be devoted to lowering the temperature from which expansion took place, and the initial refrigeration would intensifiy itself until it reached the boiling point of the gas used, when the temperatures everywhere in the system, hitherto progressive, would remain constant, and the expansion-cooling would then be devoted to liquefaction of the gas.

The regenerator, with features described in the definitions quoted above and summarised in Column I., was a familiar subject in works on Thermodynamics and Heat-engines, where it always had its proper name. But few of those works described or even mentioned

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the apparatus whose features were summarised in Column II., doubtless because its less perfect development, especially as applied to gases, had led to less striking results. In the descriptions of inventors, however, and in works specially devoted to refrigeration, such as Siebel's Compend, apparatus of this nature was always correctly described as an exchanger, interchanger, or economiser. But in Professor Ewing's important and valuable lectures on Mechanical Refrigeration, delivered last year before the Society of Arts, the interchanger received considerable attention. It was, however, both in the text and in the illustrations, called indifferently interchanger and regenerator. Moreover, the self-intensive refrigerating apparatus by which air had, without the use of other cooling agents, been liquefied, was in virtue of its interchanger called a regenerative apparatus. What could be the explanation of this confusion of terms? Apparently the trained scientific intellect, the moment it was confronted with some new and startling practical achievement, felt impelled to label the process promptly with some name different from that used by its inventor, as a process new merely in detail and easily classified among processes with which science was already perfectly familiar. Unfortunately in this case the correct names, exchanger, interchanger, and return-flow cooler, given by the inventors, were replaced by a name which, while more familiar to the scientific world, already had a distinct meaning of its own as applied to a different process, namely regenerator. To justify this, the meaning of regenerator was extended, as a generic term, to include interchangers, for which it had not been in use before, thus destroying its value as a specific term, and leaving the species which it had hitherto represented without a distinctive name. Curiously enough, the best proof that this was a strained and improper use of the word was afforded by Professor Ewing himself in the same lecture in which he so frequently used interchanger and regenerator as equivalent terms. On page 57 of the Lectures (separately printed) he said of Solvay's process, "It was a regenerative method somewhat resembling that of Siemens, but with a regenerator instead of an interchanger." This last clause was perfectly accurate. Siemens' plan was for an interchanger, with currents of constant direction; Solvay's, for a regenerator, with currents continually stopped and reversed in direction. But the phrase, "with a regenerator instead of an interchanger," made these two terms mutually exclusive, which in fact they were, whereas earlier on the same page the author used them as synonymous in the phrase, "the early suggestion by Siemens of the use of a regenerator or interchanger." The two phrases were irreconcilably inconsistent with each other. Professor Ewing was not a slovenly or careless writer. The charm of clear description and exact language was, with this exception, characteristic of the lectures. Moreover, in the phrase, "with a regenerator instead of an interchanger," the two words were used pointedly and with intention, for the purpose of indicating that essential difference of process which was the subject of those remarks; so that the form of expression could not be explained as an accidental slip. The explanation of the inconsistency must be that in employing this phrase the author dropped for a moment into what he himself felt to be the right use of the word regenerator as a specific, not a generic, term, forgetting for a time the *parti pris*, and the supposed necessity of forcing himself to use the word in a strained and unfamiliar sense. This is borne out, not only by the analysis given above, but also by Professor Ewing's own definition of regenerators, in his book on the Steam-engine—a definition which could not possibly be stretched to cover interchangers. The feature common to regenerators and interchangers was that they both intercepted heat passing with currents of fluid. But this was no more a reason for calling interchangers regenerators than for calling regenerators interchangers. If a generic term was wanted, let it be one that expressed the features common to both species, and no features which were special to one only. Such a term would be current heat interceptors, or more briefly interceptors, and a process employing them would be interceptive.

To refer to the wet and dry controversy in ammonia-compression,

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Mr J. Wemyss Anderson's difficulty, in reconciling the two passages he quoted, might be diminished by reading the two sentences that followed the last quoted passage:—" A water-jacket or oil injection is used to carry away as much of the heat as possible. As a matter of fact, in actual practice dry compression machines generally work partly wet, and the efficiency, so far as this goes, may be said to be alike in both cases." These statements of limitations and modifications in practice showed that what preceded referred to theoretically complete conditions in the dry system, just as had been the case in the description of the wet system. If the temperature in the compresser were reduced by a given amount the reduction in compression work on that account was just the same, whatever the cooling agent was; but other conditions, incidentally introduced, must also be considered. Thus, on the wet system, so far as the theory was realised by vaporisation of the liquid injected, so far there was provided by that vaporisation an additional quantity of vapour to be compressed, which prevented the full reduction of compression-work due to the reduction of temperature. That was only another aspect of the fact that the wet-compression system did not get " the full value of the liquid used for refrigerating purposes.' A portion of the ammonia liquefied, instead of being vaporised in the chill-room, where its absorption of latent heat would be used for refrigerating purposes, was returned as liquid to the compressor. Since, therefore, a part of the liquid condensed was thus diverted from refrigerating work, in order that this refrigerating work might be done, the diversion must be compensated for by providing a greater total quantity of liquid; that was to say, the compressor must do more work— which went to negative the reduction of work due to reduction of temperature in wet compression. In dry compression systems all the liquid was used for refrigerating, and none brought back as liquid to the compressor (except so far as a theoretically dry system might be, in practice, partly wet). Perhaps a correct judgment of the value of the two systems might be assisted by tabulating their chief merits and faults:—

ADVANTAGES.

Dry System, with Oil Injection.	*Wet System.*
1. Cooling by injected oil, with reduction of work.	1. Cooling by injected liquid ammonia, with reduction of work.
2. Perfect abolition of clearance and back-pressure.	2. Only one set of cooling-coils, but those of greater extent.
3. Perfect abolition of leakage at glands, valves, and piston.	
4. Perfect lubrication of piston, piston-rod, and valves, with greatly diminished friction.	
5. Easy fit of piston and piston-rod, short and single stuffing-boxes, permitted by perfect sealing, with reduction of friction.	

DISADVANTAGES.

1. Additional set of cooling-coils for oil-circulation.	1. Additional compression-work due to additional volume of vapour from injected liquid (or additional work necessary to provide additional liquid for injection).
	2. Friction from tight-fitting working-parts with long or double stuffing-boxes.
	3. Difficulty of avoiding excess of liquid, with back-pressure.
	4. Difficulty of avoiding leakage.
	5. Additional quantity of cooling coils for additional quantity of liquid condensed for injection.

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A word would perhaps be permitted in expression of the satisfaction with which the author's diagrams were studied. The art of diagram-making was easily abused, but in those exhibited an unusually wise discretion had been shown, alike in selecting, excluding, and arranging, with the result that they were real illustrations, which helped, instead of hindered, a comprehension of the subject.

Discussion.

The discussion on this paper took place on 22nd February, 1898.

MR W. D. A. BOST (Member) remarked that he had long taken a very great interest in refrigerating machinery; but the part of refrigerating installations which had interested him most was that which appertained to insulation. His desire for information upon the subject was his excuse for speaking, as he noted that this very important matter had taken up very little of the paper on Mechanical Refrigeration which Mr Murray had given them, being in fact confined to one paragraph. He had had the privilege last February, in London, of hearing Mr Donaldson, Engineer of the London and India Docks Joint Committee, read a paper before the Institution of Civil Engineers upon the cold storage warehouses of those Docks. Mr Donaldson fully recognised the importance of good insulation, and rightly devoted a considerable part of his paper to that section of the subject, as, however efficient a refrigerating machine in itself might be, the net result might be most unsatisfactory, owing to inferior insulation. He would ask whether Mr Murray, who began the paragraph upon insulation with the statement that "One of the most important points in connection with refrigeration is the providing of satisfactory insulation," had made any comparative tests, and what had been the results of those tests. He understood that Messrs L. Sterne & Co. completed an installation at Hull, in which it was sought to confine the air in wooden spaces so as to make it absolutely still. Had Mr Murray got any results from the working of that building which would enable him to state the efficiency of the insulation there? That would be of very great interest. A friend of his in Paris, who had lately been entrusted

Mr W. D. A. Bost.

with the designing and fitting up of a cold store in the South of France, and who desired specially to have some definite information for other and larger work which he was designing, made a test, during mid-summer, of the insulation, which consisted of 8 inches of Cartvale flake charcoal. The test extended over five days, and he found from the mean of the results, that the charcoal insulation permitted a loss of heat equal to one-half of a French calorie per square metre per hour, per degree Cent. of difference in temperature, which was equal to ·102 B.T.U. per square foot per hour, per degree Fah. of difference. That was for the charcoal alone, which was 8 inches thick; and after deducting the tabulated value for the woodwork within which it was packed, as also the walls, he believed that that was equal to the best results found in the most careful laboratory tests, and showed, in that case at any rate, the working on a practical scale had proved that that charcoal could be relied on in practice to give good results. For the benefit of those who might be wanting to study the question of different insulators from a comparative point of view, and who might wish to make test experiments before insulating on a large scale, he might mention incidentally an error into which one might fall, but which had only to be pointed out to be admitted. The following was an instance:—A careful engineer took the cost per cubic foot of each of the insulating materials, and then made the thickness of the insulating material to correspond with the cost, so that the total cost of the insulation surrounding each of the test boxes would be the same. The consequence was that in cases where a thickness of 4½ inches of one material was used as against 11 inches of another, the outside surface of the box with 4½ inches gave a total of 18 square feet, while that with 11 inches gave 48 square feet of surface exposed to the air and convection currents. As the surface exposed was an important factor in the question, it would at once be seen that on test boxes of small capacity, the greater surface of a thickly insulated box, to a certain extent, counterbalanced the advantages to be got from the increased thickness of the insulating material. When he pointed that out to him he at once admitted the justice of his remarks; viz., Mr W. D. A. Bost.

that to arrive at the merits of different materials the thickness should be the same, and as such experiments could only be comparative, the different insulators should all be tested simultaneously, so that all the conditions might be identical. He quite agreed with Mr Murray, and with Mr Anderson, in the correspondence, that still air spaces were the proper thing to use, but of what size? Was not still air properly subdivided acknowledged to be the best insulator? Was it not quite well known that any insulator compressed or solidified by any means, so as to prevent it *forming* still air spaces, ceased to become a non-conductor in the proper sense of the term, or at any rate lost greatly its insulating value? He quoted from Messrs. Lardner & Loewy on "Heat":—"To produce the most perfect non-conductor, the particles of the body must have naturally little conductivity, and they must be sufficiently compressed to prevent the circulation of currents of air among them, and not sufficiently compressed to give them a facility of transmitting heat from particle to particle by contact." Again, how could air be kept still so long as it had space to form currents. The attaining of that end was beset with difficulties, and he thought, with all due deference, that when an insulator like Flake Charcoal (which from its form occludes air in abundance, but minutely subdivided) was to be had, it was practically useless to try and replace that by mechanical means. The cost was bound to be far greater, the *risks* of bad workmanship certain, and the final efficiency dubious. If any members had made experiments upon different kinds of insulators, he hoped they would furnish the Institution with the results, stating at the same time all the conditions under which the insulators were tested, and explaining in full the way in which the test had been carried out, as such would be of great interest to all who had to do with Refrigeration. To show the great importance of good insulation, he would quote from "Ice Refrigeration," February 1898, a statement made by Mr J. Wemyss Anderson:—"We may talk and write about "wet" and "dry" systems of compressions and the care required in the condenser and refrigerator, but all the ordinary loss of efficiency from these points pales before the vital item of insulation."

Mr B. Harman.

Mr B. Harman (Member) said he had been associated for a good many years with refrigerating machinery on the Linde system, and it gave him a good deal of pleasure to be present to take part in the discussion on Mr Murray's paper. Certain remarks that he thought of making had been forestalled by the communication from Prof. Ewing, but he would like to add to what Prof. Ewing had said—that, in the matter of wet compression *versus* dry compression, he did not use the sealing oil. Most of the engineers connected with refrigeration, who had considered the matter, had found that the complications involved by the use of sealing oil and the difficulties of overhauling the compressor, outweighed the advantages and simplicity of a machine worked on the wet compression system. That was borne out by the fact that most of the makers of ammonia machines worked on the wet compression system. If the dry compression system and the use of sealing oil were better, they would not be very long in adopting it. With regard to the argument about the friction of packing, he did not think there was very much in that, as very few considered that the packing in a steam engine made very much difference in the horse power. Mechanical refrigeration was a branch of engineering of great importance, and was a subject that had been rather neglected by members of the Institution, but the requirements of the age were forcing it upon engineers, and the purveyors of food nowadays were compelled to adopt machinery of that kind. Mr Murray had said that it was the custom of his firm to use direct expansion-pipes for the cooling of the chambers. The more common method amongst refrigerating engineers was to cool the chamber by brine circulated through the pipes attached to the ceiling and walls of the chamber, or else through vessels of another shape. The Company which he was connected with rather leaned towards the keeping of cold-producing vessels outside the chamber altogether, drawing the air away by means of a fan, circulating it over coolers, and returning it to the chamber again. In that way, it was maintained, the air was not only cleansed, but purified and dried, as well as cooled, in its passage over the coolers. There were some very large ships now

Mr B. Harman.

running in which that method had been adopted for carrying frozen mutton, and the same system was being adopted very largely on shore. He was rather sorry that more had not been said about refrigeration on board ship. It was a very important matter to this Institution, but it was too intricate and involved a subject to introduce in the discussion, especially as it was not dealt with in the paper. He was very glad that Mr Bost had mentioned the matter of insulation, as it was a very important matter. One of the advantages on board ship was that they endeavoured to avoid running the machine more than a few hours a day, for the convenience of the engineers and passengers, and insulation under these circumstances was of great consequence. Concerning the different mediums of insulation, as far as his experience went, the choice of the different substances lay pretty much between slag wool or silicate cotton, and charcoal, and he would put the efficiency as about 10 inches of flaked charcoal, for ordinary purposes, to about 6 inches of silicate cotton, for the same duty. Both had been used with satisfactory results. He would take the opportunity of thanking Mr Murray very much for bringing the subject before them.

Prof. A. JAMIESON (Member) said he had much pleasure in complimenting Mr Murray upon his excellent paper; for, if it were combined with Prof. Ewing's "Howard Lectures" on "The Mechanical Production of Cold," they had the latest and best information on this most interesting and important subject.* As far as he knew, it was the only paper which the Institution had received upon refrigeration, except that delivered many years ago by their late and much-respected President, Dr A. C. Kirk, who was the well-known inventor of one of the earliest cold-air machines.† He

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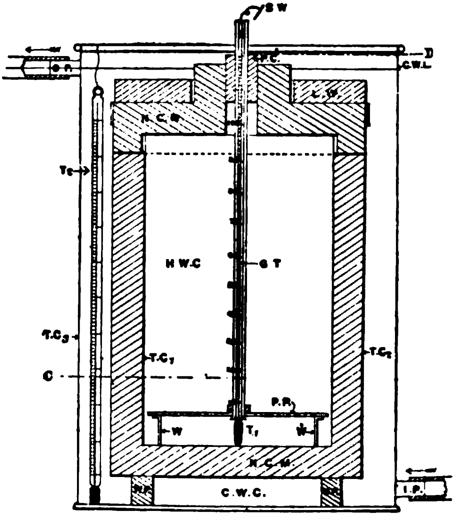
* See the six "Howard Lectures" on "The Mechanical Production of Cold," by J. A. Ewing, M.A., etc., Professor of Mechanism and Applied Mechanics in the University of Cambridge, as delivered before "The London Society of Arts" in 1897, and printed in its Journal, as well as in pamphlet form, by William Trounce, 10 Gough Square, Fleet Street, London, E.C.

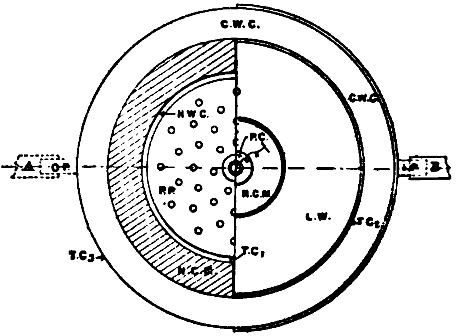
† See Trans. Institution of Engineers and Shipbuilders in Scotland, Vol. VIII., p. 14.

quite agreed with Prof. Ewing's remarks in regard to the way in which efficiencies had been dealt with in the paper before them, for the rate at which different efficiencies were increasing in the different departments of engineering was most bewildering. For example, in one department of electrical engineering they had no less than five or six efficiencies to enunciate, consider, and record, when testing the combined plant of boiler, engine, dynamo, and lamps. In defining the efficiency of the heat engine (at the third paragraph of page 166), Mr Murray said—"By efficiency we here mean the quantity of heat units expended in producing work, divided by the quantity of heat units taken in at the higher temperature." Now, Mr Murray must know that a heat unit was a quantity in itself, and hence he must agree with the speaker that it was inaccurate—and likewise superfluous—to write of a "quantity of heat units" when the following simpler expression would have sufficed; viz.:—"By efficiency is meant the heat units expended in producing work, divided by the heat units taken in at the higher temperature." In a similar way, when dealing with a refrigerating machine, the words "quantity of" should also have been omitted from the last three lines of the paragraph just referred to. Mr Murray had, by his statements and entropy diagram of a cold-air machine, Fig. 3, proved more clearly and conclusively, than any previous speaker had done before this Institution, the true causes for the very low efficiency of these machines, and how they had given way to the more economical refrigerators afterwards mentioned in his paper. Still, these cold-air appliances were the progenitors of the present types of refrigerators, and on that account alone, if for no other reason, their principles and actions would always form a useful lesson in thermo-dynamics to the student of engineering, and the models in the technical museums throughout the country would be interesting as well as instructive for many a day to come. At that late hour of the evening, when members were no doubt desirous of continuing the discussion at a future meeting, the only other remarks he desired to make, referred to the importance of using the best non-conductors of heat, for those parts of their refrigerators which required them. Consequently, in answer to Mr Bost, he had the pleasure of stating that, three or four years ago he had carried out a careful, lengthy, and uniform set of experiments on different "heat insulators" in his laboratory at The Technical College.* From Fig. 31, it would be understood that each experiment consisted of providing a separate inner sheet-tin cylindrical case TC_1 for each specimen of non-conducting material, and of precisely the same size, shape, and thickness as that for all the other specimens. These cylinders were covered to a uniform thickness of one inch by each manufacturer — in the manner, and with the material, employed by him in practice — and then carefully dried. Each cylinder of non-conducting material NCM, was then slipped into the tin case TC_2, which was in turn placed inside a larger case, TC_3, upon 4 wooden pegs WP, and held down by a lead weight LW. Ten pounds of boiling water were poured into the

Fig. 31.



SECTION THROUGH A.B.



HALF-SECTIONAL PLAN ON C.D

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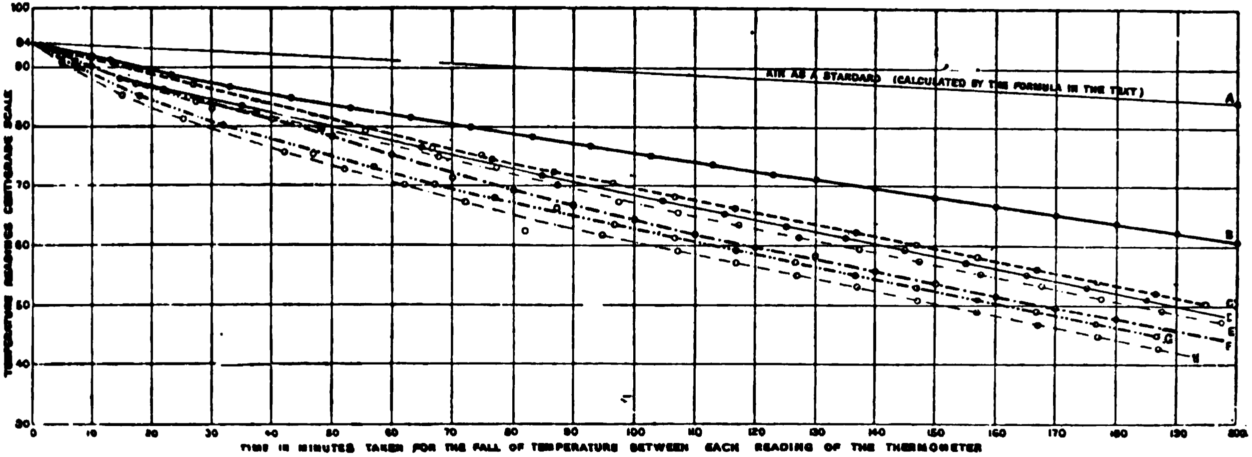
* Professor Jamieson here made sketches on the black board, and referred members to the Proceedings of the Institution of Civil Engineers, London, Vol. CXXI., Session 1894-95, Part III., for a paper on "The Determination

upper central opening as shown filled by the paraffined wooden plug PC. Cold water was allowed to flow uniformly from the Glasgow Corporation supply by the inlet pipe IP, and overflow by the outlet pipe OP, of the outer or cold-water chamber CWC. The outer surface of the non-conductor was, therefore, kept at a constant temperature throughout each test, for in no instance was it observed to rise as much as 1° Cent. In order to prevent the temperature of the hot water from falling too fast at first, and also to bring the non-conductor and the whole apparatus to a condition of constant temperature or heat-equilibrium, steam at atmospheric pressure, generated in a Florence-flask, was first passed into the inner hot-water vessel TC_1 by means of a glass tube led into it through the funnel. The steam-pipe was then removed, and the paraffined cork fitted tightly into its position. The first reading was always taken when the temperature of the hot water had just fallen to 94° Cent. The water was stirred by the perforated piston PP prior to the readings of the thermometers T_1, T_2 in the two chambers, which were taken simultaneously, and noted. Successive readings of both thermometers were then taken in the same way, and recorded every ten minutes. These readings had been plotted as ordinates, with the time between each reading in minutes as abscissæ, and here reproduced as Fig. 32. The curves showed the gradual fall of temperature of the water in the inner chamber during the tests of each of the several substances experimented upon. Each experiment lasted about three hours, during which time a fall in temperature through a good range was obtained. The loss of heat at the end of any fixed time, therefore constituted a measure of the conductivity of each substance. The results were given in the table, page 213, which showed, in each case, the total fall of temperature in degrees Cent. after an interval of two hours from the commencement of the test.

of the Thermal Conductivities of Heat Insulators," by himself. By the kind permission of the Council of that Institution, the copper electros for the above mentioned paper have been presented for reproduction herewith.

Fig. 32.

CURVES SHOWING FALL OF TEMPERATURE DURING THE TESTS OF SEVERAL HEAT INSULATORS, BY PROF. JAMIESON.



REFERENCE LETTERS TO CURVES. (See also, the Table on the opposite page.)

A. Dry air.
B. Fossil meal composition.
C. Silicate cotton, or slag wool.
D. Kieselguhr composition.
E. Cement with hair-felt.
F. Fibrous composition.
G. Papier maché composition (*a*).
H. ,, ,, ,, (*b*).

RESULTS OF THE TESTS ON HEAT INSULATORS, BY PROF. JAMIESON.
(From the Proceedings of the Institution of Civil Engineers.)

Index Letter for Curves.	Names of Materials.	Weight of Sample (including its Tin Case).	TotalFall of Temperature in 120 Minutes.	Thermal Conductivity in Absolute Measure.	Conductivity as compared with Dry Still Air.
		Lbs. Oz.	°Cent.		
A	Dry air - - - - - -	...	6·0	0·0000558	1·00
B	Fossil meal composition -	7 2	21·5	0·0002689	4·82
E	Cement with hair-felt - -	5 15	30·0	0·0003613	6·47
C	Silicate cotton, or slag wool -	...	29·0	0·0003875	6·95
D	Kieselguhr composition - -	7 13	29·0	0·0004336	7·77
G	Papier maché composition (*a*)	7 6	35·5	0·0004424	7·93
F	Fibrous composition (flax, hemp, cow-hair and clay) - -	9 9	34·5	0·0004550	7·98
H	Papier maché composition (*b*)	8 12	37·5	0·0005019	8·99

Finally, Professor Jamieson said that Mr Murray's paper deserved not one hour of a cursory glance at the type and numerous figures, but at least ten hours of careful study. That time, he thought, would be time well and profitably spent upon the principles which underlay the action and construction of the very machines now supplying the comparatively new, but rapidly extending industry of refrigeration.

The discussion on this paper was resumed on 22nd March, 1898.

Mr WILLIAM HOWAT (Member) said, that having had seven years experience of mechanical refrigeration, he was not altogether in agreement with Professor Ewing's and Mr Harman's remarks. In the first place, Professor Ewing remarked on oil injection, and the additional complication which it involved. He (Mr Howat) had failed to find that such was the case, and justified that statement by saying that the firm with which he was connected had erected a machine in Edinburgh, and found that it could do in two hours all that was required. Over and above that, a man of ordinary intelligence had been instructed in three hours, not only how to work the machine, but also how to manipulate the gas engine in

Mr Wm. Howat.

addition. A machine that could be understood by such a man, in that short time, could hardly be called a complicated machine, and he thought there was a great advantage from oil injection. Moreover, he would say, that as far as his knowledge went, the only compressor that was worked on a thoroughly lubricating system was the L. Sterne compressor, and there was hardly any wear or tear in connection with it. As a proof of this, his firm had a machine in their establishment which had worked for seven years, and during that time it had only been packed and stripped twice. Now there was not much wear and tear in a machine that could work for seven years without undergoing repair, and he questioned if any other machine, wrought without oil, bore such a record Again, he would like to make a few remarks in connection with the packing of the Linde machine. It had been remarked that too much had been said about the stuffing-box, but he thought that more might profitably have been said concerning it, as it was altogether an unsatisfactory way of packing a compressor, to have two stuffing-boxes one inside the other As regarded the inside box, no person could rely upon it being right. There might be no escape from the outside, but there certainly might be an escape from the compressor into the hollow ring, and from there into the back pressure, thus forming a circuit from the cyclinder to the back pressure. There were no means of ascertaining whether that was the case or not, and indeed, friction and uncertainty were its only virtues. Finally, the oil system secured the better sealing of the valves, thus preventing undue escape. Less noise and less wear and tear were, in short, its principal features.

Mr George E. Tidd (Member), considered that Mr Murray had prepared a most able and carefully written paper, and showed a grasp of his subject from a technical as well as a practical point of view. He also showed that his practical work had been connected principally with machines using ammonia, and when he departed from that system he quoted the experience of others, but not any practical experience of his own. Mr Murray also gave a number of formulæ, interesting in so far as they proved ammonia to have all the requisite

Mr George E. Tidd.

qualities for refrigerating purposes, and carbonic acid gas, or carbonic anhydride, to have none, or at any rate very few. Those who were interested in the carbonic anhydride machines had heard the arguments mentioned by Mr Murray before, and no doubt in Germany, where the greatest possible faith was attached to figures and very little attention given to practical experience, they would have the greatest possible weight. In this country, however, procedure, as a rule, was on other lines. Perhaps the best evidence of this was that although the air compression refrigerating machine had admittedly an extremely low efficiency, and produced refrigerating work in extent a mere fraction of the chemical machines per pound of coal consumed, yet that expensive (and in theoretical countries practically useless) machine had been the means of starting and carrying on for ten or fifteen years an enormous trade which had revolutionised the food supply of England, and had brought three square meals of meat per day within the capacity of the humblest factory operative. During all that time, what was the highly efficient chemical doing? It was doing its best to produce a competing machine to compare with the cold air machine, and until 1890, it had not met with any success, though it was in practical use in breweries many years before the cold air machine came into existence. In 1890, three ships were fitted for importing meat, two with the ammonia machine, and one with the carbonic anhydride system. Full particulars of the two ammonia machines referred to might be found in the annals of the Law Courts; the carbonic anhydride installation opened the way to three other ships being fitted for the same owners, each for importing 1,000 tons of frozen meat, which were in those days record cargoes. Since the above date, a great number of ships have been fitted on both the ammonia and carbonic anhydride systems, and the air compression machine has practically died a natural death, except in such special cases as for Admiralty purposes, where considerations not of a commercial nature have to be taken into account; but even in the case of our own navy, a number of machines on the carbonic anhydride principle have been supplied, both for ice making and for cold

Mr George E. Tidd.

storage. In the latter connection might be mentioned H.M.S. "Sanspareil," where the magazines were cooled by means of a carbonic acid machine, which was fitted after the absolute failure of the cold air machines. Carbonic acid machines had also been fitted on a number of H.M. ships of war for making ice, and several others were on order, but it was not known that the Admiralty had ordered any ammonia machines whatever. After hearing the manifold theoretical, as well as practical advantages of ammonia machines, it came as a surprise to hear that many of the largest Companies engaged in shipping, ice making and cold storage, bacon curing, and oil cooling, should have in many cases commenced with the ammonia machine, and continuing with the carbonic acid machine, should have placed their further orders with the latter and not with the former. In stating the above, it was not intended to suggest that the reverse had never occurred; for when a brand new system was being carried out for the first time, the same success was not to be expected as with an old established system which had been in vogue for a great number of years; but it was when the new system, carbonic acid, ousted the older ammonia system, as could easily be proved to have taken place, that practical people were inclined to think that theory was not everything. Mr Murray gave them the figures of the latent heat of vaporisation of carbonic acid and ammonia, under two comparative conditions of temperature, viz. 22° Fah. and 86° Fah. respectively, from which he argued that the efficiency of ammonia at the latter temperature was almost unimpaired, while that of carbonic acid almost reached the vanishing point. Yet if two actual refrigerating machines were compared, it was found that the results did not agree by any means with Mr Murray's figures. Thus, with water at 86° Fah., the carbonic acid machine lost only 15 to 20 per cent. of its efficiency; as compared with water at the ordinary temperatures in this climate, the loss of efficiency with ammonia in practice was found to be very much the same. A paper was read a short time ago by Mr H. F. Donaldson, engineer to the London and India Docks Joint Committee, who had under his care two cold storage installations, one

Mr George E. Tidd.

fitted with ammonia machines after the De La Vergne system, and another fitted with carbonic acid machines by Halls, of Dartford. Both of these stores being the same size, the same cubic capacity should serve to illustrate the difference in efficiency of the two machines. Yet, it was found after most careful experiments by an absolutely independent engineer, with a large staff of carefully trained assistants who carried out the trial under his supervision, that, whereas the ammonia machine required about 70 I.H.P. to do the work, the carbonic acid machine required 72 I.H.P. The ammonia system was certainly to be congratulated upon that appalling victory. Let them now look into the conditions which controlled those comparative tests and see whether they also compared. It was found that the ammonia machine was working with water from the dock at about 65° Fah., while the carbonic acid machine was using the same water over and over again, which entered the condensers at about from 75° to 80° Fah. Moreover, the store at the docks, fitted with the ammonia machine, was in the habit of receiving its sheep direct from the ships at a very low temperature, but the store of the Smithfield market was situated some seven miles from the dock, the frozen meat being conveyed in more or less covered vans, exposed to the heat of the day, this meat having to be refrozen on arrival at the stores; and yet the horse power of the machinery was practically the same under these very adverse conditions to the carbonic acid machine. It was stated that, carbonic acid gas having no smell, a leakage might occur from the machine which might not be detected for a long time. There was no doubt that a leakage from an ammonia machine called attention to its existence in the most definite manner, in fact the whole neighbourhood of the machine became impregnated with the fumes, and the difficulty was to tell which of the joints, when there were many, was the delinquent. In order to meet that difficulty, in the earlier days of the carbonic acid machine, special gas possessing a smell was used in a very few instances, but this was discontinued, as the difficulty to which Mr Murray referred did not, as a matter of fact, occur with the Hall machine, the joints of which were absolutely tight, being made with

Mr George E. Tidd.

that material which was the best adapted for the purpose; carbonic acid, unlike ammonia, attacked no materials. Mr Murray referred to certain tests made by Professor Linde between an ammonia machine manufactured by the Linde Coy., and a carbonic acid machine, in which the former was awarded the palm of victory with a great flourish of trumpets. This would be a severe defeat if the last and best ammonia machine had been pitted against the last and best carbonic acid machine, which conditions anyone reading the paper would conclude had regulated the fight. When, however, it was appreciated that the last and best ammonia machine was pitted against the first, or at any rate, the second, carbonic acid machine built for the purpose of the test by the makers of the ammonia machine, the practical value of the comparison suffered a slight depreciation. He had no doubt that there were many makers of other systems of refrigerating machines who would be capable of making a very bad ammonia machine on the same lines. Mr Murray had been good enough to say that, for marine purposes, the carbonic acid machine had met with a fair amount of favour, and as many of the largest Companies had adopted the carbonic acid machine after having tried and given up the ammonia machine, that remark might be endorsed. As, however, many of the largest users of refrigerating machines on board ship, had put down twenty and more installations on the carbonic acid system in their fleet, and this after having commenced with the ammonia machine and given up that system, he thought that Mr Murray might even have used a slightly stronger expression. Perhaps this success was due to the fact that, with the carbonic acid machine, copper coils could be used for condensing purposes, while with the ammonia machine only wrought iron coils were possible, which were necessarily corroded away by the action of the sea water in a more or less short time. Again, the carbonic acid machine, owing to the absence of poisonous fumes in the refrigerating engine room, might be placed in any part of the main engine room, where, coming under the eye of the engineer on watch, it did not increase the staff, and under no circumstances could the machine become a source of danger to its

Mr George E. Tidd.

surroundings. Unfortunately the ammonia machine did not enjoy similar immunity, and many cases had occurred where the engine-room, and even the stokehold, staff had been obliged to vacate their posts and come on deck, while a man, clad in a diver's suit specially kept on board for the purpose, had gone down to turn on the steam to absorb the ammonia. The question of the possible danger to life, and the risks due to the engine-room, being rendered untenable owing to the fumes of ammonia, had reached the Board of Trade, who in consequence had published a circular on the subject. Refrigerating machines could, of course, be put in a separate room, as recommended by the Board of Trade, but that would necessarily involve an increase of the staff, to which owners appeared to have a rooted objection. These accidents were by no means limited to the installations on board ship, but with good material and first-class workmanship, and great care, such as was known to be attached to the construction of machines made by Mr Murray's firm, manufacturers had been able to render such accidents comparatively scarce. Still, they were a possibility with the ammonia machine, and they were not possible with the carbonic acid machine.

Mr T. R. **Murray**, in reply, said that Mr J. Wemyss Anderson in his communication took exception to the position he (Mr Murray) held regarding the much debated question of wet *v.* dry compression, and professed to find difficulty in reconciling some of his statements. It was now generally considered that the importance of that question had been vastly over-rated, and Prof. Ewing in his Howard Lectures had shown that even as a purely theoretical matter of thermodynamics, and assuming an adiabatic compression, the difference between an absolutely perfect "wet" process and one involving a moderate amount of superheating was only about 2 per cent. He had already explained that it was *impossible* to carry out the wet process in a perfect manner, as the least surplusage of liquid in the compressor, at the end of the stroke, was disastrous to efficiency; and when it was considered that the amount of liquid entering could only be regulated by the comparatively approximate method of the expansion-valve, and when it was further considered that,

Mr T. R. Murray.

in practice, the relative proportions of liquid and gas returning to the compressor varied with every change of temperature in whatever was being refrigerated, it was evident that a sufficient amount of margin must be allowed, or in other words, that the "wet" process must be worked partly "dry." There was, moreover, in practice an important element in connection with that matter which must be considered—that was the fact that compression did *not* take place in a perfectly adiabatic manner, but that there was a constant interchange of heat going on during compression between the walls of the compressor and the ammonia. To go fully into that matter was unnecessary and beyond the scope of these remarks, but such high authorities as Profs. Schröter, Ewing, Denton, and Jacobus, and Mr George Richmond, were agreed that the loss of efficiency from that cause increased with the humidity of the ammonia, and was thus in favour of dry compression. As he stated, the so-called "dry" compression machines were in practice generally worked partly "wet," as anyone could see by examining such a machine at work, when frost would generally be found on the suction pipes right back to the compressor, indicating that expansion of liquid ammonia was still going on. Taking all these facts into consideration, he did not see that it was possible to come to any other conclusion than that to which Mr Anderson objected, namely, that in practice the efficiencies of the two methods were practically alike. That was, of course, not considering in any way the oil seal, for which he claimed special practical advantages, such as increasing the life of the compressor, also the smoothness, ease, and economy of working. Prof. Ewing objected to the use of the term "efficiency" as against "co-efficient of performance," and perhaps the latter was to be preferred; but he thought there was no possibility of doubt as to the meaning, which he took was the principal object to be aimed at. Prof. Ewing was not altogether guiltless in this respect himself, and he would recommend for his consideration Dr Hampson's remarks in his communication regarding the proper use of the terms "regenerator" and "interchanger." With regard to his entropy diagram of carbonic acid,

Mr T. R. Murray.

he was aware that it differed slightly from that of Dr Mollier, but he had been unable to find any error in his calculations, and as he had explained in his paper the method he used and the data from which he worked, it was open to any one to check his results, and he should be very pleased indeed to have any error pointed out. Regarding the method of obtaining a refrigerating effect from carbonic acid when the upper limit of temperature exceeded the critical point, Prof. Ewing correctly pointed out that the superheating of the vapour did not necessarily require to take place in the refrigerating coils, but might be done in the compressor. As to scientific experimental tests of dry compression ammonia machines, he would refer him to the very complete series by Prof. Denton, published in the American translation of "Ledoux's Ice-making Machines." Comparative tests of any value under actual working conditions were not so easily obtained, but there was one installation in London peculiarly adapted for such a purpose. That was a large cold storage plant, where the first machine placed was of the "wet" compression Linde type. A second machine of the De La Vergne type was afterwards installed, and as both these machines were arranged so that they could be worked on to the same expansion pipes, and driven by the same gas engine, an exceptional opportunity was afforded for comparison. He might say that tests had already been made, which showed a very marked economy indeed in the De La Vergne machine as against the Linde. He had no doubt that facilities for testing that plant could be obtained by Prof. Ewing if desired. The result would probably enable him to more fully appreciate the advantages of oil injection in actual practice. As a tangible result of the above, he might perhaps be permitted to state that the Company owning that plant had since placed an order for two 40-ton De La Vergne machines for their new stores in Liverpool. He was pleased to note Mr Birkett's corroboration of his views regarding "direct expansion" as against "brine circulation." As a refrigerating expert of long and varied experience his opinion was of value. Dr Hampson's communication was a valuable

Mr T. R. Murray.

addition to the literature of refrigeration, recording as it did for the first time his most recent successes in the production of excessively low temperatures, and he would heartily congratulate him on the magnificent results obtained. A glance at the comparative table of results obtained by his apparatus as against Prof. Linde's, which was the only other one of similar type, showed clearly the very marked superiority of Dr Hampson's in every respect. His (Dr Hampson's) references to the comparative advantages of "wet" compression of ammonia, and of "dry" compression with oil injection, gave valuable support to what he stated on that subject. Mr Bost seemed disappointed that he did not give more space to the subject of insulation, but if Mr Bost looked over his paper again, he would find that it was distinctly stated that the methods and arrangements in connection with the various applications of refrigeration were outside the scope of present consideration. Insulation was naturally of prime importance, and no one conversant with refrigeration could think otherwise, but he strictly confined himself to the consideration of the methods and machinery for removing heat, and could not possibly consider in detail the methods and means requisite to prevent the heat leaking back again. He might state, however, that his firm had carried out insulations with Mr Bost's charcoal, and not only one, but many insulations with still air; and the latter had been so successful that now his firm in all cases gave it the preference. Mr Bost would also note that Mr J. Wemyss Anderson, whose statement he quoted as to the value of good insulation, had also come to the conclusion that still air was best. Prof. Jamieson also showed, in his record of tests on the thermal conductivities of heat insulators, that he found dry still air to be the standard of highest efficiency. Mr Harman, in his remarks, referred to complications in the application of an oil seal, and difficulties in overhauling the compressor; but these were entirely imaginary, and an examination of Fig 18, which was a section through a De La Vergne compressor, would show that the removal and examination of all the valves and working parts could be effected in the simplest possible manner, without interfering

Mr T. R. Murray.

with a single pipe or connection. In practice the oil kept everything working so well that it was a very unusual thing indeed to have to even examine a valve. Mr Harman stated that if other makers of refrigerating machines considered oil circulation an advantage they would not be long in adopting it, but he would remind him that there were certain difficulties to get over connected with patents that probably accounted for their consideration. Such difficulties did not exist in connection with the type of machine with which Mr Harman was associated, and unless convinced of the valuable advantages in connection with oil circulation, the makers of the latter type of machine would not be slow in abandoning it for the older and cheaper form. Again, regarding Mr Harman's remarks about the slight importance of packing in a steam engine, he did not think many engineers would agree with him, as an amount of power could be wasted with tight packing that was very appreciable indeed. He would thank Mr Howat for giving the results of his experience in that direction, and would ask Mr Harman to carefully study Mr Howat's remarks. Mr Harman also referred to the use of air circulation for cooling chambers, thus keeping the piping entirely outside. That was in some cases an advantage, though more costly in working, and was an arrangement his firm also used when rendered desirable by special circumstances. He would thank Prof. Jamieson for his appreciative remarks and for placing his insulation tests on record in the Transactions. The subject of insulation was, however, as already stated, much too wide to attempt to deal with in the present discussion. Mr Tidd, in his remarks, seemed to have somewhat mistaken the position he had taken up with regard to the carbonic anhydride machine. He was quite aware, and had so stated in his paper, that that machine had met with a considerable amount of application in this country, especially for ship use, and he would congratulate the manufacturers for their capabilities as salesmen. But he would point out that, as compared with the number of machines in use all over the world, the carbonic acid machine was in a very small minority indeed. In America, where

Mr T. B. Murray.

there was far more refrigerating done than in any other part of the world, it was practically unknown. He had shown in his diagrams the reason for this, and Mr Tidd did not seem to be able to controvert that reason in the slightest way. Mr Tidd acknowledged that the old cold-air machine, on account of its comparative inefficiency, had to abandon the field in favour of the more modern type, and he was inclined to think that practice was bearing out theory on somewhat the same lines as regarded carbonic anhydride and ammonia. The only reliable comparative tests of the two different types of machine with high temperature condensing water of which he had been able to find particulars, were those of Prof. Linde, referred to in his paper, and if the supporters of the carbonic anhydride machine could controvert those and show him where his calculations and diagrams were wrong, he would be very pleased to reconsider his position on that question. In the meantime, Mr Tidd had given nothing in the way of data, except a vague statement that with water at a temperature of 86° Fah., the carbonic anhydride machine lost only from 15 to 20 per cent. of its efficiency as compared with water at ordinary temperatures in this climate. It would be necessary to bring proofs, and to show how it was possible to reconcile that with all former knowledge of the subject, before such a statement could be accepted as accurate. Regarding Mr Tidd's reference to Mr Donaldson's paper, read before the Institute of Civil Engineers, the figures given, which by the way were 74 H.P. for the carbonic acid machine instead of 72 as stated by Mr Tidd, were not in the remotest manner intended to convey that the same amount of refrigeration was being done in both cases. Mr Donaldson only gave those figures as part of a descriptive sketch of the various installations under his charge, and took care to safeguard himself by stating that the conditions of working at the various stores varied so much that practically no such comparison was possible. With reference to the remarks as to possible danger in using ammonia as compared with carbonic acid, it was only necessary to refer to Fig. 6, when it would be seen that the pressures in the latter case were about six times greater than with ammonia. As a matter of fact, in all his experience of ammonia machines he had not known one single case of any accident such as Mr Tidd referred to, nor had he known of any man being hurt with ammonia, and personally he would much rather work with ammonia at 120 lbs. pressure than with carbonic acid at 800 lbs., these being the average pressures in both cases with a moderate temperature of condensing water.

The CHAIRMAN considered Mr Murray's contribution was one of the most carefully thought-out papers that had been laid before the Institution during the session, or, indeed, for several sessions. It showed very great research and an extreme amount of care.

On the motion of the Chairman, Mr Murray was awarded a vote of thanks for his paper.

BASIC REFINED STEEL ON THE CONTINENT.

By Mr C. E. STROMEYER, Member.

Held as read 21st December, 1897.

MY opportunities for studying what I have ventured to call Basic Refined steel, and comparing it with acid steel, have been exceptionably favourable and extensive, both in English, German, Austrian, and Belgian works; and I believe that this experience may help to familiarise the members of this Institution with a material which has proved itself equal, if not superior, to steel made in this country. Although it is produced in a basic furnace, I do not wish to class it with the two other basic qualities which are made, respectively, in a Thomas (basic) converter or in a basic open-hearth, because these two qualities have not earned for themselves in this country a good reputation in shipbuilding yards and boiler shops. In fact, the word "basic," when applied to steel, is to many ears but another name for "rotten." To tell shipbuilders in this country that German ships and boilers are almost exclusively built of "basic" steel awakens their curiosity, but to volunteer the further information, that failures with such plates are rare, is to court being classed as a romancer.

Although the details of the manufacture of acid steel are sufficiently well known in this district, it will be necessary to refer to them occasionally; and as there are three basic processes, and not merely two as is generally supposed, they will have to be discussed somewhat in detail.

The object of Messrs Thomas and Gilchrist, in their invention, was the removal of the phosphorus out of the pig iron during the time that it was being converted into steel, and the commercial success of their process was due to the fact that many iron ores and the resultant pig irons contain large percentages of phosphorus, which, if allowed to remain in the steel, as it would do in any acid furnace, would make the steel cold short. It was the removal of a comparatively large amount of phosphorus, say two or three per cent., which they aimed at; and for distinction's sake, the methods recommended by them will be called Thomas-Bessemer and Thomas open-hearth processes, while the third one will in this paper be called the basic refining process. The last named is in many respects very similar to that of the Thomas open-hearth, because an open-hearth with a basic lining has to be used, but with this difference, that the materials with which such a furnace is charged are nearly, if not quite, as free from phosphorus as those which are used in the acid open-hearth. In fact, as will be explained further on, acid steel is sometimes passed through the basic furnace in order still further to refine it.

When Mr Henry Bessemer invented his now famous converter, it was believed that the rise of temperature in the molten metal was chiefly due to the combustion of the combined carbon, but recent investigations show that a charge of pure cast-iron, *i.e.*, one composed only of iron and carbon, would blow cold, whereas, if it contains a large percentage of silicon, the melting temperature of steel could easily be reached. Cast-iron intended for this process is therefore made to contain such silicon, and is commercially known as Bessemer pig. When the two elements, carbon and silicon, are present in large quantities, they do not continuously burn away at the same rate, although just when the blowing operation is completing they both disappear together, so that, although the spectroscope can give no indications as to the presence or absence of silicon, the necessary information is obtained by watching the carbon lines. When they disappear, both the carbon and silicon have been burnt out; but not so the phosphorus, which does not commence to burn, or only to a very slight extent, until the carbon has disappeared, and as it also gives no indications in the spectroscope, the attendant in charge of the converter has to proceed as follows:—He is first of all supplied with the results of the chemical analysis of the pig iron to be used, which tells him the relative proportion of carbon to phosphorus; as soon as the blowing engine is started he counts its revolutions, and notes their number at the instant when the carbon lines disappear, a very simple proportion will then tell him how many more revolutions are required to consume all the phosphorus, and when they have been completed he stops the engine, for the process is practically finished, except that the ferro manganese, etc., have to be added. Unfortunately for the final product, the information obtained from the chemist is never quite reliable, more particularly if the pig is run direct from the blast furnace without the use of a mixer, and naturally therefore the duration of the second blow is never quite the right one. If stopped too early, all the phosphorus will not have been removed, and the resultant steel will be cold short; if continued too long the oxygen in the blast will attack the iron, and a large percentage of the oxide formed will dissolve in the metal, giving to it some of the objectionable qualities of burnt iron. This uncertainty as regards obtaining a material of a definite composition is evidently one of the reasons why Thomas-Bessemer steel cannot be used for ships and boilers. It is well known that the combustion of the phosphorus in iron will only take place in the presence of a basic slag, and for this reason a large quantity of lime has to be added to each Thomas-Bessemer charge.

It appears, that at a white heat, silicon and carbon are chemically stronger than phosphorus, they therefore are the first to combine with the oxygen of the air, which is blown through the molten metal; the carbon oxide being volatile, escapes, while the silica combines with any basic substance at hand. In the acid converter it combines with oxide of iron, and in the Thomas converter with the lime of the slag, or the magnesia of the lining. In order therefore that the latter, which is very expensive, shall not be wasted away in this manner, Thomas pig is made to contain little silicon; and as the combustion of carbon supplies practically no heat, the percentage of phosphorus should be a high one, for the combustion of this element, like silicon, also supplies much heat.

The calorific values are:—Carbon, 4,340, calories, (Fah.); silicon, 14,000; phosphorus, 21,000; but from these very substantial deductions have to be made, not only because of the heat escaping with the white hot gases, which weigh seven and a half times as much as the carbon burnt, four and a half times as much as the silicon, and eleven times as much as the phosphorus, but also because of the heat required for tearing either of these elements from the iron with which it is combined. Some heat is, of course, generated by the combination of the silica and phosphoric acid with the lime. It is thus seen that the percentage of phosphorus must be at least equal to that part of the silicon which has been kept out of the pig, otherwise the charge will blow cold; and the general practice is to make it about two and a half per cent. In districts where the phosphoric ores are not sufficiently rich, the necessary heat has to be supplied by melting and heating the pig in an open-hearth instead of in a cupola, otherwise the metal in the converter loses its fluidity when it approaches to the qualities of mild steel. It then gets lumpy, which can be noticed by the jerkiness of the flame, and the process has to be stopped before all the phosphorus has been extracted. It thus strangely enough appears that the original amount of phosphorus must be high in order that none may remain in the finished Thomas-Bessemer steel.

The contact of the highly-phosphoric slag with the molten steel is another trouble. From what has already been said about the antagonism or rivalry between silicon and phosphorus, it will readily be understood that the two, finding themselves together in the slag, do not live in perfect harmony. Silicon appropriates to itself, firstly, rather more than its own weight of oxygen, forming silica, and in addition about nine times its own weight of lime, whereas the phosphorus is not allowed to take any oxygen while silicon is in the metal, and the phosphoric acid formed is only allowed to join itself to any excess lime, every pound of which will absorb up to one quarter of a pound of the acid; or, in other words, ten pounds of lime are required for every one pound of phosphorus in the pig. Even then a small quantity of phosphorus remains in the molten steel, a rough estimate fixing it at one-twentieth per cent., when the superimposed slag contains twenty per cent. of silica and phosphoric acid. But this is only true for very mild steel of less than twenty-five tons tenacity, which is practically pure iron. As has already been remarked, carbon has a greater affinity than phosphorus for oxygen. If, therefore, ferro-manganese, with its high per centage of carbon, is thrown into a charge of mild Thomas steel, it first comes in contact with the phosphoric slag, for it naturally floats on the surface of the steel, and an exchange takes place; the carbon and manganese combine with the oxygen of the phosphoric acid, while the phosphorus in parting with its oxygen, leaves the lime and enters the steel. For this reason some works run off the greater part of the slag, and throw in more lime before introducing the ferro manganese. Others do not add this alloy until the steel is being run into the ladle, in which case there is of course the danger of getting it irregularly distributed.

These remarks apply to both the Thomas Bessemer and open-hearth processes, and it will thus be seen that they are not particularly well suited for a material like ship and boiler steel, which must contain a relatively high percentage of carbon. Enquiries into the manufacture and behaviour of the first named material having awakened my curiosity, an ingot of a high carbon Thomas-Bessemer charge was cast and rolled into a plate 8 feet long, 3 feet wide, and ½-inch thick, which was cut up into about sixty test pieces intended for various experiments, including punching, drifting, flanging, riveting, etc., but the following, and a few other preliminary tests, showed the material to be thoroughly unreliable, so that the other experiments were abandoned.

Four of the six tensile pieces were analysed, and showed the carbon to be 0·145 per cent., manganese 0·60 per cent., silicon a trace, phosphorus varied from 0·057 to 0·095 per cent. Two temper bends were good. Twelve cold bends with sheared edges were all bad, many were quite brittle. Some samples were punched and bent, they cracked, not at the hole, but at the sheared edges. The most curious result was obtained with two tensile test pieces which were first planed on their edges, and then each had a hole drilled into it. In one sample tested lengthways, it elongated from ·81 of an inch diam. to 1·05 inches, and tore through the hole with a crystalline fracture at a stress of 30 tons per square inch. The other sample, with the fibre crossways, elongated its hole from ·81 of an inch to ·98 of an inch, and broke with a crystalline fracture, *not through the drilled hole, but one quarter of an inch away from it.* The maximum stress was 30 tons on the section of the metal on either side of the hole, and at the fracture it was much less. It will be admitted that a material which fulfils, or nearly fulfils, the usual conditions as to tenacity, elongation and tempered bends, and then fractures in the testing machine at the side of a drilled hole, and which besides will not bend cold, is not suitable for ships and boilers, even if, as might be possible, only one out of a hundred charges were to behave in the same erratic manner. As nothing more could be learned by further experiments, these were not continued.

Table I.—Thomas-Bessemer steel plate half-inch thick.

Position of sample.	Edge of Plate.		Centre of Plate.			
In Ingot.	Lengthways.		Lengthways.		Crossways.	
	Stress.	Elongation.	Stress.	Elongation.	Stress.	Elongation.
	Tons per sq. inch.	Per cent. in 8 ins.	Tons per sq. inch.	Per cent in 8 ins.	Tons per sq. inch.	Per cent. in 8 ins.
Top end	26·4	24	25·8	5*	29·5	20½
Bottom end	26·4	23	28·5	19	28·4	23

**Note.*—This sample broke with a crystalline fracture.

The Thomas open-hearth process, lasting almost as many hours as it takes minutes to blow a Bessemer charge, naturally affords better opportunities for improving the steel, and it must be admitted that good results have been obtained, but the presence of the highly phosphoric slag, which in volume is sometimes equal to the metal, must always be a source of great anxiety, so that a reliable material can only be produced by the most diligent attention, and this cannot always be expected. The subject will be better understood, by comparing the Thomas open-hearth with the acid open hearth. Both are producers, which is not the case with a converter. The ore which is used for the purpose of oxidising the carbon, loses its oxygen, while the iron thus formed increases the weight of the charge, and if there were no other losses, this increase would amount to from three to three and a half per cent., for every one per cent. of carbon, silicon, and phosphorus originally contained in the pig. Thus, if they sum up to five per cent., the ore would add fifteen per cent. pure iron, making a total of one hundred and ten per cent. instead of only ninety-five per cent. as in a converter. But this idea cannot be thoroughly carried out in the acid open-hearth, because the ore may not be introduced until the pig-iron has been melted, and by that time the greater part of the carbon and silicon will have been oxidised by the flames, and are therefore not available for the reduction of the iron ore, which, if it had been introduced at first, would have dissolved the silica bottom of the open-hearth, and the life of the furnace would thus be materially shortened. Iron ore (oxide) being a basic substance, would, of course, eat into the furnace sides above the molten metal, it is therefore added to the slag only in small quantities at a time, and is then quickly converted into iron by the carbon and silicon in the steel, but when these have been reduced to small percentages, the oxidising action of the flame makes itself disagreeably felt, through the superimposed slag, by burning, and of course wasting the steel, even while it still contains carbon. Thus, when a very mild quality of steel with little carbon is aimed at, the acid open-hearth is clearly not a producer, but a waster. The large amount of iron oxide which would under such conditions exist in the slag must seriously injure the lining of the open-hearth and shorten its life, and it is thus quite clear that the acid open-hearth is not suited for turning out the very mildest qualities of steel; in fact, its natural product is a material of from 25 to 30 tons tenacity, and doubtless for this reason these were the limits originally fixed upon for ship and boiler steel.

In the Thomas open-hearth the conditions are, as it were, reversed, the furnace lining being basic, is not attacked by iron ores, and these may therefore be charged with the pig, and the chemical reaction between the two can proceed undisturbed, because they are well covered with a large quantity of lime, which has to be introduced early so as to absorb the silica as it is formed. The weight of the steel is therefore materially increased by the addition of ores, which may even be present in excess without loss to the charge, for the slag, being very thick, permits of no chemical action on the part of the flames. It is thus possible to extract practically every trace of carbon, and the resultant steel, or rather pure iron, is now largely used for dynamo magnets. The natural product of such a furnace is a very mild steel of less than 25 tons tenacity. As soon as an attempt is made to increase the tensile strength, by the necessary additions of ferro manganese, the danger is at once incurred of reintroducing phosphorus from the slag into the steel. The Thomas open-hearth process does not depend for its heat on the combustion of silicon and phosphorus, as is the case in the converter, the pig to be used need therefore not necessarily contain much of the latter element, but the silicon should of course be low, so as not to injure the furnace lining, and also because it would prevent the phosphorus from leaving the metal. As both silicon and phosphorus require ten times their weight of lime, one per cent. of either element in the pig has to be neutralised by about 30 per cent. (volume) of lime.

It is almost needless to say that the basic open-hearth has troubles peculiarly its own. One, which is frequently mentioned, is that the lime dust settles on the gannister roof and in the air passages, and, under the influence of the prevailing white heat, eats away the silica bricks. Occasionally sufficient heat penetrates to the boundary between the dolomite lining and the gannister surroundings, the two substances of course combine, and forming a very fluid slag, eat their way further down. The channels thus formed are generally deep and sometimes quite narrow like mouse holes, at other times they are very large and destroy the furnace. I was fortunate enough to witness two such mishaps after dark, and a grander sight cannot easily be imagined. The first warning was given by the appearance of a red hot patch at a point about four feet away from the furnace mouth. Before the ladle could be placed in position and the furnace tapped, one furnace side had melted through, and the white hot steel and slag burst out, forming several cascades, which melted many of the cast iron columns of the surrounding stages as if they had been made of ice, the molten mass then spread itself out in front of the furnace. Nobody was hurt, but, in the anxiety to break up the escaped steel before it got cold and hard, the strong overhead travelling crane was called into requisition, and was made to pull in a slanting direction, until the shed gave unmistakeable signs that it, the crane and the roof were going to fall on top of us. The second accident was not so serious, half the charge being tapped into the ladle.

After these preliminary remarks, it will be easier to explain in how far the basic refining process differs from that of the Thomas open-hearth. The same furnaces are used, but instead of charging much phosphoric pig iron, a little scrap, much lime and the necessary amount of iron ore, the refining furnace takes at most twenty-five per cent. pure pig, seventy-five per cent. scrap, very little lime, and no iron ore; for as the layer of slag (lime) is thin, the flame readily oxidises the carbon in the pig iron. The pig is, in fact, necessary to balance this reducing action, as well as to prevent the cold scrap from coming into contact with the white hot basic bottom, which would thereby be seriously injured. Soon after the charge is melted, it is found to have been refined to almost pure iron, the carbon and silicon of the pig, as well as the small percentage of phosphorus in the whole charge having disappeared. Several of the charges which passed through my hands contained less than 0·01 per cent of phosphorus. The pig iron intended for this furnace is neither a Bessemer pig, for it contains little silicon, nor a Thomas pig, for it contains little phosphorus. The scrap may be either iron or steel, the only condition with all these materials being that they shall not contain much sulphur, for this is not extracted by the basic refining process. Sulphur, when it exists alone in steel, is not nearly so injurious as when it occurs combined with phosphorus, for these two elements seem to react on each other, and to intensify their respective bad influences, while manganese, as is well known, produces the opposite effect. There being few impurities in the charge to begin with, it is not necessary to add much lime for their absorption, but even the little which is thrown into the furnace, and which is required as a protection for the iron from the flame, is in excess of the chemical requirements; the steel is therefore in contact with a slag containing very little phosphorus, and there is practically no danger of reintroducing this element when the ferro manganese is added. It will thus be seen that although the natural product of the basic refining furnace is a mild steel, or a pure iron, it is also capable of turning out a pure material with a high percentage of carbon. Among upwards of fifty charges made by this process and tested by me in every conceivable way, none were unsatisfactory, either as regards obtaining a definite quality (it seemed possible to work within one ton) or as regards their behaviour under the severest mechanical treatments. These latter included not only the ordinary tensile and temper bending tests, but also tensile and bending tests of sheared, punched, drilled, annealed, tempered samples, drifting tests, and such manipulations as doubling up imitation treble riveted single butt joints, doubling up or flattening out Z beams formed by riveting together two angles, four folding plates with or without a punched hole in its centre, and also several severe forge tests, particularly as regards welding.

Steel producers in this country who find it difficult to obtain even sufficient scrap for the acid open-hearth, will doubtless wonder where their continental competitors obtain the very much larger quantities required by the process under consideration. There is of course this difference :—Scrap for the acid furnace must be pure; it may neither be red short nor cold short; it must contain neither much sulphur nor much phosphorus. Scrap for the basic refining furnace ought not to be red short, but it may be quite cold short; in fact, the worse it is in this respect the smaller will be its percentage of sulphur, for when both it and the phosphorus are high, it is practically impossible to make anything of such steel or iron, which therefore never finds its way into the market nor thence into the scrap heap. When the phosphorus is high, the amount of lime has to be increased, but not at all to the same extent as in the Thomas open-hearth. In spite of this advantage, there can be no doubt that continental steel makers have for years past been confined to using newly manufactured scrap; about fifteen per cent. are returned from the plate shears, and sixty per cent. have to be got elsewhere. In one district where the Thomas converter was in full swing, producing rails, beams, and sleepers, large quantities of very serviceable scrap with about one tenth per cent. phosphorous could be got, but only as long as trade was brisk. When, as sometimes happens, the Thomas converters are lying idle, while the basic refining furnaces have plenty of orders, it has been found necessary to charge the latter with ingots from the Thomas works. I was unable to ascertain whether these contained the usual admixture of ferro manganese, but in case the practice was carried out systematically, it would not only be costly, but would increase the percentage of phosphorus if such addition was made. Considerable trouble seems also to have been experienced in charging the open-hearths with these heavy converter ingots, for they melted slowly, and, being cold, affected the lining. It would of course be an easy matter to cast smaller ingots, and instead of charging them cold they could be stored in soaking pits.

The charging of some of the continental open-hearths is done by mechanical means, and although this is a great relief to the men, particularly during their very hot summers, little or no time is saved, because the scrap can be introduced faster than it melts. Pig iron of course melts more easily.

In districts where scrap is permanently scarce, the idea of manufacturing it regularly is strongly entertained, and strange as it may appear, the puddling furnace is looked upon as the most likely channel for supplying the cheapest and most suitable scrap. The production of a good wrought iron is of course not necessary, and as attention need only be directed towards the removal of silicon, sulphur, and cinder, any mechanical puddler would answer. In America, the rotary furnace is said to have been successfully adopted, and as there steel is manufactured on lines very similar to those followed on the continent, this process is expected soon to be adopted in Europe. At Witkowitz, in Austrian Silesia, the scrap, if one may call it so, is produced in small acid converters, which remove all the silicon, the molten steel or scrap is then run direct into the basic refining hearth, each one requiring about three or four blows to fill it. Six and even seven charges have been got out of these open-hearths in 24 hours. Such refining furnaces will have a long life, and, on account of their many charges, will show a heavy production. The general run of continental furnaces take charges of from 10 to 20 tons, each heat lasting about six hours.

Frequent samples are, of course, taken during the refining process, and its progress is thus ascertained. When all the impurities have been removed, which is effected simply by the excess oxygen of the flames and without the addition of any ores, then the ferro manganese, or perhaps spiegel, is added, and when it has been thoroughly incorporated with the steel the charge is at once tapped, for a delay of one minute effects perceptible reduction both of the carbon and manganese. The mixing is accelerated in some works by poling, but as the charges tested by me were perfectly uniform in quality, although not all treated in this way, it was impossible to say whether the poled steel was better than the other. Instead of using ferro manganese, the necessary carbon was in some works added in the form of charcoal, and no manganese found its way into the steel; the results were said to be highly satisfactory, but it seemed doubtful whether by this means a tenacity of 30 tons could be reached without imparting hardening properties to the steel, and I have been informed that this process is not reliable for ship and boiler steel.

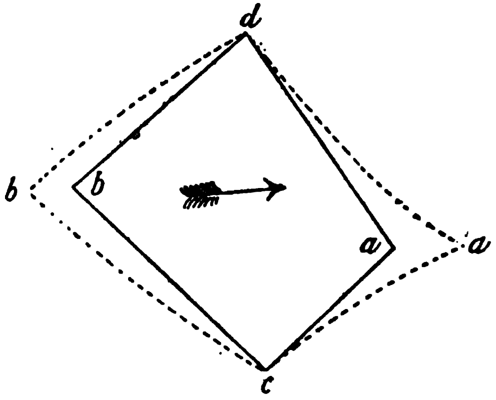
Steel made by any one of the three basic processes is said to contain dissolved oxide of iron, no matter whether the percentage of carbon, due to the final admixture, is low or high, and this oxide is blamed as being the cause of many of the bad qualities of Thomas steel. The suggestion has therefore been made and acted upon of refining the metal in a basic furnace and charging it into an acid open-hearth before adding the carbon. Such a proceeding must be costly, but it is said that the resultant steel is almost as good as that from crucibles. A modification of the idea is perhaps to be found in the following practice:—The metal in a basic refining furnace is raised to an exceptionally high temperature, and is then poured into a ladle lined, as usual, with silica, the ferro manganese being also thrown in; the casting of the ingots is not proceeded with until about a quarter of an hour has elapsed, but always before the metal begins to solidify; this allows plenty of time for the perfect amalgamation of the manganese and carbon, and for the expulsion of the oxide of iron.

As regards further operations on the refined steel, the only points worthy of note are that the ingots are mostly cast from below, about six to twelve at a time. Generally these are then rolled without being hammered. They are cast about twelve to fifteen per cent. heavier than the plates (into which they are to be transformed) will ultimately weigh, and are of about the same proportions as the cogged slabs of our works, *i.e.*, about five to six times as wide as they are thick. These ingots had every appearance of being solid up to the very top, and that the quality was uniform will be seen by a glance at Table II., the distance of those samples marked crossways being only about six inches from the top or bottom end of the plate. Of course the centres of those tested lengthways would be about six inches further away, but those cut from the centre of the plate almost touched it.

It may be as well to mention here, that the ingot moulds were placed in two, or more generally in three, groups, each group being fed by a central stand pipe. After rolling the ingots, six test pieces were cut from one plate of the first (bottom) third of the charge, as well as from one plate of the last (top) third of the charge, three of these test pieces come from the top end of each plate and three pieces from the bottom end of each plate. (See Table II.). In only one of the works were the ingots hammered before rolling, but without reducing them much in size, the main object appearing to be to square them. It was stated that the chemical composition of steel intended to be rolled direct, had to differ somewhat from that intended for the hammer. The unhammered ingots could be rolled into perfect plates, and judging from sketches which were made at the time, it was only amongst the hammered steel that the edges of the plates were at all torn. Possibly hammering was necessary on account of slight red shortness.

Ingots which are neither cogged nor hammered are naturally of tapered form, and if uniformly rolled out, would be converted into plates which would be wider at the one end than the other, and then there would be much waste; but by entering the slabs diagonally into the rolls, and pulling alternately at either of the small corners, they are drawn out until the plate is fairly rectangular.

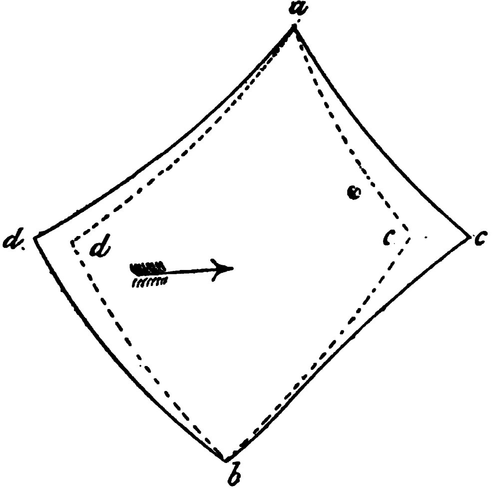
FIG. 1



The black line in Fig. 1 is the shape of the ingot after it has been rolled flat; it is then passed through the rolls in the direction of the arrow. The point *a* is thereby drawn out to a_1, and the sides *ac* and *ad* are stretched slightly concave. The reverse is the case with the other half of the slab, the lines *cb* and *bd* being altered into convex ones, and naturally the distance *aa*, is greater than *bb*. The slab is now turned through an angle of 90°, see Fig. 2, and the corner *c* is drawn out more than the corner *d*, the result being an approximate rectangle with irregularly shaped sides, as shown in black line Fig. 2, which, as the plate grows longer and longer, appear to be almost straight. The rolling is then proceeded with in the ordinary way. By pulling at the corners *b* and *d* the final shape can be made to approximate to that of an end plate of a boiler.

Although the basic refining process is suitable both for mild and

Fig. 2



hard qualities of steel, I was aware that it was the mildest qualities only which were generally made in it, and that there might be some difficulty in obtaining satisfactory results with ship and boiler qualities. Most of the charges intended for testing were therefore arranged to have a tenacity of 31 tons, and some of course exceeded this point a little, yet in all cases the tests were highly satisfactory; in fact, it is doubtful whether any acid open-hearth could produce a steel plate one and three-eigths inches thick, having a tenacity of 31·8 tons per square inch, which would, as did a sample of basic refined steel, stand a temper bending test to a radius of ½-inch, the edges of the sample being left ragged just as they came from the shears. In general it was found that ordinary untempered test pieces of this steel, and plates up to eighteen inches wide and up to half-inch thick could be bent and closed up double even although the sheared edges had not been removed. Three-quarter inch plates, with sheared edges, would stand bending to a radius of one or two inches; the edges of thicker plates had to be planed, but then they would bend and close up double under the steam hammer. The various tortures to which plates and angles from this material were subjected, have already been mentioned, and the tensile tests contained in Table II. may be taken as a fair average example as regards the uniformity attainable.

Table II.—Tensile tests from two half-inch plates from one charge of basic refined steel.

Position of Sample.		Near edge of plate.		Near Centre of Plate.			
		Lengthways.		Lengthways.		Crossways.	
Charge.	Ingot.	Stress	Elongation.	Stress.	Elongation.	Stress.	Elongation
		Tons per sq. inch	Per cent. in 8 ins.	Tons per sq. inch.	Per cent. in 8 ins.	Tons per sq. inch.	Per cent in 8 ins.
Top	Top end	31·4	21	31·6	20	30·6	22
	Bottom end	31·1	21½	31·4	21	31·4	21
Bottom	Top end	31·5	22	30·7	23	30·7	23
	Bottom end	31·7	23	31·7	23½	31·7	22

This material welded perfectly well.

Four annealed samples gave stresses varying from 30·4 to 31·3 tons per square inch, while in four tempered samples the tenacity varied from 43·9 tons to 44·7 tons per square inch. The temper bending tests were all good, two of the samples doubling up close. All the cold bend tests (unannealed) bent up close. In neither case were the sheared edges removed.

A comparison of one plate of Thomas Bessemer steel (see Table I.)

with fifty basic refined charges which were rolled into both thin and thick plates, and which behaved as well as the samples in Table II., confirm the opinion which is universally held on the Continent, that the two steels, although they both go by the name of "basic," cannot, as is done in this country, be classed together. It has been my endeavour to make this clear, and, if possible, to pave the way for the introduction of what I have ventured to call basic refined steel, a material which seems to surpass that produced in the acid open-hearth, and which may perhaps be the stepping stone to higher limits of tenacity, and further reductions of scantlings.

The discussion on this paper took place on 25th January, 1898.

Mr William Cuthill (Member) said that he was in some doubt as to whom the paper really was intended to be addressed. Nominally, of course, it was as stated at the close of the first sentence, "to familiarise the Members of this Institution with a material which had proved itself equal, if not superior, to steel made in this country;" but the reading of the paper led one to think that it was intended rather for steel-makers—the process of manufacture being much more largely the theme than the material itself. That it was not intended for steel-makers, however, was finally proved by that unsympathetic remark on page 235 in describing a melting furnace disaster. There the break-out of a melting-furnace, the melting of columns like ice, and the tumble-down indications of crane and roof, were described as the grandest sight that could be imagined! Turning to the first sentence again, where Mr Stromeyer spoke of his exceptionally favourable and extensive study of English, German, Austrian, and Belgian steel works, it was a pity that his study did not extend to the Scotch works in this locality, and almost at his own door, when this paper was written. There he would have found that such superior steel as he spoke of, and better, had been made regularly by the Steel Company of Scotland for a dozen years at least. He did not say

Mr William Cuthill.

it was made by the basic process at all, but what was of more importance to engineers and shipbuilders, it was steel of the very finest quality, with all the impurities, such as phosphorus, sulphur, and silicon, at the very lowest ebb, while the carbon could be made of any percentage required. It was, of course, more costly to make than ship and boiler steel, and was never employed for these purposes; but no finer steel could be employed for special purposes, where a little extra price could be afforded, and certainly there was no need to go to Germany for it. The following were a few sample analyses of the steel made by the Steel Company of Scotland, with their present respective uses:—

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Carbon, - -	·06	·12	·19	·39	·80
Silicon, - -	·05	·04	·06	·03	·10
Sulphur, - -	·04	·03	·035	·03	·016
Phosphorus, -	·012	·015	·02	·018	·008
Manganese, -	·10	·5	·45	·6	1·00

No. 1.—For electro-magnets, wire, &c.
No. 2.—For boiler tubes.
Nos. 3 & 4.—For special forgings.
No. 5.—For gun wire, &c.

Mr Sinclair Couper (Member) agreed with Mr Cuthill that this was a question for steel-makers, and he was sorry that there were so few present to discuss the paper. With deference to Mr Cuthill, he felt they were very much indebted to Mr Stromeyer for bringing forward what was being done on the Continent. A few years ago a book was put into his hands by a well known firm on the Continent and it was filled with illustrations of flanged work. Some of that work was as intricate as any that had ever been done in this country, and he was informed that it was all made from basic steel. At that time he did not know what kind of basic steel it was, but he concluded, from the name, that it was similar to the material that had been tried in this country—namely, basic Bessemer steel. He

Mr Sinclair Couper.

would like to ask Mr Stromeyer one question. At the foot of page 235, Mr Stromeyer said that the pig iron, intended for the special furnace for making what he called basic refined steel, was "neither a Bessemer pig, for it contains little silicon, nor a Thomas pig, for it contains little phosphorus." It would be interesting to know, then, what kind of pig iron it was. This seemed to be an important point in the manufacture. The question of rolling and the other processes in the manufacture of the material would no doubt be treated by the steel-makers, and he hoped that something might be heard from them.

Mr F. **Finlayson** (Member) asked Mr Stromeyer what proportion of scrap he used in regard to pig iron, and also asked Mr Cuthill whether he got the ·06 of carbon in the Siemens' furnace, or by the basic process.

Mr **Cuthill** thought this was not the place to discuss the process. All the steels in the analysis which he had given were made in the one furnace.

Mr C. E. **Stromeyer** (Member), in reply, said he had hoped that the discussion on water-tube boilers might have been finished at an early hour. The steel-makers had known better than he, and had wisely stayed away, and therefore said nothing; but, as it was not possible for him to return next month, he would reply to the remarks which had been made. His reason for bringing forward the question of basic steel was primarily to raise a discussion. Similar papers had been read in England by Mr Jeremiah Head (on "The American System of Steel-Making," which was very similar to that adopted in Germany and Austria) and in the Cleveland district by Mr P. Gilchrist. It was about the time of the reading of those papers that his paper was written, and he had thought it would be the proper thing to have the whole matter ventilated by the members of the Institution, just as it had been ventilated further south. He had been accused of ignoring the Scotch works. That was not so. He had had few opportunities of visiting them while in this locality, and did not care to introduce hearsay matter; besides, being so near at hand, members would know more about

Mr C. E. Stromeyer.

them than he did. On the other hand, he had visited the Continental Works, and, as far as he could, had given what information there was to be given. He did not mean to say that he had given them all that was to be got, but he had explained as much as he felt at liberty to state. There were many other matters which had come under his notice, but they appeared to be peculiar to certain works; at anyrate he did not see them in use elsewhere, and therefore he did not feel at liberty to divulge what appeared to be secrets any more than Mr Cuthill felt inclined to give the information which had been asked of him that night. He should, however, like to say that, as far as could be judged by Mr Cuthill's analyses, the steels mentioned by him were made by the basic process. Not only did he feel sure that no acid furnace could reduce the carbon to so low a percentage without burning the steel, but if one wished to obtain as low a percentage as ·01 phosphorus from an acid furnace, the price to be paid for the pig and the scrap would be prohibitive Besides, these samples of steel were intended not for boiler plates, but for dynamos, and this quality could easily be made from certain inferior pigs if the basic furnace was used. His paper pointed to the fact that good ship and boiler steel was made by the basic process on the Continent, and he did not see why they should not do the same here. It was a well-known fact that for certain reasons the Germans had to pay no royalty for Siemens' basic furnace, whereas English works had to do so. The result was that several important iron and mild steel trades left this country altogether, but, now that the patents had run out, he did not see why there should not be an attempt made to bring these trades back again. By the raising of a discussion on that subject, he thought steel manufacturers would be led to think over the matter and attempt to deal with it. Mr Cuthill said that he had suggested that they should go to Germany to buy the steel, but that was not the case; on the contrary, he knew that here there was every facility for making steel as well as there was in Germany, and he did not feel at all ashamed of having suggested that attempts at even cheaper and better results should be made

Mr C. E. Stromeyer.

here. In connection with the matter of steel-making, he would like to add that it was a matter of regret that comparatively little time and money were spent by British manufacturers on research Germany had certainly forged ahead on that particular point. As to Mr Finlayson's question regarding the relation of scrap to pig, he had mentioned that in his paper. It was usually 75 per cent. scrap and 25 per cent. pig. In reply to Mr Couper, he could only say that blast-furnace men were able to produce pig iron at will with high or low percentages of carbon, manganese, silicon, phosphorus, etc., but he could not now explain the details of basic furnace work. The basic process was capable of making a useful material, even when using pig with a large amount of phosphorus; and by using very pure pig and scrap the basic furnace enabled them to obtain qualities of steel which could not be produced in the acid furnace. Now that high tenacities were in favour, it was very necessary that the steel should be perfectly pure, or at least as pure as it could be made, and he did not consider that the acid furnace could reduce the phosphorus much below ·04 per cent., unless the very purest and dearest raw materials were used. Taking, however, the commercial materials available, the basic process permitted them to obtain a really high-class high-tenacity steel with ·01 per cent., or less, of phosphorus. In the steel works which he had visited, experimental research was always being carried on. As an instance, he might mention that, on going to one of the works within two months of the reading of a paper by Mr Hadfield, he found that tons and tons of his new alloy had already been produced, which showed that on such slender facts as were contained in the paper German steel-makers at once started to experiment, to see what they could do with that material. Those particular experiments were costly ones. A Siemens' furnace was not always available, but he found on the Continent that researches into the properties of alloys could be carried out cheaply by the judicious employment of crucibles made of gannister, dolomite, or graphite. If it was a question of finding out the influence of metallic admixtures, free from carbon, such as nickel or aluminium, a basic crucible would

Mr C. E. Stromeyer.

be used, which would eliminate nearly all the carbon and phosphorus, and introduce none of the injurious properties of the silicon; and, if a high-carbon material was wanted, it was melted in a graphite crucible. The two or three materials in the various crucibles were then poured together, mixed, and cast. In conclusion, he wished to say that he would have liked to have made his paper more comprehensive, both as regarded the production of steel and also as to the capabilities of the material, but he thought he had said enough to make clear his main point, which was that one should not condemn a steel because it was made by the basic process.

On the motion of the President a vote of thanks was awarded to Mr Stromeyer for his paper.

WATER-TUBE BOILERS.

By Professor W. H. WATKINSON, Wh.Sc.

Professor W. H. WATKINSON, Wh. Sc. (Member), in response to an invitation, exhibited, at the meeting of the Institution on 25th January, 1898, a number of models of water-tube boilers in action. He remarked that the models were intended to show the nature of the circulation in water-tube boilers of different types. It had frequently been urged by those who had not tried experiments themselves, that such experiments being carried out at atmospheric pressure would, of necessity, not show what took place in the actual boiler under working conditions. About three years ago he made experiments at a pressure of 150 lbs. per square inch, and, so far as he could tell, there was no observable difference whatever between the nature of the circulation at that pressure and at atmospheric pressure. He had a model which, if there was time, he would show working at a pressure of 200 lbs. per square inch. This model had a thick plate glass in front of it, so that observations might be made of what was going on without any danger due to a possible fracture of the glass tube. It had also been urged against experiments of this kind that, seeing that they were made with models at rest, they gave no indication as to what happened when a ship was rolling or pitching. Two or three years ago, he robbed the nursery at home of the rocking horse rockers, and had mounted the models on the rockers, causing them to roll under similar conditions to those existing in an actual ship. He found that the circulation was not appreciably interfered with, by rolling, in those models which had their tubes inclined at a considerable angle to the horizontal, but in those cases in which the inclination of the tubes was slight, the direction of the circulation was in some cases reversed. In putting boilers on board ship care had usually to be taken to put them fore and aft instead of athwartships, and when this was done there could be exceedingly little chance of reversal. In making experiments with glass tubes considerable care was necessary to avoid fracture; but with the greatest care fracture would sometimes happen, and it usually happened on an occasion of this kind. Some time ago, immediately after he had read a paper on this subject and had shown the models at the Institution of Naval Architects, he saw a letter in one of the engineering journals, saying, that surely he had by exhibiting his models put the last nail into the coffin of the water-tube boiler, because, from the fracturing of some of the tubes, it was quite evident that the water was driven out of them. He considered the only reasonable conclusion was that glass tubes were not suitable for actual boilers. He then exhibited models of the Babcock & Wilcox, Niclausse, Thornycroft, Yarrow, and other boilers in action. He further showed and explained the apparatus which he had used for determining the ratio of the mass of water circulating in a given time, to the mass evaporated in the same time. This was shown in Fig. 1, and consisted of an upper and a lower drum connected by one downcomer *a b*, and one upcomer, *c d e*. Open-topped guage-columns, g and g^1, were fixed to the upper and lower drums respectively. The column g showed the level of the water in the upper drum, and column g^1 measured the pressure in the lower drum. When circulation was set up, by applying heat to the upcomer, or by admitting air to the lower end of the upcomer, the surface of the water in the column g^1 would fall, and it was evident that the difference between the levels of the water in the two gauge-columns was the head available for circulation if the temperature in the columns had been maintained the same. If the temperature of the water in the columns had not been maintained the same, then a correction had, of course, to be be made on that account. As the corrected difference of levels was the head available for circulation, the velocity of flow through the downcomer was proportional to the square root of the corrected difference of level. The mass of water that flowed through the downcomer per second was

$$= \sqrt{2gh} \times A \times C \times M \text{ lbs.}$$

h, being the corrected difference of levels in feet.
A, the area of downcomer in square feet.
C, the co-efficient of discharge for the pipe.
M, the mass of one cubic foot of water in lbs.

In the experiments which he had made, in order to eliminate possible errors in the determinations of A, M, and C, he had disconnected the upcomer *d e*, plugged the hole *e*, and then syphoned hot water into the upper drum, allowing it to flow out of an adjustable orifice at *d*. By adjusting the size of the orifice at *d*, it was possible to reproduce any deflection of the gauge-column g^1 which had been obtained in the ordinary experiments. By proceeding in this way, and weighing the water which flowed out at *d*, he had been able to determine very accurately the mass of water flowing through the downcomer per second, for different deflections in the gauge column g^1. In that way he had found that the ratio of the mass of water circulating per second, to the mass evaporated per second, varied in the model, at the usual rates of working, from about $\frac{50}{1}$ to about $\frac{250}{1}$ according to the size of downcomer used. When the latter value was obtained, the area of the downcomer was approximately equal to the area of the upcomer. He had also used the same model in order to determine whether there was any gain in the velocity of the circulating-water due to discharging that water above the water level into the upper drum. In order that that might be done there was a tube in the upper drum of the same diameter as the upcomer, which could be quickly attached to, and detached from, the end of the upcomer, by means of a handle projecting through the upper surface of the drum. That tube and its handle were shown by dotted lines in the figure. He had found that when the usual ratio of area of upcomer to area of downcomer was adopted, there appeared to be a gain of 3 or 4 per cent.

in favour of the above-water discharge. Professor Watkinson then showed two of Mr Yarrow's experiments, the apparatus used for

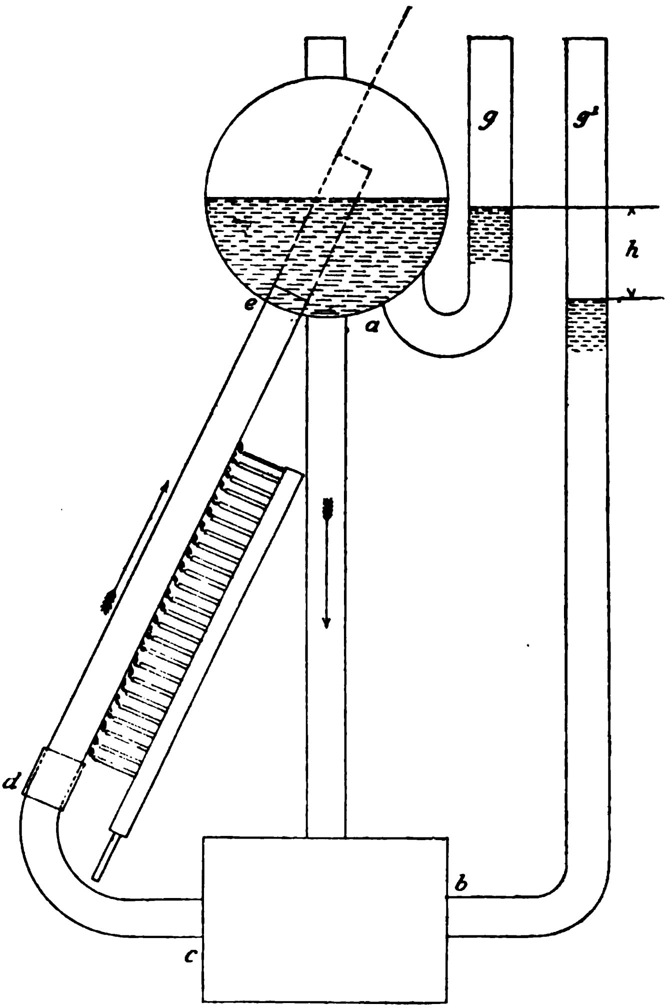


Fig. 1.

this purpose being illustrated in Figs. 2 and 3. Oxygen gas was caused to flow from an oxygen cylinder into the U tube at *a*, Fig. 2.

Circulation was in this way started in the direction of the arrows. Oxygen was then similarly admitted at *b*, and it was noted that the flow continued in the same direction as before, but at an increased

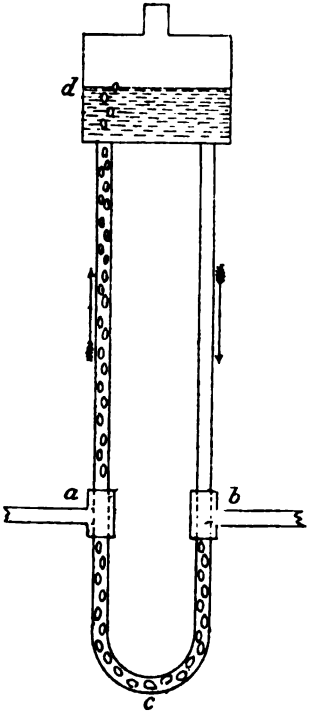


Fig. 2.

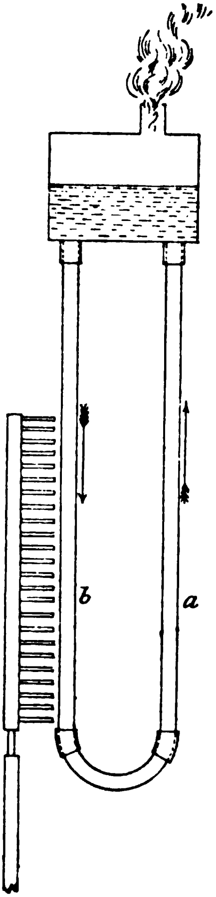


Fig. 3.

velocity. The supply at *a* was then cut off, and the flow still continued in the direction of the arrows. The action in that case, he said, was somewhat similar to the action in an ordinary syphon, *cd* and *cb* being the longer and shorter legs respectively. A certain amount of work had to be done in pushing the gas from the level *b* to the level *c*, but this gas did more work in rising from the level *c* to the level *d*, and there was, therefore, a surplus of energy available for maintaining the flow in the direction of the arrows when it had once been started in that direction. If the rate of admission of gas was increased beyond a certain limit, reversal of the direction of flow would take place. The analogous experiment with steam was made at atmospheric pressure, as illustrated by Fig. 3. Heat was first applied to the leg *a* of the U tube, and the circulation started in the direction of the arrows. When steam was being given off freely, the leg *b* was heated by the Bunsen burners shown. It was noted that the velocity of flow was greater than when the leg *a* only was heated. The flames were then entirely removed from the leg *a*, and the heat applied to the leg *b* only. The circulation continued in the direction of the arrows, and it appeared to be quite as stable as in the experiment with oxygen. He stated that in the case of steam the action might be explained in the same way as in the case of oxygen gas, but with steam there was the additional advantage, due to the increase in the boiling point of the water as it flowed down the leg *b*, on account of the increased pressure of the water at the greater depths below the surface of the water in the drum, and the corresponding reduction in the boiling point of the water as it flowed up the leg *a*. It had been erroneously stated that this experiment could not be made at atmospheric pressure, and that it could only be made satisfactorily at pressures above fifty pounds per square inch. Prior to reading that statement, he had always made the experiment at atmospheric pressure, but immediately after reading it he had tried the experiment with the steam drum connected to a condenser, and at the lowest pressure he could obtain; viz., about 26 inches below atmospheric pressure, by the mercury column vacuum-gauge, the vacuum-gauge being connected directly to the steam drum, there was no more difficulty in making the experiment than at atmospheric pressure. Since then he had frequently made the experiment, at pressures varying from about 2 lbs. absolute up to 185 lbs. absolute, and he had never found any more difficulty in making the experiment at low pressures than at high pressures. He had always maintained that experiments carried out at atmospheric pressure would give approximately the same results as experiments at any other pressure, provided the simple and obvious rule were observed, that the volume of the steam, and not the mass, generated in a given time, must be the same in the parallel experiments, in order that the results might be comparable. When experimenting with the apparatus shown in Fig. 3, and when heat was being applied to both legs of the U tube, it was found that, if from any cause the flow was momentarily interrupted, the circulation could not re-establish itself; both legs tried to act as upcomers; they soon became nearly filled with coarse foam; and the only supply of water was due to some falling down into the legs through that foam. The water in the bend at the bottom of the U tube under these conditions remained almost stationary, its direction of motion being alternating, and through a very small range. The prolongation of one of the legs in order to make the discharge take place from that leg above the water level, was not usually sufficient to cause the circulation to be restarted, so long as the application of heat to both legs continued.

A vote of thanks was passed to Professor Watkinson for the exhibition of his models.

THE CAUSES OF COLLAPSE IN MARINE BOILER FURNACES.

By Mr Wm. R. Austin (Member).

(SEE PLATE XIII.)

Held as read January 25th, 1898.

The collapse of a vessel's boiler furnaces is always a serious affair from the shipowner's point of view. If they require renewal, the cost may amount to a claim against the underwriters; but the loss caused by the detention of the ship has frequently to be borne by the owner. No matter how it is considered, the underwriter or owner, or probably both, lose by such an accident.

Where furnaces have collapsed to only a slight extent, and have been set fair again, there is on the part of those in charge a certain amount of anxiety as to whether they will give further trouble. This is only natural, as there can be little doubt that under conditions similar to those which caused collapse in the first instance, such a furnace has not the same strength to resist pressure tending to collapse it a second time. Nevertheless, furnaces which have collapsed and been made fair, have frequently worked well for a considerable length of time.

Those whose duty it is to survey the boilers of steam vessels will acknowledge that the furnace is the part which most frequently comes under repair in consequence of injury. It will also be apparent that of the many accidents which occur only a few cases can be satisfactorily accounted for. In the large majority of failures subsequent examination does not reveal any visible cause, and from the instances which have come under my notice, I estimate that in quite 70 per cent. of these accidents no cause has been assigned for the collapse.

By some, an accident of this kind may be attributed to weakness. If the furnaces were old or much wasted from corrosion such a contention might hold good, but new furnaces, on which there is no deterioration, often give trouble, and seeing that they do not become permanently deformed under hydraulic pressure until between five and six times the working pressure is attained, such a thought as weakness, in the ordinary acceptation of the word, may be dismissed. Nor is it any particular type which is more liable to collapse than another. So far as I have seen, Fox's, Purves', Morison's and plain furnaces all seem to yield in the same way, and at the same place; viz., at the part of the circumference immediately above the fire.

From what I have said respecting hydraulic tests, it will be granted that furnaces possess ample strength, and, as collapse always takes place above the fire, the inference is only reasonable that over-heating of the plate at the furnace crown is in all cases the cause of these accidents.

In what follows, I will in a few words set down the known and assumed causes of collapse, and afterwards mention a theory which I consider may account for some cases of collapse which have hitherto been unexplained.

The causes generally assigned are:—

(1) Excessive deposit of scale on the furnace crowns.

(2) Grease deposited on the furnace crowns.

(3) Absence of water from the boiler.

(4) Oxide falling from zinc plates placed above the furnaces.

The first of these is one that can be readily prevented by having the boiler opened and cleaned at certain intervals, or by fitting an evaporator, which would not only save the expense and delay of cleaning, but also enhance the efficiency of the boiler by keeping excessive scale from the heating surfaces. When carefully and regularly worked, an evaporator will repay the ship-owner its cost in a very short time.

The second cause is one of which I have often heard, but in none of the accidents which have come under my notice has a vestige of greasy deposit been found on, or close to, the part of the crown which had collapsed. On the other hand I have seen boilers, where the internal parts, with the exception of the furnace crowns and other effective heating surfaces, were actually covered with grease, and the furnaces were in perfect condition.

I am aware that some engineers have formed very decided opinions on the collapse of furnaces, always assigning the blame to the necessary though objectionable lubricant; and, on examining a boiler after an accident, they say that the fine dust found on the furnace crowns is oil which has become carbonized by over-heating. Now it will be evident to many that, if the dust so found is oil carbonized, it becomes difficult to explain how this takes place, for in hundreds of boilers dust of this kind may be gathered from the steam-space in large quantities, when there has been no over-heating. I am therefore of opinion that the dust found on a furnace crown after an accident from over-heating, is not the remains of oil deposited there before the accident, but the ordinary impurities in the water reduced to a minute state of sub-division, and deposited on the crown when circulation had stopped, and the water was run out of the boiler. When the matter is carefully considered, it will be found well nigh impossible for oil to lodge on furnace crowns or combustion chamber tops under ordinary working conditions. If we assume that oil gets into the boiler and circulates with the water, the surfaces to which it must naturally adhere are the sides of the shell, the under side of the furnaces, the under sides of the smoke tubes, and the longitudinal stays at the water level of the boiler; and *these are the places* where oil is always found when present in a boiler in visible quantities. Being specifically lighter than the water its upward course is more direct, and should it approach any heating surface, such as a furnace crown where steam is generated rapidly, it is for the same reason driven off before it can lodge.

From my observations, I consider it doubtful if grease has been the cause of even a small percentage of the accidents which are attributed to it. Apart from this, however, grease is in the wrong place when inside a boiler. It may not lodge on the crowns under ordinary working conditions, but it is almost certain to be deposited on some of the heating surfaces, if present in large quantities, when the water is run out of the boiler. On this account a filter is a necessary adjunct to all modern high pressure boilers, although, as is well known, it will not stop the entrance of all grease.

The third cause is one which has occasionally brought about an accident when raising steam, the reason being a choked gauge-glass, or a cock left shut, whereby the gauge glass did not show the true water level inside the boiler. Collapse of furnaces has also taken place when too much water has been blown out of the boiler, and the fires left to die out. In both these cases the remedy is apparent.

The fourth cause has occasionally produced collapse, the defect being local in character. Any accident from this cause can be prevented by fitting the zinc plates in another position, or if they *must* be put at the wide spaces above the furnaces, then a receiver should be fitted underneath them to catch any oxide which may fall.

While I have enumerated some of the causes which are known, or are stated to have caused collapse of furnaces, the fact remains that in the majority of such accidents no cause has been found. In looking more closely into the cases where no cause had been assigned, I found that in most of the instances such accidents were reported to have occurred when the vessel *was lying under banked fires.* This suggested the thought that while the primary cause lay inside the boiler, it might be induced by the method of treating the fires about the time they were banked; and I will now put before you what I consider takes place at such a time.

The action of water when steam is being raised is well known. The boilers are ready, the fires are lit, and then the water nearest the heating surfaces becomes warm, expands, ascends, and its place is taken by a cooler and denser portion until constant circulation is set up. Bye and bye the temperature reaches such a point that bubbles of steam are slowly formed, these *cling* for a time to the heating surface until they have attained a spherical form, when they bound upward to the steam space, giving off on their passage a portion of the heat they received below; and in due course the required pressure is obtained. Let us assume the case of a vessel that proceeds on a voyage, and arriving near her destination, has to anchor unexpectedly with bright fires, which are ultimately banked, and all steam connections on the boiler closed.

Up to the time of stopping, the furnaces have been generating steam in the usual way, and nothing is noticed wrong with them. The banking of the fires, or it may be the opening of the furnace doors, however, cools the furnaces down until there comes an instant when the heat passing through the crown plate is only sufficient to generate steam, but not sufficient to throw it off the plate. The vapour cells cling to the plate in myriads, awaiting such an addition to their temperature as will send them floating upward; but, instead, the temperature falls a little lower, and they remain, the boilers being now quite still, and no steam being used. These cells practically cast a film of vapour over the upper portion of the furnace plate, as shown at Furnace 1, but aided by the slight deposit of sediment which then falls over them they subseuqently assume the form as shown at Furnace 2 (Plate XIII.), owing to the slight difference in the head of water between the points A and BB, and thus prevent the water from touching the surface of the plate. The fires (which had been covered with "green" coal) gradually break through, and the heat then begins to strike on a plate which is not in contact with the water. It soon becomes overheated, and ultimately the internal stress causes it to collapse. It may be said that the heat imparted to the plate should restore circulation at this particular place, but the transmission of the heat will be greatly retarded by the film of vapour. Again, the cooling of the furnace lowers the temperature of the water in its vicinity, thereby increasing its density, and confines the film of vapour in a covering of sediment; and water which is of lower temperature than that in the upper portions of the boiler, renders it difficult for the vapour to move, owing to the lack of circulation in the water. This will be more clearly seen if we assume that there is 8 feet of water above the furnace crown plate, and that the pressure is 165 lbs. per square inch. The density of water at this pressure is about 55 lbs. per cubic foot, and this gives a pressure due to that head of:—

$$\frac{8}{2{\cdot}306} \times \frac{55}{62{\cdot}4} = 3{\cdot}05 \text{ lbs. per square inch}$$

tending to keep the film of vapour down. With this pressure above, and the water and sediment over it quite still, the vapour cannot move from the crown until its volume has been considerably increased. While this is taking place the furnace is becoming very hot. It ultimately collapses, and in the act of doing so, liberates the steam.

An illustration of this action, which might be described as "arrested generation of steam," can be seen if a tube be introduced at the bottom of a vessel holding water, and air be gently pressed through it. If the pressure be applied slow enough, a small hemisphere containing air may be formed over the orifice, and kept under water for a considerable time. The head of water above keeps it from rising—or, rather, tries to force it back into the tube—and it will not rise until sufficient air is forced through to cause it to take a more spherical form, thus enabling the water to get underneath It is then almost entirely enveloped by a body of greater specific gravity, and it rises to the surface. This, I think, fairly shows what takes place in the generation of steam. At the time the fires are banked, the heat energy is arrested or intercepted by the current of cold air passing along the furnace crown plate, and the steam contained in hemispherical cells adheres to the plate in myriads, and ultimately forms, as already stated, a film of vapour over the upper portion of the furnace.

This action is, I think, the only explanation to account for the 70 per cent. of the cases in which no cause could be found for the accident. The last case of this kind, which came under my notice a few weeks ago, was in the steamer "Lennox." This vessel and her machinery were built by an eminent firm in this city, about two and a-half years ago. At the end of a voyage of 64 days—from New York to Shanghai—the furnaces partially collapsed, when lying under banked fires, prior to entering port. At the time, the vessel was still; the stop valves were closed, and no steam was being used. A few hours after stopping, the accident occurred. Subsequent examination revealed no cause for the accident, the furnaces being quite clean. A Weir's evaporator and Edmiston's filter were fitted, and the water, a portion of which was kept, was found fresh to the taste. This water, and the cylinder oil used during the voyage have since been analysed, and the results are given herewith (see Appendix).

On gauging the furnaces, which were of Morison's patent type, the greatest deformation was found to be nearly three inches, and all the eight furnaces were slightly distorted, the centre ones being the worst. The furnaces were set up, and, on examination at home, had not altered in form since the vessel left Shanghai. It is stated that there has not yet been a scaling tool used in the boilers of this ship; and, when I examined them they were in excellent condition.

The procedure which I consider should be adopted, if fires have to be banked, is to burn them well down when the engines are working, and keep currents of cold air from passing through the furnaces. After banking the fires, raise the safety valves, and reduce the boiler pressure about 10 lbs. or 20 lbs. per square inch. This will cause the water in the boiler to give off steam and set up circulation immediately over the furnace, where the danger seems to lie.

Accidents of the kind described appear to be more frequent now than in the days prior to the introduction of the triple-expansion engine, and that notwithstanding the large number of evaporators and filters in use. This would seem to indicate that the increase in boiler pressure, with its consequently higher temperature and density of steam, is to some extent responsible for the greater number of these accidents. The increase from 315° Fah. to 380° Fah. produces, at the latter temperature, a steam whose density is fully twice that of steam at the former temperature, while the water, in rising from the lower to the higher temperature, is reduced almost $\frac{1}{28}$th in density. Thus the specific gravity of the steam at 380° Fah. is increased, while that of the water is decreased. These two alterations cause the steam, when formed in the boiler, to rise through the water more sluggishly than at lower pressures. The hemispherical vapour cells, when arrested by a fall of temperature as described, are, therefore, more likely to adhere to the crown plates the higher we go in our working pressures.

APPENDIX.

Laboratory and Assay Office,
Newcastle-on-Tyne, 15th Jan., 1898.

I do hereby certify that I have analysed a sample of water taken from the boiler of the s.s. "Lennox" and forwarded to me by The Leeds Forge Company, Ltd. I find as follows:—

Calcic chloride, - -	·803	grains	per gallon.
Magnesic chloride, - -	·695	,,	,,
Sodic chloride, - -	18·987	,,	,,
Sodic sulphate, - -	6·554	,,	,,
Sodic carbonate, - -	42·91	,,	,,
Oily matter in solution, -	1·388	,,	,,
Total, - -	71·337		

The sp. gr. of this water at 60° Fah. was 1·002.

The density of this water is very slight, and would indicate that it consisted chiefly of distilled or evaporated water.

There does not seem to be any constituent in this sample of water which is present in sufficient quantity to cause serious damage.

I may say that the water of any boiler may seldom contain in solution any evidence of what may have caused damage. My experience is that the clear water from a boiler only furnishes evidence as to density, and is even then only evidence of condition for a very short time—in fact, only just for the time during which the sample is being taken—and a boiler may be in a very foul and dirty condition as to its surfaces and deposits, and yet furnish a sample of clear water quite free from any damaging evidences.

(Signed) JOHN BRADBURNE DODDS.

Laboratory and Assay Office,
Newcastle-on-Tyne, 15th Jan., 1898.

I do hereby certifiy that I have examined a sample of cylinder oil taken by Mr Shute from the s.s. "Lennox," and forwarded to me by Messrs The Leeds Forge Company, Limited:—

Sp. gr. at 60° Fah. - - ·884
Vapour point - - - 310° Fah.
Viscosity at 212° Fah., water being taken as unity, 2·38
„ 320° Fah. „ „ 1·17
„ 360° Fah. „ „ 1·06

In my opinion this oil is deficient in viscosity and lubricity at the higher temperatures, which would necessitate the use of increased quantities to obtain useful effect, and as this oil passes largely into the boilers, it might then do considerable damage.

I could not detect any artificial addition to this oil.

(Signed) JOHN BRADBURNE DODDS.

These analyses show that a quantity of soda had been used in the boiler, but the water was free from objectionable ingredients. The oil I consider of excellent quality, notwithstanding the remarks made by Mr Dodds, the analyst.

Correspondence.

Mr C. E. STROMEYER (Member) wished to add a few remarks to Mr Austin's valuable paper, with the greater part of which he agreed, but he thought the explanation which was intended to account for 70 per cent. of the cases of collapse required a slight modification before it became acceptable. The steam bubbles, or rather the sheet of superheated steam on the furnace crown, required some non-conducting tough material to make it retain its shape, and to protect it from the cooling action of the surrounding water. This essential material, in his opinion, was the engine oil which had found its way into the boiler, and, instead of the film of steam, he preferred to believe in a film of dense hydro-carbon vapour. The following

Mr C. E. Stromeyer.

were some of his reasons for this belief. The so-called unaccountable collapses occurred only in the presence of oil in the boiler. This substance was, it was true, rarely found on the surface of a collapsed furnace, but the tubes, stays, and furnace bottoms were in such cases either sticky with grease, or covered with a spongy compound of grease and sediment. The water in the boilers, even although there was plenty of oil adhering to the plates, was not objectionable to the taste, it was either fresh or held salt in solution, but was not oily like condenser water; which proved to his mind that all the volatile, and therefore tasty, hydro-carbons had been driven off by the heat, and only the denser oils, such as would not evaporate at temperatures below 400° Fah. were left in the boiler. These would in many respects behave like their near relative gutta percha, which, as was well known, was one of the worst conductors of heat. It was urged that oil being lighter than water would rise to the surface, and that there was no reason why it should adhere to the heating surface, where so much repellent steam was being generated. His own experiments had convinced him that this view was not tenable, and anybody could repeat the experiments for his own information. He had kept bottles of condenser water, which possessed a slightly milky appearance and an oily taste, for over a year, and found that no change in the turbidity or the taste had taken place; so that at least the finer particles of oil do not rise to the surface. He had also taken samples of this water and boiled it in an open porcelain dish, and found that it behaved differently to either pure or salt water. The boiling was most erratic, sometimes absolute quiescence reigned for perhaps half a minute, and then there would be a burst of steam bubbles, which always rose from the same lines in the bottom of the dish. These localities were so well defined, although not marked in any way, that he at one time believed them to be cracks, but that was not the case. There was a dark edge of oil at the water line of the dish, but the bottom of the dish, as seen through the water, seemed to be clean and white; however, on pouring off the water, one saw that this lower surface (the heating surface) was slightly darkened by oil, yet thin as the film must have been, it was capable of seriously interfering with the steadiness of the boiling. The oil had evidently gone down instead of up, and had moved towards the heating surface instead of away from it. He could therefore see no reason why an equally almost invisible film of dense hydro-carbon oil should not produce similar but stronger effects in a boiler. Mr Austin mentioned that the furnaces of the S.S. Lennox came down while the fires were banked. It was more than probable that the bulges were not discovered until then, for it was astonishing what little one saw unless the eye was trained to search. He would mention a case where a Superintendent, while looking for bulges in the furnaces of a steamer's boiler, passed over a pair, which, when afterwards measured, turned out to be distorted by 2 inches. Some light might perhaps be thrown on this subject by experiences with land boilers ; grease, even the small amount, which got into the feed from injection condensers, had to be most carefully watched, for it had caused many collapses. Sugar was another substance which led to collapse of furnaces, as did also paper pulp and other similar refuse which accidently found their way into boilers. In a recent case, which came under his notice, paper pulp was the cause of a collapse which proceeded very gradually. The attendant stated that he noticed the first indications in the morning, he said nothing, but went on firing and watching, the deformations gradually grew larger and larger, until at about three in the afternoon the furnaces flattened down on the grates, fortunately without a rent or other mishap.

Mr JOHN SANDERSON (Member) stated that he had read Mr Austin's paper with pleasure, but he did not quite agree with him that the actual collapse of furnaces generally took place while the fires were banked. It seemed to him that the most dangerous period was (from causes not mentioned by Mr Austin) when the fires were set away, after having been banked for a considerable time. Mr Austin's theory of vapour cells forming on the furnace crowns after ebullition had ceased was no doubt correct, but more serious things than that might have happened inside the boiler to tend towards a collapse. When the stop-valves were shut, and no

Mr John Sanderson.

more feed-water sent in, the main body of the water in the boiler itself would be at rest, and any impurities contained in it (let it be grease, mud, clay, or a mixture of these) would commence to settle down towards the bottom. In an ordinary single-ended boiler, having three furnaces, three feet in diameter by six feet in length, there was a horizontal area of over fifty square feet, and it was on that surface that a large quantity of the solid matter contained in the water would settle. The fact of that surface being covered with oval vapour cells made it all the more likely to do so. When the fires were set away, after having been banked long enough to allow the above to take place, there was then a great danger of over-heating the crowns, and it was doubtless in the time between the setting away of the fires and the commencement of generating steam that mischief was done. As long as the fires were properly banked the current of air would keep the crowns in a cooler condition than when the boiler was working, and consequently they were more able to resist collapsing. When steam was again being generated and the feed-pumps were set to work, the water would again be mixed up, and if, when the boilers were eventually blown down, a collapse was found to have taken place, no surprise need be felt if the crowns were found comparatively clean —*dirt that had at one time lodged on the same having done the mischief.* There were other causes that Mr Austin had not mentioned; the practice of fitting bar stays between the furnace front and the combustion chamber in too close proximity to the furnace itself, might prevent unequal expansion of the flue, and cause it to buckle. No doubt that and other points would be touched upon by members who would be present when the paper was under discussion.

Mr A. E. SHUTE (Member)—Mr Austin estimated that 70 per cent. of furnace accidents had no cause assigned to them. He could quite well believe that, because in the majority of instances, either from ignorance or design, those in charge of the boilers did not take the proper steps to find out why the accidents occurred. He had noticed that in the case of accidents which took place near at hand, where a superintendent engineer could be on the

Mr A. E. Shute

spot immediately, there was hardly ever any doubt as to the cause; but in cases that happened abroad, human nature was a bit too strong, and the cause was wrapped in mystery. It was too ridiculous to think that furnaces which were practically able to resist a collapsing pressure nearly six times greater than the working pressure, should collapse without cause, and yet to read some of the reports on such accidents one would almost think that the writers believed that the furnaces could do so. Mr Dodds, the analyst, who had had good experience in dealing with boiler feed-waters and deposits, said, that samples of the water, unless drawn at the time the accident took place, were useless, and it would be too much to expect an engineer to be calm enough to bottle off some water and watch the furnaces coming down at the same time, but if he carefully collected samples of the deposits to be found at the bottom and other parts of the boiler after it had been cooled and emptied, he had the key to the whole situation. Mr Austin said, "In none of the accidents which have come under my notice has a vestige of greasy deposit been found on, or close to, the part of the crown which had collapsed." He could quite believe that, because oil or any other kind of dirt could hardly be expected to retain its individuality after being on a red hot, or nearly red hot, plate for even a very short space of time. He had seen a piece of scale so fused on the underside next the furnace crown, that it had all the appearance of a piece of glazed pottery. In the same paragraph Mr Austin said he had "Seen boilers where the internal parts, with the exception of the furnace crowns and other effective heating surfaces, were actually covered with grease, and the furnaces were in perfect condition." He would say that this was owing to chance more than anything else. Probably the boiler in these cases was well scummed before being emptied, or else it was emptied before the steam was entirely off it, and before the dirt had time to settle. As to the dust found on furnace crowns after collapse not being carbonized oil, he could only say that, on more than one occasion he had found the dust gathered under such circumstances as like carbonized oil as the residue left after burning cylinder oil in an iron ladle; in fact,

Mr A. E. Shute.

there could not possibly be any doubt on the subject. He did not say that all the dirt found on furnace crowns was oil, but a goodly portion of it was; and if Mr Austin cared at any time to furnish him with a reliable sample of the dirt remaining on a furnace after collapse had taken place, and supposing there was evidence that oil was present in the boiler, he thought he would have very little difficulty in proving that he was right. A sample of dirt from the boiler bottom, as well as some of that from tubes, etc., would help. As long as a boiler was working steadily and constantly, there was very little danger that oil would become deposited on the furnace crowns, as the violent movement in the water at those parts kept it away, but it was when the circulation was stopped that, the oil or dirt became deposited in a more or less uneven way according as the various parts of the boiler were cooled; therefore, a centre furnace would receive most deposit if it became cooled before the other two. It was a very curious thing that collapse always occurred after the boilers had been emptied and refilled, when no examination had been made or cleaning done. He had known several instances of that, and in all of them the evidence was conclusive; and yet the furnace crowns were clean, except as to the carbonized oil and a light coating of other dust. He could not understand how it was possible for a layer of steam to form in the way Mr Austin suggested, and if it did do so, he could not see how it was possible for it to remain unchanged, either as to volume or position, while the crowns were getting red hot, or very near it. He would imagine that immediately the fires were broken up, after being banked, the bubbles of steam would receive a little heat and rise at once. Perhaps steam might lie in that way on a plate which had already had some greasy dirt deposited on it; if so, the one would help the other to cause collapse; the water would be kept away from the crown by the bubbles, and the heat would be kept from the bubbles by the dirt. He could not express anything else but an opinion in the case of the "Lennox" affair, because he had no evidence. His opinion was that the accident was caused by dirt settling on the furnaces during the time the fires were banked, and collapse occurred

Mr A. E. Shute.

shortly after the fires were broken up. In the United Kingdom there were hundreds of land boilers which were lying under banked fires night after night from one year's end to another, except when laid off for cleaning and repair, and yet one rarely heard of a case of collapse, unless through dirt or scale. He had had some correspondence with the Leeds Forge Co. on this matter, and their general manager, Mr Gearing, wrote him as follows:—"Prof. Lewes proved conclusively that a very small quantity of grease was sufficient to allow the plates to be overheated; and in proof of this he had a small iron pot at the reading of his paper on boiler deposits, in which he placed water, after putting on the bottom of the pot a coating of the greasy deposit taken from a surface condenser. He explains the great difference in the resistance to heat passing through plates under these conditions, and in the experiment mentioned he was able with a blow pipe to melt a hole through the bottom of the pot, although it was full of water, so that it is obvious that a very small amount of oily deposit on the crown of a furnace, in these days of high pressures, will allow a furnace, when it is already at about 400° Fah., to be heated so as to lower its elastic limit, and in consequence it will sag under the conditions named. Mr Parker, of Lloyd's, also read a paper on this same subject about the same time. As to Mr Austin's theory that a furnace comes down when the fires are banked, I simply do not believe it. Take the general practice in banking fires; some engineers swear by the system of banking at the back ends only, and leaving the front of the furnace covered over with ashes. If this is done, it is obvious that Mr Austin's carefully constructed theory of a film of vapour being present on the crown of the furnace is wrong, as it could not possibly be formed under these conditions; and the fires banked in this position, as stated by him, would obviously not affect the furnaces so much as the combustion chamber. Taking the other system of banking at the front end, I cannot conceive it possible with the leakage of cold air into the furnace, how it could rise to the temperature he mentions, and am quite prepared to take a furnace, fit up a set of bars in it, bank a fire in the front of it, and by attaching properly

Mr A. E. Shute.

arranged apparatus for taking the temperature, see how long it takes under these conditions, with no water at all on the outside of the furnace, to raise it to a temperature such as he indicates. There is, of course, one well-known means of taking temperatures under these conditions, namely—the le Chatelier Thermo-couple; anyway, it is the system adopted for taking the temperatures at the different parts of a gas flame, and has been extensively used by Prof. Lewes in his experiments. Personally, I do not think the collapsing takes place under these conditions. I do not doubt for a moment that it is probably only then found out, but I maintain that the mischief is done before the fires are banked; and it is only under the conditions of banked fires, when you have the light at one end of the furnace and not at the other, that the deformation is apparent. It is obvious that a deformation of 1″, or 1½″, or even 2″ is somewhat difficult to see when the fires are active. One proof that it is not the fault of the furnace or any inherent weakness that causes this, is the very few cases that we, as manufacturers, hear of. During the whole time that we have manufactured Morison suspension furnaces, the case of the "Lennox" and two other steamers are the only ones about which any information has reached us, and the whole of them have come to our knowledge within the last six months. This obviously proves that the fault is considered by the shipowner not to be in the furnace, or we should very soon have some claims made against us; as we have never yet had a claim on these grounds, the inference is fairly obvious. Of course, there is something in the fact that when the boiler is in use the upward current from the furnace crowns is very active, as at least from 55 per cent. to 65 per cent. of the total evaporation of the boiler is done from the furnace; but, after steaming sixty-four days, it is quite conceivable that there may be particles in mechanical suspension in the boiler which may be surrounded by oily deposit, and which are, in consequence, somewhere about the same specific gravity as the water. The boiler being in active use, the steam currents would keep these particles in circulation, but when the fires are banked and all ebullition ceases, they may deposit

Mr A. E. Shute.

on the furnaces and eventually cause collapse. This, I think, is a much more reasonable explanation than the theory of Mr Austin's. You will bear in mind that even with the fires in the most active state, there is a layer of unconsumed gases on the top of the furnace, and under banked fires the layer would be much thicker, and consequently much lower in temperature. It must be remembered that such only exists when the water is in contact with the plates, because it is the fact of the furnaces being so much cooler than the gases that causes the layer. When the water is away from the plate, of course the plate rapidly rises in temperature, and the layer of unconsumed gases disappears." In conclusion, he begged to thank Mr Austin for his valuable and clever paper, and hoped that some good might result from it, and the discussion that would follow.

Discussion.

The discussion on this paper took place on 22nd March, 1898.

Mr **Austin** said if reference were made to Plate XIII. it would be seen that a film of steam was shown over Furnace No. 2. He did not fully explain in the paper how he considered that attainable, for the reason that it was an action which could not be observed; it was a matter of surmise. It might, however, facilitate matters if he did so now before the discussion began. When steam was arrested, as shown at Furnace No. 1, the circulation of the water above was stopped, and the superfine sediment in suspension was deposited over the vapour cells, displacing the water where it was in contact with the plate. This sediment, by its contact with the steam, became hardened on its under side, and effectually separated the steam from the water. On the application of additional heat, this casing was lifted and the steam was forced into a continuous film, as shown in Furnace 2.

Mr **Sinclair Couper** (Member), remarked that more people would agree with the first part of Mr Austin's paper than the second part. Most would accept the four causes, which he gave on page 258 as being quite sufficient to account for all cases of collapsed furnaces

Mr Sinclair Couper.

met with in ordinary practice, and he did not think that the theory of "arrested generation of steam" would be so readily accepted and approved of; nevertheless, the paper was worthy of their best consideration. Although Mr Austin had confined his remarks to the collapse of the furnaces of marine boilers, the matter ought to be looked at in a general way. Mr Austin had gone into a calculation and gave figures to show what the amount of pressure would be tending to keep the volume of steam down upon the furnace crown. Now, without following him in that, the matter might be looked at from another point of view. Boilers used on board ship differed from boilers on land in respect that they were under steam for days or weeks on end, and consequently did not require to be put under banked fires except at long intervals. But there were now many boilers of the ordinary marine or of the dry-back return-tubular type used on land in electric light and electric power stations, and also in public works generally. His firm had supplied such boilers up to 14 feet in diameter to work at pressures up to 200 lbs. per square inch, and in those boilers the fires were banked every night, yet he had never heard of their furnaces collapsing, nor could he say that he had ever heard of marine boilers used on land giving any trouble. He looked upon the multi-tubular boiler, indeed, as being superior to the Lancashire boiler, in respect that there was a large depth of water above the furnace crown. In the former, there would be sometimes some feet of water over the furnace crowns, while in the latter there were only some eight or nine inches. He was inclined to attribute the cause of collapse to the presence of oil in the boiler. That had been shown almost conclusively by Professor Vivian Lewis, in a paper on Boiler Deposits, contributed to the Institution of Naval Architects some years ago. He showed that the oil very often formed a leathery or spongy mass on the top of the furnace, and that being a non-conductor of heat, the furnace crown could not be otherwise than overheated and rendered unable to withstand even a very slight pressure. He further showed what was very interesting, that a deposit of oil was more likely to take place in boilers using absolutely fresh or distilled

Mr Sinclair Couper.

water than in boilers using water with a strong saline solution, because in the former case the low density of the fresh water permitted the oily matter to settle more quickly; hence the reason that, notwithstanding all the care that was bestowed upon marine boilers, there were still occasional cases of collapsed furnace crowns. It would be interesting, if those who had to do with the actual working of marine boilers, could tell them whether it was actually the case that a large percentage of the misfortunes to furnaces took place when the boiler was lying under banked fires.

Mr JAMES MOLLISON (Member) considered the subject of the paper under discussion was one, which, to many engineers, had been a matter of much concern, particularly with respect to the carrying out of repairs consequent upon accident, such as the replacing of damaged furnaces by new ones, or setting collapsed and distorted portions back as nearly as possible to the original form, both of which operations were attended with considerable difficulty. Mr Austin said that in the majority of cases subsequent examination did not reveal the cause of collapse. In all the cases which he (Mr Mollison) had been called upon to deal with, he had no difficulty in that respect, the cause being only too apparent—whether through the want of water, scale deposit, or cylinder oil adhering to the furnaces. Perhaps his experience had been somewhat unique, and it might not be out of place to mention one particular case which had engaged his attention a few years ago, in a new vessel which had more than one large double-ended boiler. On her maiden voyage from this country one boiler was disabled through the collapse of some of its furnaces, and on the homeward voyage several of the furnaces in the other boilers also became damaged and distorted. A good deal of talk and speculation was indulged in regarding the matter, not to speak of irritating correspondence. He was requested by Lloyd's Committee to examine the furnaces on the vessel's arrival at her home port, and report upon their condition. He visited the vessel on the morning after her arrival somewhat earlier, he believed, than expected, and found the boilers all opened up and quite an army of boiler cleaners ready to begin operations. He took charge

Mr James Mollison.

for a time, and found scale deposit quite three inches thick in the corrugations of the furnaces—solid material that could be lifted and carried without crumbling away. He had no doubt, whatever, that had he arrived a little later the scene would have been completely changed (as far as the scale and dirt were concerned), and, perhaps, an endeavour made to surround the cause with some degree of mystery; the case might then have been added to those mentioned by Mr Austin as not having been satisfactorily accounted for. The theory advanced by Mr Austin that the banking of the fires and consequent cooling of the furnaces produced a film of steam bubbles over the furnace crowns, sufficient to cause collapse, was somewhat hazardous, because often in boilers those conditions could not be very far removed. With regard to the damage done by oil and grease deposited over the furnaces, he had observed that it had invariably occurred in comparatively new boilers. It would then appear that the deposit, which was quite plastic, adhered more readily to the heated surfaces when the plating was free from the smallest quantity of scale or deposit of a porous nature. Hence, he looked upon oil and grease as a most insidious enemy, and every precaution should be taken to prevent those materials from getting into the boilers at all. From Mr Austin's use of the term 70 per cent, it might be inferred that there were hundreds of cases of furnace collapse. He was very glad, however, to say that, considering the large number of steamers now engaged in all trades, coasting and otherwise, comparatively few accidents of that kind occurred; for which great credit was due not only to the superintending engineers throughout the mercantile marine, but to the intelligent skill with which the engineers who went to sea carried out their duties, often under trying circumstances. He might mention that a good many years ago, an engineer of some experience in the working of boilers at sea, in conversation with himself regarding such accidents, expressed the opinion that the oily and greasy matter floating on the surface of the water in a boiler (referring to vegetable oils which were more in use in those days), if not scummed off, formed such a cushion as prevented the steam getting through, thus creating a series of explosions and lifting of the water over the furnace crowns—which might be sufficient to cause collapse. That was the only theory approaching Mr Austin's which he had heard.

Mr F. J. ROWAN (Member), observed that Mr Austin had unconsciously supplied an argument in favour of the introduction of water-tube boilers, because they entirely abolished the use of furnaces which could collapse, and hence the class of accidents referred to. There were, however, one or two things which Mr Austin had not taken into account in his endeavour to explain the cause of collapse. For instance, on page 258, he spoke of the furnaces not becoming permanently deformed under hydraulic pressure until between five and six times the working pressure was applied, but in those circumstances the pressure was applied to the iron or steel when it was cold. It was well known from experiments that had been made, that iron or steel very rapidly lost its strength with increase of temperature. Experiments had been made by Mr William Parker when he was chief engineer surveyor at Lloyd's, and later experiments were carried out in Germany, by Dr Kollmann, which gave figures showing a gradual loss of ductility and tenacity under increase of temperature. These results were very interesting, and were as follows:—

MR PARKER'S RESULTS OF TENSILE TESTS ON ENGLISH AND GERMAN STEEL AT VARIOUS TEMPERATURES.

Temperature Fah.	Stress in Tons per square inch.		Elongation per cent.	
	English.	German.	English.	German.
70°	31·5	30·3	18·7	16·7
450°	35·7	39·2	14·5	10·2
610°	32·0	34·4	12·5	13·2
1000°	13·8	11·7	*3·0	24·2

* Broke close to the end.

In Mr Parker's experiments the tenacity appeared to increase at temperatures from 70° to 450°, whilst the ductility diminished, but between 450° and 1000° both rapidly fell away, except in the case of

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the German steel experimented with, which showed remarkable results. Dr Kollmann's tests were carried out in 52 experiments, to show the effects of rise of temperature in reduction of resistance to rupture, and increase in the contraction of sectional area, as well as of extension. Taking his initial temperature at 0° C. (32° Fah.) and the resistance of iron to rupture at this temperature at 37·5 kilos per square millimetre, or 23·81 tons per square inch, and calling this breaking load 100, then the percentages of loss in breaking load sustained by increase of temperature were as follows:—

At 200° C.	the loss was	5	p. cent.	At 700° C.	the loss was	84	p. cent.
,, 300° C.	,,	10	,,	,, 800° C.	,,	89	,,
,, 400° C.	,,	27	,,	,, 1000° C.	,,	96	,,
,, 500° C.	,,	62	,,	,, 2250° C.	,,	100	,,
,, 600° C.	,,	81	,,	*i.e.*, the iron broke with no load.			

It was evident, therefore, that these boiler furnaces, which collapsed, must have had their temperature increased in some way before collapsing under ordinary working pressure. Then as to the question of the deposit of oil or grease, Mr Austin said that in many cases no vestige of greasy deposits had been found on, or close to, the collapsed part of the boiler flues after collapse, but it was evident that the heating and the bending of the metal which took place during the collapse, or at the moment of collapse, ought to be in most cases sufficient to remove such a deposit at these points. He (Mr Rowan) did not refer to such an exceptional thickness of deposit as Mr Mollison had spoken of; that would assuredly require something more for its removal. The question of how oil reached those surfaces was one which he thought was capable of explanation. Oil was, no doubt, very seldom deposited simply as oil on the heating surfaces of boilers, but it had a faculty of seizing hold of and coating any solid matters which might be in the water, partly floating or carried about by the circulating water, and was thus deposited along with them. Mr Austin, on page 259, raised an objection to the statement sometimes made, that the fine dust found on the

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furnace-crowns after an accident was oil that had been carbonised. He said, " Now it will be evident to many that, if the dust so found is oil carbonised, it becomes difficult to explain how this takes place, for in hundreds of boilers dust of this kind may be gathered from the steam space, when there has been no overheating." But here he evidently did not distinguish between the temperature at which iron was overheated and that at which oil was carbonised. Where he said there had been no overheating there might certainly have been none of the iron, and yet it was quite possible to have had overheating of the oil, so that there was nothing remarkable, with the high pressures of steam now in use, in carbonised oil being also found in the steam spaces. Whenever the heating surface of boilers, which was exposed to the hot gases, was in the slightest degree coated with oil, it had been found that the temperature of the plates was considerably raised thereby. He did not exactly remember the results given by Professor Lewes in the paper to which Mr Couper referred, but it was probable that they would bear out the results previously given by Mr (now Sir John) Durston and by the late Mr Blechynden. They had found that the difference between the temperatures of the dry and wet sides of the heating surfaces of boilers did not exceed from 67 to 86 degrees when clean, but when slightly coated with oil, or made greasy, there was at once a difference between the two sides of about 500° Fah., so that if there was a slight coating of oil on the surface of these boiler flues which collapsed, that would account for their rapidly attaining a higher temperature than they ought to have. With regard to Mr Austin's theory of the cause of the collapse of boiler flues, he (Mr Rowan) agreed with Mr Couper that it was not likely to find many supporters. The theory of the existence of a continuous film of steam was one very difficult to accept unless in the case where the plates were red hot, or sufficiently hot to cause the water to assume the spheroidal state. In that state there was a film of steam which supported the water and prevented it touching the plate, but short of that temperature it was not easy to understand how such a film could exist in the position referred to. The

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experiment quoted on page 262 did not afford an explanation, because in that case there was an external force applied to maintain the bubble of air in its position at the end of the tube. Even then as soon as the bubble of air exceeded the diameter of the tube it was bound to escape, or portions of it were bound to escape upwards through the water. He (Mr Rowan) thought there was one explanation to be found for the sudden collapse of boiler flues under the conditions which Mr Austin had mentioned — that was to say, where the fires had been banked for some time — which would apply in many of the cases of such collapse, and that explanation was known as the theory of delayed ebullition. Some land boilers at factories had been known to explode or to have had their flues collapsed immediately after the stoppage during a meal-hour, and no other cause could be found for the accident. The stoppage of the firing caused the generation of steam to cease, and the steam already formed then rapidly cooled down, so that the temperature in the steam space fell below its proper point. Then there was a mass of water which was hotter than the steam, ready at a moment's notice to produce, almost instantaneously, a large quantity of steam when any shock was given to it either from sudden firing up and the flame striking against the plate, or from some other cause. Exactly similar conditions existed in the case of marine boilers having the fires banked for some time. Along with that, the flues might have been gradually overheated at one or two points, and if a sudden formation of steam took place, under such conditions it was natural to suppose that the hottest and therefore the weakest part of the boiler would be the first to give out. On page 261 Mr Austin spoke of "vapour cells in myriads clinging to the plate, and only awaiting an addition to their temperature to send them floating upwards," but a few lines further down he said—"The fires (which had been covered with "green" coal) gradually break through, and the heat then begins to strike on a plate which is not in contact with the water," being covered, as he supposes, with a film of steam. Under these conditions, the steam evidently did not escape upwards according to his view of the matter, even with an addition of temperature, but it was difficult to understand how these two statements could go together, without overturning in some degree the theory of a film of steam adhering to the surface of the flue.

Mr W. R. AUSTIN, in reply to the discussion, said he could not see how the banking of fires and general working conditions of land boilers of the multi-tubular type could be compared with marine boilers. It would be obvious that accidents to furnaces were the exception, not the rule, and as in the majority of cases of collapse there was a want of satisfactory evidence as to the actual cause, it was only natural and reasonable to infer that they occurred under exceptional, and yet somewhat similar, conditions. Believing this to be so, he had assumed the case of a vessel brought to anchor unexpectedly, with heavy fires. He failed to see how such a case could be compared with a land boiler, where those in charge knew to a minute when the engine would be stopped, and worked their fires accordingly. For that, and other apparent reasons, he did not think a fair comparison could be made. The paper stated distinctly how the 70 per cent. was obtained. He did not contend that those figures bore any relation to the number of vessels which had been free from accident; still Mr Mollison would, no doubt, admit that accidents occurred with sufficient frequency to merit enquiries as to the cause; and it was to be regretted that he, with his vast experience, failed to give his opinion as to those irregular forms of collapse so often met with. On the strength of a single case, Mr Mollison suggested that the accidents were not satisfactorily explained, because those in charge were dishonest enough to remove the evidence. Such a reflection was not warranted, as cases investigated by disinterested parties had not shewn what was deemed sufficient evidence to cause collapse. Mr Rowan suggested that not a few of the unexplained accidents to furnaces might be caused by what was known as delayed or suspended ebullition. In describing that, he said "The stoppage of the firing caused the generation of steam to cease, and the steam already formed then rapidly cooled down, so that the temperature in the steam space fell below its proper point. Then there was a mass

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of water which was hotter than the steam, ready at a moment's notice to produce, almost instantaneously, a large quantity of steam." Was it to be understood that steam could exist in a steam space at a temperature far below that due to the pressure existing in the boiler? It was generally accepted that with steam in a boiler, temperature and pressure were indissolubly related. If it were assumed, as Mr Rowan suggested, that with fall of temperature the pressure remained constant, how could the addition of heat instantaneously generate a large quantity of steam, while the pressure in the steam space was maintained? On the other hand, if the temperature fell rapidly and the steam became condensed, as it undoubtedly would, the lessened volume of steam would at once produce an alteration in the condition of the water, and cause it to give off steam to take the place of that condensed. Mr Rowan had not, he thought, fully grasped the conditions existing within a vapour cell. It should be borne in mind that the furnace plate underneath each particle of steam was quite dry. It therefore followed that, before the steam could rise, there must be moisture beside or around it from which additional steam could be generated on the application of heat. If the moisture was not there owing to its being displaced, and the steam confined as Mr Rowan suggested, how could the steam be thrown off the plate? Mr Stromeyer quoted an experiment with water taken from a condenser, and they would note that, when he removed the water from the vessel he found decided evidence of oil on the bottom. At an earlier part of his remarks he admitted that oil was rarely found on furnaces which collapsed; and yet in view of his experiment, and the presence of oil which it distinctly showed, he did not attempt to explain its absence from marine boiler furnaces. In many cases only one furnace got distorted, while the others in the boiler retained their form; in other cases one side of the furnace crown became distorted, while the other side of it was quite circular. (See Figure.) Again, three or four corrugations might be distorted, while those adjacent were not affected; no oil being visible on the parts which retained their shape. Mr Stromeyer preferred to believe in the

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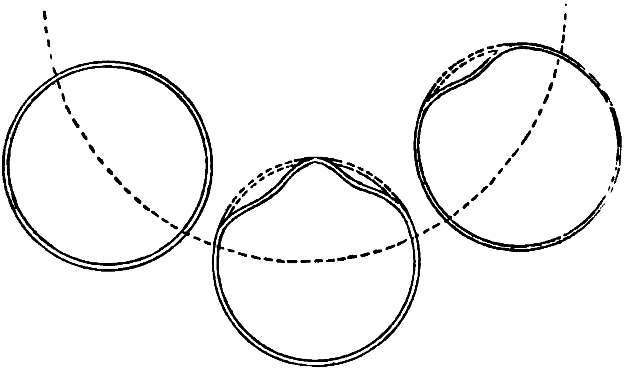
existence of an almost invisible film of dense hydro-carbon oil. He could not agree with him in that opinion. It was stated by some authorities that, when a plate became red hot it lost five-sixths of its strength to resist pressure tending to buckle it. In furnaces generally, a factor of safety of a little over five was allowed. It was therefore evident that the furnace crown plate would have to be red hot before it would buckle, at about the working pressure of the boiler. In his opinion oil would become carbonised before this temperature (say 1500° Fah.) was reached, and if that were so, its non-conducting power to keep water from the furnace plates would be destroyed; while if it did not become carbonised before reaching that temperature it would be found on those portions of the plate which had not been distorted by overheating. As it was not found on those parts, how was it possible to account for its absence? He held the opinion that the oil was never there. It had been suggested that accidents occurred at sea, and were not noticed until the ship's arrival near port. He had already mentioned one case (and there were many such) where collapse took place on one side of the furnace only. If such an accident occurred at sea, from any kind of deposit, when the temperature of the fires was at its highest point, the deposit should have produced general distortion of the crown; and the fact that it did not do so proved that the accident took place at a time when



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the temperature of the furnace was extremely variable, *i.e.* from such a condition of the furnace temperature as obtained under banked fires, when one side of the fire broke through and became red before the other. The same argument applied to cases where one crown in a boiler collapsed and the others did not. These considerations, taken in conjunction with what was stated in the paper as to the time such accidents occurred, made it plain that the damage was done under banked fires. It might be said that in other cases where general distortion of all the furnaces took place, it occurred at sea, and was not noticed until arrival near port. For the sake of argument, let a case be assumed where such an accident occurred at sea from a deposit of oil (scale might be neglected, as it always left evidence of its presence, and also sediment which was not likely to be deposited while circulation went on), could it be contended that when the furnaces first became distorted all the oil in the boiler was destroyed, that after such an accident they started afresh, having got rid of the whole of it? He did not think so. From whatever point they viewed the matter, the evidence appeared to him altogether against the suggestion that such accidents occurred at sea under ordinary working conditions. He would admit that sediment played a contributory part in producing collapse, but the amount of deposit in the form of dust found after these accidents was so small, as in his opinion, and that of many others, to preclude the possibility of its being the sole cause. The thickness of dust found on furnace crowns, on opening the boilers after collapse, was, in the worst cases he had known, about one-eighth of an inch. Frequently it was very much less, and was always found evenly distributed over the furnace crowns. The deposit to cause collapse would require to be very much greater than that, so great, in fact, that it could not be thrown off by the conversion of the moisture underneath into steam. If Mr Sanderson's theory were accepted, that after collapse took place, the sediment got mixed up with the water of the boiler, and again went into circulation with it, the question would naturally be asked. What ultimately became of it, as sufficient evidence of it was

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not found afterwards to account for the accident ? Assuming that collapse took place in a furnace from this cause, say at Greenock, when lying at anchor, and the deposit after it caused the damage was thrown off and circulated with the water, it would be found present in a slightly diminished quantity when the boilers were opened, say at Glasgow. Mr Sanderson stated that such accidents occurred after the fires, which had been banked, were set away to raise steam. This was contrary to the evidence he had placed before them that, these accidents had been noticed when lying under banked fires. If sediment caused collapse of one side of a furnace, it should do the same to the other side with a bright fire; and as it would settle down on all crowns alike, it would naturally be expected that they would all collapse. As that did not take place, he thought it disposed of the theory that sediment alone was the cause of collapse. He had been favoured with a copy of the analysis of some scale found on the crowns of furnaces which had collapsed, and he gave it, as well as the analysis of the sediment which was found suspended in the water of a high pressure marine boiler. A comparison of these might be interesting, not only in connection with Mr Stromeyer's suggestion as to the formation of a film of hdyro-carbon vapour, but also in connection with what was stated in the paper respecting the dust found on furnace crowns after collapse—

Analysis of a Sample of Boiler Scale found on the Collapsed Furnaces of a High-Pressure Boiler.

	Per Cent.
Protoxide of Iron, ...	50·62
Peroxide of Iron, ...	42·00
Lime, ...	1·10
Magnesia, ...	·14
Oil, ...	1·20
Carbonaceous Matter, ...	·70
Siliceous Matter, ...	4·20
	99·96

(Signed) John Clark, Ph.D.

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Analysis of a Sample of Deposit in the form of fine dust, taken from the Steam Space of a High-Pressure Boiler. Furnaces perfect in shape.

	Per Cent. on Sample dried at 212° Fah.
Calcium Carbonate, ...	3·03
Magnesium Carbonate, ...	3·17
Magnesia, ...	22·20
Oxide of Zinc, ...	16·30
Sulphate of Soda, ...	2·05
Chloride of Sodium, ...	11·00
Oxide of Iron, ...	4·29
Alumina, ...	9·31
Silica, ...	10·70
*Oil (Mineral), ...	5·78
Water of Combination, etc., ...	12·17
	100·00

(Signed) Wm. Galbraith.

* Oil vaporizes at about 380° Fah.

In the paper, he had stated that he considered those accidents due to steam arrested by a fall of temperature, which subsequently took the form of a continuous film as shown at Furnace 2, Plate XIII., and as the action was one which could not be observed, he deemed it best to leave over till the discussion an explanation of what he considered took place in order to attain this formation. It would be apparent to all that the maximum formation which steam could attain unaided in water at that temperature and pressure, was approximately that shown by a vapour cell at Furnace 1; therefore, the formation of the film of steam as shown at Furnace 2 could not take place without external aid. This aid was supplied by the impurities in the water of the boiler. What he considered took place was, that after the arrestment of steam, as shown by the vapour cells, there was a cessation of circulation, and consequently a precipitation of the sediment. When the sediment had fallen on the

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crown, its under surface (because of the dryness of the plate and steam beneath) became hardened sufficiently to withstand the stress caused by the expansion of the steam, when heat was applied to it. At the least upward movement, the water acted at the outer edges of the coating of sediment, forced it upwards a little, and made it in reality a continuous film, as shown at Furnace 2. Doubt had been expressed as to the possibity of sediment confining steam in the way he had suggested, but from some experiments he had made with dust found on furnace crowns, he had no doubt that it could do so. That casing of partially hardened sediment which really only separated the water from the combined steam was not subject to internal stress as Mr Stromeyer suggested. It was quite free at the ends, and had only to withstand the crushing stress due to a pressure of water of about 3 lbs. The steam, when confined beneath it thus, might to some extent be likened to air confined in an inverted glass under water, and it behaved in a similar way to gas when heated in a closed vessel at constant pressure, *i.e.*, it would continue to expand until, in all probability, the yielding of the plate from overheating would produce a sudden stress, and thereby rupture the casing and liberate the steam. The casing of sediment would then be thrown off by the action of the water, and would soon dissolve into its original state of superfine sediment. Hence they found no trace of it afterwards. For the reasons stated, he thought that neither oil nor sediment alone accounted for the unexplained cases of collapse. He considered that the arrestment of steam was the primary cause of collapse in furnaces, and that, aided by the sediment, produced the effects they saw, but found so much difficulty to explain. Fires should always be well burned down before stopping the engines, and when they had to be banked, it should be done close to the bridge. If such precautions were adopted, he was confident that such accidents would be avoided. Mr Shute's remarks were apparently dictated by a fear that the Morison patent furnace would suffer in reputation because of the subject of his paper. In stating what was required to determine the cause of collapse, Mr Shute said, "If he (the engineer) carefully collected samples of the deposits

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to be found at the bottom of the boiler . . . he had the key to the whole situation." Further on, he said, "A sample of dirt from the boiler bottom, as well as from the tubes, etc., would help." From which it would seem neccessary that before he could say what caused the collapse of a furnace he must have grease, not only from the crown of the furnace, but from the bottom of the boiler; and that the evidence to be gathered from the crowns would not be sufficient to determine the question. A case came under his notice a few weeks ago. The furnace bottoms were ⅜-inch thick, and the shell bottom fully 1-inch thick, with solid grease. Mr Shute would probably say in such a case that the furnaces collapsed from a deposit of grease; but they did not The shape of the corrugations was as perfect as the day they left the Leeds Forge Co.'s works, and there was no oil to be found on any of the effective heating surfaces. He was inclined to think that Mr Shute did not realise the amount of grease which was to be found in many high-pressure boilers, and still the furnaces in those boilers were uninjured. Mr Gearing, who was quoted by Mr Shute, referred to Prof. Lewes' experiment with a small iron pot smeared with grease, but he did not state that to melt a hole in the bottom of the pot it required a temperature of 1000° Fah. higher than usually obtained in the furnance of a marine boiler.

The Chairman, Mr Robert Caird, F.R.S.E., Vice-President, remarked that the thanks of the Institution were due to Mr Austin for the excellent paper which he had read, and also for the full and interesting discussion it had evoked.

On the motion of the Chairman, a vote of thanks was accorded to Mr Austin for his paper.

PHOTO-SURVEYING.

By Prof. E. J. Mills, D.Sc., F.R.S.

(SEE PLATES XIV., XV., XVI.)

Read 22nd February, 1898.

The principles of metric perspective were originally investigated by Desargues (1593-1661), and more particularly by Lambert (1728-1777); but Beautemps-Beaupré, a French engineer, was the first to employ them practically in his surveys of the islands of Santa Cruz and Van Diemen's Land. Results, however, which depended solely upon accurate adjustments of the observer's eye, were necessarily liable to much error; and it was not until Laussedat (also a French engineer) adapted Wollaston's camera lucida (1854), and subsequently the camera obscura, to the work, that measurements began to acquire precision.

It is well known that Fox Talbot, a number of years before the last-mentioned date, had used the camera obscura in his Swiss journeys, and that to the need for greater rapidity of record was due the origination by him of various methods of photographic impression. It now became clear that one and the same optical combination could be employed both for photography and for geometrical measurement. Accordingly, Laussedat in 1861 completed a photographic survey of Paris, on the scale of $\frac{1}{8667}$; another, of Grenoble, was made in 1864; and a third, in Savoy, extending over 2½ square miles, with a very considerable range in height, was completed in 1867. Since that time the method has been actively pursued in Germany by Meydenbauer and many others; in Italy by Paganini, who has executed a long series of ordnance surveys; and in Austria by Pollack, who (in addition to ordinary survey work) especially distinguished himself by his maps of mountains.

For the most extensive application of photographic surveying we must, however, look to Canada. In 1892 an International Commission was appointed to examine the boundary between Canada and the

United States territory of Alaska. Mr W. F. King, the Canadian Commissioner, carried out his share of the work photographically; and it is stated that in 1893-94 his parties surveyed about 14,000 square miles. Mr E. Deville, the present Surveyor of Dominion Lands, has done much work of this kind in the Rocky Mountains. Surveyors are under a considerable debt to him for his very able treatises (1889, 1895) on the subject. Deville finds the cost of the camera method to be about one-third of that used in ordinary surveying, and adds—"Properly used, it gives results far beyond what can be accomplished by any other process." Since the time of Laussedat's early work, the improvements in apparatus have been chiefly matters of detail. Rectilinear lenses and backed gelatine plates are now always employed; and, for distant work, isochromatic plates. Means are adopted for automatically recording on the picture the critical optical positions. Even very distant objects can now be brought under examination by means of the telephoto lenses of Dallmeyer and others. Indeed, a modern photo-theodolite possesses every essential of an excellent surveying instrument, with a range of work more extensive than is possessed by any of them.

Various forms of photo-theodolite have been from time to time proposed. For a description of them, reference may be made more especially to the works of Meydenbauer and Deville. The following is an illustration of my own pattern, now exhibited to the Institution, Fig. 1.

The instrument consists of a 5″ × 4″ box camera constructed of teak, which keeps its dimensions better than metal, and is naturally waterproof. The front has a rising and cross motion, each of which can be adjusted by scales and verniers; hence it can be used, if desired, to measure a picture, negative, or print. The back carries four teeth, as shown in Fig. 2; these are so set that the intersection of the horizontal with the vertical line is at the position of the optical centre of the lens, such lines being truly vertical and horizontal respectively when the levels are in a certain assignment. Following Le Bon's admirable suggestion, I use a graduated ground glass, Fig. 3; the vertical and horizontal lines on which exactly correspond with those given by the teeth. The slides are "single," and the plates they contain are pressed against the teeth during exposure. The top of the camera carries levels and a compass. The side of the camera has a scale and vernier, whereby the actual focal length can be at any time ascertained. The lens is a Zeiss widest-angle anastigmat of 143·9 millimetres focus. A camera thus equipped is capable of very accurately measuring both horizontal and vertical angles, the tangents of which can be easily obtained by dividing the ground-glass readings by the actual focal length. Vertical angles are not so much in request as horizontal ones; hence it is a saving of time to set the camera on a horizontal circle, preferably reading to minutes at least. The connection should be rigid and adjustable. The lens' centre is placed immediately over the circle's centre.

The ancillary apparatus is of the usual character. A measuring tape, plummet, signals, and a levelling rod, are required as in the older procedure. In levelling, a French veterinary rod, as recommended by Le Bon, is of great service. For rough verifications of angles of buildings, I have designed the goniometer shown in Fig. 4. It will be seen that this consists of a wooden triangle with movable joints. The joint at *a* is opened in or shut upon the angle to be measured, and then held tight by a butterfly nut placed there. On bringing *bc* to a pin or mark *p* on the arm *ad*, at the intersection of *ad* with *bc*, the angle is read off on a scale.

The methods of carrying out some of the ordinary operations of photo-surveying may now be indicated.

Dimensions.—A machine, building, or other object is photographed in some plane parallel to the plane of the ground glass. In the case of a building, such parallelism is generally secure when the lines of masonry are evidently parallel to the lines of the ground glass. Very visible scales of feet and inches—or, still better, metric scales—are placed where required, and photographed with the subject. If the building be in a flat plane at right angles to it, a point upon it opposite to the optical centre will have the same height as the lens, and this height will serve as a scale.

Heights and distances.—In order to determine the height H of an object (a chimney, house, or mountain, for example) at a known distance, the camera is set up vertically, and the object sharply focussed, preferably at centre. The height h of the object is read on the ground-glass scale, and the actual focus F on the side scale. The relation

$$\frac{H}{h} = \frac{D}{F}$$

evidently must give the height (or width), Fig. 5. If the focus and distance can always be kept the same, a pocket reference table can easily be calculated whereby heights or widths can be read off at once without calculation.

When the object is inaccessible, a base line of known length B, Fig. 6, is measured towards the object, and two observations, h, h', are made of the respective lengths of the image on the ground glass. It can easily be shown that

$$H = \frac{B}{F} \cdot \frac{hh'}{h - h'},$$

F being, of course, kept the same in both determinations. The unassisted eye can read, with practice, to $\frac{1}{20}$ mm. This method is, therefore, sufficiently accurate for all heights up to a few hundred feet. For greater exactness, it is preferable to make photographs at each station, and measure the negatives or prints at home. Prints should be made on bromide paper, with amidol developer. Such paper, I find, does not shrink if first soaked in a 2 per cent. solution of formalin and then dried at a gentle heat.

Levelling.—This is done in the ordinary way, the lens taking the place of the telescope. It is clear, however, from the equation

$$\frac{H}{h} = \frac{D}{F}$$

that, if the height of the rod be known, no chain is required.

Surveys.—Surveys of buildings can be plotted out from single photographs, provided the position of the horizontal and vertical lines and the focal length are accurately known. From two to four photographs are usually required for one building. Subjoined is one of the methods employed for this purpose, Fig. 7.

This method gives best results when lines that are horizontal in the subject are also horizontal in the photograph. When this is not the case, they should be rectified by re-photographing with the aid of the necessary "horizontal swing."

The position of the optical centre having been ascertained, a line is set off to the left, having the actual focal length. From the optical centre, and from the left-hand extremity of the line indicating the focal length, lines are drawn through the points to be plotted out on an arbitrary horizontal line. The distance between the positions of these points on the horizontal line is the radius of a circle whose intersection with a perpendicular below the first intersection, gives the plotting out of the first point. The successive points are joined up to give the ground plan. A general ground plan of a street, a shed, or an interior, can be drawn in a similar way.

Another method is indicated in Fig. 14. The best work, however, and especially field work, is always done with two photographs taken at either end of a base line of known length. In this case, more than usual care should be taken to obtain photographs showing all the points of interest with the greatest possible contrast.

The camera is set up, and adjusted to cover at centre a signal at the other station. The circle is then rotated until some very well defined object now appears at the centre. The angle of rotation is read off, and a photograph taken "at point." The camera is then set up at the other end of the base line, and the angle to (preferably) the same point is observed; here also a photograph is taken. Prints from the negatives are made upon the unshrinkable paper before referred to. The marks of the teeth will as a rule be very strongly visible, and must be carefully joined up. From every point intended to be plotted out, a perpendicular is dropped to the horizontal line; and a pencil copy of this line, marked with the corresponding widths, is made on a strip of paper. The subsequent operations will be clear from Fig. 8.

First, a base line is drawn equal to the actual focal length. At either end of this, lines (also of the focal length) are drawn at the angles previously measured with the circle. At the extremity of each of these lines, a line is drawn at right angles. This represents the horizontal line in the picture, and to it are transferred in each case the marks from the paper-strip. All that is necessary is to join the station points A and B with these marks successively, and prolong them. It will be found that by their intersections, which of course are to be joined, an orthogonal ground plan of the subject will be arrived at. The scale of the drawing will be the scale (in this case 54·62 metres reduced to ·143—say $\frac{1}{382}$) indicated by the absolute measure of the base line. All horizontal dimensions, angles, and distances, are given in such a plotting. Thus, for example, the distance of any point from either station is measured at once on the plan. Obviously, also, the triangle between the base line and the flag staff is completely known, and can be used as a starting place for other triangulations.

In order to determine the height of an object from plottings of this kind, the following procedure is adopted. Let HH, Fig. 9, be the horizontal line, and p a point in the picture, whose height is to be determined. From p let fall a perpendicular to x on HH; join Ox, and draw $xy = px$ at right angles to Ox. Prolong Ox to P, the intersection-point already plotted out; draw PQ at right angles to OP, and prolong Oy to intersect it in Q. PQ is the height required, as determined from the station O. The angle a is obviously the visual angle. A similar determination is made with the other drawing, and, if the stations were on the same level, there should be a very close agreement.

In the particular case under consideration, the height of the flag-staff at Doune Castle above the lens' centre—after a slight correction found by levelling—was found to be very nearly the same in both cases, the difference being about ·05 metre (about 2 inches)—which may be considered fairly satisfactory work for a misty afternoon.

As the method is capable of giving heights and distances, it is obviously applicable to contouring—*i.e.* the consecutive distances of points of equal height. Fig. 10 shows a contour, traced in this way, of Stob an Fhithich, a hill lying to the west of Glen Falloch, near Ardlui.

The survey was made from the opposite side of the glen, looking over Geal Loch and the River Falloch. I have added a profile

(Fig. 11), which, of course, can be readily traced anywhere (in this case through AB). A collotype illustration (Fig. 12) of a print used in this work is subjoined.

Profiles are of much use in excavation work, and other problems of content. If, for example, we have two contiguous profiles, it is easy to cut them out in cardboard or tin and set them upright against a rectangular background. The interspace is filled with clay, or some other plastic material, and this is dressed to shape. The clay is then transferred to a measure measuring ounces, or to a rectangular box, and its bulk in terms of cubic feet ascertained. Sand may also be used. When this result is multiplied by the cube of the inverse of the scale of the photograph, the number of cubic feet to be excavated is known.

Photographic surveying can be utilised for a great variety of subjects. Messrs William Denny & Bros., of Dumbarton, were good enough to permit me to visit their works, where I had intended to operate on a ship in dock. Unfortunately, however, a second "station" could not be obtained on the day of my visit, owing to the presence of some large obstacles. I have, however, the pleasure of submitting to the Institution (Figs. 13-16) a plotting of some sheds, etc., presenting several features of interest. For this opportunity I desire to express my cordial thanks to the Messrs Denny.

The following writers may be primarily selected for reference:—

Le Bon, G. Les Levers photographiques, et la photographie en voyage. Paris, 1889.

Meydenbauer, H. Das photographische Aufnehmen. Berlin, 1892.

Steiner, F. Die photographie im Dienste des Ingenieurs. Wien, 1893.

Deville, E. Photographic Surveying. Ottawa, 1895.

Discussion.

The discussion on this paper took place on 22nd March, 1898.

Mr Charles C. Lindsay (Member) looked upon the paper by Prof. Mills as being a very interesting and useful addition to the transactions of the Institution; and not only was the Institution indebted to Prof. Mills for a great deal of useful information, but also the civil engineering profession generally, as well as surveyors and

Mr Charles C. Lindsay.

architects. He believed that photo-surveying was of great use in many ways, but was afraid he would have to qualify his remarks with regard to its use in ordinary practice. In the practice of civil engineering or surveying, nothing would be more delightful than that a photograph might be taken and the detail laid off in one's own office, but he feared that the peculiarities of the system would not admit of that being done as economically as the ordinary system of surveying and taking measurements; chiefly because of objects such as trees, chimneys, hedges, etc., coming in the way, to eclipse what had to be filled in afterwards, and that with great difficulty. At the same time he looked upon the system as unique and perfect for military surveys and pioneer work, and also in the delimitation of frontiers, such as that, between Canada and the United States, referred to in the paper. There a wonderful amount of work had been done in a very short space of time, but ultimately the details, which would require to be more definite and correct, would have to be filled in. The system which Prof. Mills had adopted seemed to him to be scientifically almost perfect, and the only defect was in the lens. Every photographer knew that the further he went from the centre of the plate the less correct were the distances, either vertically or horizontally; and althongh Dallmeyer and Zeiss had come very close to perfect lenses, so that they almost gave perfect results at the sides as well as at the centre, still absolute accuracy was required in civil engineering operations. In that respect, coupled with the difficulty of filling in eclipsed portions of the work, the method must, in the meantime, be considered somewhat defective, although he did not think it required any qualification, so far as pioneer work was concerned. He merely excepted work done in the ordinary practice of the civil engineer, surveyor, and architect.

Mr James Waddell (Member) asked Prof. Mills whether the method had been used except on what Mr Lindsay called pioneer work. He could imagine that it would be sufficiently accurate in Canada, where a few acres was neither here nor there; but his experience of about twenty years was, that he was afraid land owners and others in districts where engineering was carried on, Mr James Waddell.

especially where property was very valuable, would not take the results of scaling. Prof. Mills gave a scale which was to form part of the photograph, as it were. His experience was that a drawing to be the very acme of perfection would be one that would not require a scale at all, but all the dimensions would be marked on it. For instance, the fall in some parts of the Loch Katrine aqueduct was 10 inches to the mile, and he did not know whether 10 inches could be shown by that system. His experience in surveying was that the angular measurements were not so accurate as one was apt to suppose. For instance, in setting out a building it was far more accurate to measure a right angle by a right-angled triangle with a multiple of 3, 4 and 5; and in the length of a building with 300 or 400 feet of a side, a measurement with a steel tape was more accurate than with an ordinary theodolite.

Professor Mills, in reply, said that photo-surveying was certainly not exclusively confined to pioneer work, and it was as accurate as theodolite work. There was no reason whatever, why work with the camera should not be as accurate as with the theodolite. It was entirely a question of proper construction and in having the apparatus arranged with due regard to centre, and then results could be as accurately obtained as with an ordinary theodolite, and in some instances more accurately. With the photographic lens, the two Gauss points could be readily adjusted over the centre of rotation, which was not the case with the theodolite construction. Mr Lindsay had suggested that the further one was from the centre of the lens the less accurate would the angles be, and the less accurate his measurement. That was no doubt very true with a small lens for a large plate, but if one took a lens with a very wide angle such as was used for a big plate, by taking only a small portion of the field, accuracy was obtained up to the margin. The photo-theodolite, which was shown by him at the last meeting of the Institution, was furnished with a lens which ordinarily worked up to ten inches by eight inches, and this was used for a plate measuring only five inches by four inches. He thought it might be taken for granted that they had almost perfect accuracy with such an arrangement. Con-

Prof. Mills.

cerning the question whether the photo-theodolite had been used for anything else than pioneer work, he might mention that in Italy a large number of beautiful maps had been made for the Italian Government, for military purposes, by means of it. The same thing had been done in Austria, and a good deal of work had been done with it in France and Germany. The accuracy of land surveying as against photo-theodolite surveying seemed to be very strongly emphasised. He had been informed by an eminent land surveyor that six inches in the chain was, or had been, till recently, a common allowance in land surveying here, and if people were capable of being satisfied with an accuracy of that description, surely they must be satisfied with the photo-theodolite giving as great accuracy as any theodolite constructed. At the present moment heights could be measured closely approximating to the Ordnance Survey, up to three or four miles. Now that telephoto lenses were coming into use as accurate results would probably be obtained up to at least ten miles. Beautiful photographs had been taken, showing almost perfect detail, up to a distance of fifty miles. There was one existing, a photograph of Mont Blanc, made with a first-class telephoto-lens, and that at fifty miles showed perfect detail. He was, therefore, of opinion that the possibility of photo-theodolite work, whether for near objects or very distant objects, was as great as that of any theodolite that was ever made. One advantage was that, in a few seconds of exposure, almost limitless details were acquired, whereas the theodolite had to bring out one point after another, and a single mistake ran through the whole. On the other hand photographic records were done with equal accuracy all over the field. The fact that this method was coming so largely into use abroad struck him as a strange phenomenon, and it was with the purpose of placing its great advantages before a Scottish institution, that he had been induced to read this paper at the last meeting.

The Chairman, Mr ROBERT CAIRD, F.R.S.E., Vice-President, said that Dr Mills' paper was one of extreme interest and great novelty, and he had much pleasure in proposing a vote of thanks to the author for his most attractive paper.

The vote of thanks was carried by acclamation.

NOTES ON THE BELLEVILLE BOILERS OF THE T.S.S. "KHERSON."

By Mr G. GRETCHIN (Member).

Held as read 22nd February, 1898.

SEE PLATE XVII.

DURING the last three meetings of the Institution I have noticed that the members take great interest in the question of water-tube boilers, therefore, I thought it probable that they would like to hear something about the sea-going practice with boilers of the Belleville system on board the Russian Volunteer Fleet steamer "Kherson." The full description of the machinery of the "Kherson" is to be found in *Engineering* of December 6th, 1896, and the graphic log of a part of the vessel's run from St. Petersburg to Vladivostock, and from Vladivostock to Odessa, has been printed in the Transactions of the Institution. (See page 161, and Plates X., XI., and XII.)

There are 24 boilers placed back to back along the ship (with furnaces athwartship), in three separate groups of 8 boilers each. Each boiler contains 8 elements; and each element 20 lap-welded iron tubes of $4\frac{1}{2}$ inches outside diameter. The two lower tubes of each element are $\frac{3}{8}$-inch thick, the two next $\frac{5}{16}$-inch thick, the rest being $\frac{1}{4}$-inch thick. The connecting boxes are of cast steel. The total heating surface amounts to 35,350 square feet, and the fire grate 1132 square feet.

From erection on board ship to the departure from Newcastle.—The building of the boilers was begun in the beginning of March, 1895, the erection on board ship commenced in November, 1895, and the boilers were ready for steam trials in February, 1896. Before the trials commenced the boilers were cleaned out with soda; about 70 lbs. of soda was put into each boiler, and steam was kept up for about 12 hours. The boilers were then blown down. On the 28th of February the first mooring trial took place. The boilers of the middle group were under steam, but it was found that they did not work with equal satisfaction on the port and starboard sides. Everything went well on the starboard side, but, at the same time, in all the boilers on the port side leakage took place in the joints of the bottom boxes with the feed-collectors. The feeding of the port boilers was not quite so regular as on the opposite side. The irregularity I have just mentioned became worse towards the end of the trial. All the conditions of working the boilers on both sides were similar, with the exception that there was a list to the starboard side of 10½° at the end of the trial The following day the tubes of the boilers were examined, when it was found that those of the starboard boilers were practically straight, while those on the port side were nearly all bent downwards; 13 of them were out of line from 1 inch to 1½ inches, and were replaced by new ones. On the 8th of April the second mooring trial took place. The after group of boilers was then under steam, and it happened that on this occasion the list was to the port side. Precisely the same irregularities took place, but on the opposite side of the ship. The subsequent examination of tubes showed that those of the port boiler were straight, while those of the starboard boilers were bent downwards, but not to such an extent as on the previous trial. The list during this trial was not more than 5°, and the trial was carried on for a shorter period—only 2½ hours.

The coincidence of the list of the ship and the irregularity of working of the boilers on one side was observed afterwards, during the whole round voyage; each time the list was on one side, leakage was found in the feed-collector orifices on the opposite side; and the feed-pumps on that side also worked irregularly. The examination of the tubes, which was made each time the boilers were stopped, showed the bend of the tubes to be downwards on the opposite side from that to which the ship was listed, and, what was of greater interest, the tubes on the other side, which were bent before, had a tendency to become straight, and some of them even got bent upwards. As a rule, the lower tubes of Belleville boilers tend to bend upwards if the boilers are working in their normal condition. I may observe that I had previously noted this phenomenon on board the "Ville de la Ciotat," a French steamer, on which I made a passage from Marseilles to Port Said, at the end of 1895; and in that case saw a number of tubes bent in such a manner as I have described.

The correspondence of the bending of the tubes and the list of the ship can be explained, I think, in the following way:—Supposing the list is on the starboard side, the first, third, and all the uneven tubes of the elements of the port boilers will be horizontal if the list is equal to 2½°; and the back ends of those tubes will be higher than the front ends when the list is greater than the above. (See Figs. 1 and 2.) In this case, the bubbles of steam generated in the first lowest tube, which is directly connected with the feed-collector, will go, or have a tendency to go, to the feed-collector. It is possible, that under certain conditions the power of motion of the bubbles in this direction is greater than the force which produces circulation. At the moment this comes into action the water supply will be checked, the tube overheated, and liable to be bent downwards. Probably the main reason why M. Belleville placed on the downcast pipe a non-return valve (the action of which Professor Watkinson illustrated so clearly at the January meeting) was to prevent water running away from the elements should the boiler be placed in conditions similar to those above mentioned. If this return motion of the bubbles takes place, and if the tubes get bent, as experience proves, it is quite possible that these two phenomena may occur at the same moment. When the tube is bending, the female cone of the bottom connecting-box moves on the male cone of the feed-collector, and the result is leakage through the joint. This supposition is proved by the fact that, the leakage was always much worse in the boilers which were working under conditions unfavourable as regards circulation of the water.

On the 16th of May the official twelve-hours trial took place. The boilers worked quite satisfactorily, and without a hitch, excepting that the uptakes got hot twice or three times, but without any serious result further than burning away the paint on the funnel-casings. There was any amount of steam for 13,000 I.H.P. On account of other causes, which have no connection with the boilers, the delivery of the "Kherson" did not take place after this trial; but the trial trip was repeated on the 26th of August with full success, and on the 2nd of September the "Kherson" left Newcastle for St. Petersburg.

From Newcastle to St. Petersburg, and stay in the last port.—This passage was made in 117 hours. One group of boilers, the after one, was under steam. There was not a single hitch during the run except that one fusible plug gave out and could not be put in when under steam. All the apparatus which go to make up the Belleville installation; viz., the automatic feed-regulator, the reducing-valves, the separators, and the automatic blow-off valves, worked satisfactorily, without giving any trouble. The feed-pumps acted well also, but on the last three days they started to work with knocks at the ends of the strokes. These knocks were afterwards found to be caused through the tails of some suction, and delivery-valves being torn off. The valves were of cast brass, which probably accounts for the breakages. During the whole voyage there was a leakage through the joints of the bottom boxes of the port boilers. The ship was inclined to the starboard side all the time. By tightening up the anchor bolts this leakage was stopped for a time, and then it started again.

Careful observations were made during the passage, of the saltness and acidity of the water in the boilers. Lime was not put into the boilers during the first two days, but at the end of the second day the water was found to be slightly acidulated, as litmus paper, when immersed in water drawn from the boiler, became somewhat red in colour. Lime was then put into the boilers, and after the quantity of it had been increased to 2½ lbs. per day for each boiler in use, the litmus paper test did not show any acidity. The boilers were blown out twice in 24 hours, for 8 or 10 seconds every time. During the first run we were unable to fire the boilers in accordance with M. Belleville's rules, as it was found impossible to overcome the old habits of the firemen—habits of keeping pretty thick fires, and to fire each boiler independently of the other, a practice which was quite unsuited to the firing of the Belleville boilers, where the main principle ought to be a thin fire, and a regular supply of coal to one boiler after another in a certain order. The result was overheating of the uptakes and, of course, a pretty high coal consumption.

During the stay in St. Petersburg, the following work in the boiler room was done :—

(1) The tubes were examined outside, and measured. The results of measurement of the two lowest tubes, which were in direct contact with the fire, will be found in the Table on Plate XVII. The Roman figures represent different elements in the boiler; the Arabic ones represent the boilers themselves. For comparison, I have put in the same table the result of measurements of the same tubes made in Newcastle. The figures without arrows represent downward bending, while those with arrows indicate upward bending. It can be seen from the table that nearly all the tubes of the port boilers bend downwards, and three of them as much as ¾-inch. In the second row of tubes, which was more inclined when the list was to the starboard side, the bends decreased, and many of the tubes returned to their original form. The change of form of the tubes on the starboard side was not so considerable as on the port side; nevertheless, in 23 out of 32 tubes the bend had decreased. Six of the above 23 became quite straight, and four tubes even got bent upwards.

(2) The next work in St. Petersburg was the examination of the inside surface of the lower tubes in all the boilers. In some boilers the tubes were examined diagonally, one in each row, from the bottom to the top. In the lowest tubes some soft sediment was found, in the form of lime mixed with oil. The thickness of the sediment did not exceed 1 millimetre. In the second row of tubes, the quantity of sediment was so small that it was neglected, and the

remainder of the tubes were found quite clean. To remove the sediment, it was sufficient to push a piece of rag, attached to a stick and moistened in a solution of caustic soda, through the tubes three or four times. It may not be without interest to mention the form and position which this sediment took. In all the tubes in which sediment was found, it was distributed as shown in Fig. 3. The thickest part of it was on the top half of the tubes. In the end tubes, placed next to the walls of the boiler, the sediment was found to be thickest on the upper segment of the circle nearest the wall. It is necessary to add, that the total amount of sediment was always greater in these end tubes, the cause of this being their near position to the mud drums. I was under the impression that the only cause for the sediment being deposited as indicated in Fig. 3, was the active generation of steam bubbles on the part of the tubes most exposed to the heated gases, which prevented particles of lime and oil sticking on the bottom side. Observation of the working of the Belleville boiler model showed that, immediately the bubbles were generated, they occupied the top part of the tubes, and, as Professor Watkinson rightly supposes, the particles of lime and oil have more chance to stick to the wall in the steam space of the tubes, than on the bottom portion where the water runs and tends to wash them away.

(3) The mud drums were examined through the hand-hole doors, and no sediment was found.

(4) Some of the bottom covers of the water-gauge column were taken down, and the interior of the column examined, but no sediment was found in it either. The absence of sediment in the column was the result of blowing out through the special cock fitted in the bottom cover. It is useful to blow out the column, because the pipe which connects the column with the boiler is thus kept clear.

(5) The valves of the Belleville pumps were examined, and seven of them were found without tail-pieces, while many of the seats required grinding.

These were the principal items of work done in St. Petersburg. The steamer left that port on the 9th of November, 1895. I do not propose to give a description of each run, but shall try rather to explain generally the system of keeping up the boilers, the main defects which were noticed, and the work which was performed to keep them ready for use, *from Cronstadt to Vladivostock and from Vladivostock to Odessa.*

MANAGEMENT OF THE BOILERS.

Filling up the Boilers.—The boilers, when not under steam, were always filled up with fresh water. The sediment in the tubes, if any, never hardened under such conditions.

Raising Steam.—It generally required about two hours to raise steam in the boilers. If the fire increased gradually during that time no hard knocks could be heard in the tubes, but otherwise water-hammer action was experienced in them, which doubtless weakened the joints. In some cases steam was raised in the space of an hour. Here it may be to the purpose to remark, that although with water-tube boilers on board it is perfectly possible to get steam at an hour's notice, still, such a period of time is too short to warm up the engines, and specially where large L.P. cylinders have to be considered. It is, therefore, absolutely necessary to have connections from the donkey boiler to the main engines, as in the case of the "Kherson."

Firing the Boilers.—The most difficult, and at the same time the most important part of the management of Belleville boilers is their firing, for on this depends not only the furnace efficiency, but also the length of life of the boilers. The rule for firing seems to be a very simple one; viz., to keep the fire constant at a thickness of not more than 3 or 4 inches, and everything will be all right. Such a system of firing gave very good results on all the evaporative trials, short sea runs, etc., when the firemen, and specially the conductors of the trials, were experts. On the long runs, and with ordinary firemen, firing is by no means so simple, and the difficulty on this point counted as a considerable disadvantage of the Belleville boiler in comparison with boilers having combustion chambers. The method of firing which was found most suitable on the "Kherson" was as follows:—One fireman to each boiler. The fireman of No. 1 boiler opened one-half of one furnace door, and put three shovels of coal into the furnace. He then put the same quantity of coal through the second half of the same door. When No. 1 boiler had thus been fired, the fireman of No. 2 repeated the same operation with his boiler. When the fourth fireman (I refer only to one side, but, of course, on the other the method was the same) finished firing, the fireman of No. 1 boiler began again, but this time put the coal through the second door, and so on at certain regular intervals. Some suggested that one fireman should shovel a certain amount of coal into all four boilers, then another fireman should follow up and do the same. We failed, however, to manage firing in this manner, as the responsibility was divided, and one could not find the man who spoiled the fire, etc. I may mention, however, that the firemen got used to their work, as can be proved by the gradual decrease of the coal consumption during the homeward voyage.

Cleaning Fires.—Fires were cleaned twice a day when using Cardiff coal, with Japanese coal (Itchimuri) every 8 hours, and with Japanese Tokasima coal about five times in two days. During the cleaning of the fires the graduating feed-valves were kept full open as usual; some people recommend, however, that these valves should be slightly closed to prevent filling the boiler too much, and so avoid any possibility of priming. No difficulty was experienced with priming, but at the same time, it was thought safer to depend on the automatic feed-regulator than on human judgment as to the quantity of water required for the boiler at a given moment. It was noticed that the quantity changed very rapidly, and that the boiler might easily run short of water in a very few minutes, as there was no reserve of water in it. The ash-pans were always kept full of water, with the result that the fire-bars of cast-iron never burnt away. Only 25 of the total number were replaced on account of being twisted considerably.

Cleaning Tubes Outside.—This was accomplished by means of a jet of steam, and generally took place after a four or five days' run when changing on to a fresh group of boilers. One of the boilers was kept under steam to furnish a supply for cleaning the boilers which had previously been working. Every time while in port the tubes of the working group were cleaned. Sometimes when the boilers were cold, the tubes were brushed by means of specially soft brushes. The two lower tubes of the boilers, after being under steam for 24 hours, became covered with silicious ash, but as soon as this was noticed it was rubbed away by means of half-moon scrapers with a long handle. If this ash was left untouched, the thickness of it, after two days, would be about half-an-inch, and being a bad conductor, it would prevent good transmission of heat.

Feeding the Boilers.—The feeding of the boilers never gave trouble during the whole voyage. The water level, when the engines worked regularly, kept steady. It is true that there was no heavy rolling all the time, but when rolling up to 10° or 12° no disturbance was noticed in the feeding. Whenever rolling began, however, the non-return valves in the mud-boxes could be heard clacking, showing that under those conditions such valves are severely worked, and that they are absolutely necessary, and must be kept in good order. The height of the level in the column sometimes required to be regulated by removing or adding to the weights on the back end of the levers. So at the end of the outward voyage three or four weights were removed from each lever, but after overhauling and cleaning all the spindles of the feed-regulators in Vladivostock, it was found necessary to put them back again, as without them the water level was kept too high.

Lime in the Boilers.—As mentioned before, 2½ lbs. of lime were put into each boiler once every 24 hours. Litmus paper showed no acid in the water, and the condition of the tubes inside was good; this quantity of lime was, therefore, adhered to as a standard. The density of the water was always less than $\frac{1}{32}$, with the result that no hard scale was present in the tubes. Besides the lime, caustic soda was sometimes put into the boilers, following the practice of the French engineers. Four hours before entering port, from 7 to 10 lbs. of caustic soda for each working boiler were put in the lime tank, and the pump allowed to work through this tank for about 45 minutes. In port, the boilers were blown down, and afterwards filled up with fresh water. Less sediment was always found in the tubes after introducing caustic soda.

Blowing out the Boilers.—This took place twice during every 24 hours, and for not more than 7 or 8 seconds at a time. When the boilers were stopped, the water was blown down until out of sight in the gauge-glass. The boilers were then filled up with fresh water after they had cooled down. It was observed that the tubes were covered with moisture on the inside if there was water even in one tube, and the sediment only turned hard when all the water had run away and the hand-hole doors were opened. Drops of rusty water were noticed in the upper tubes of a boiler which was kept half full for some days. The examination of the tubes was made by the aid of an electric lamp attached to a long tube.

Belleville Feed-Pumps.—The pumps worked without failure all the time, but there was a knock at the end of the stroke similar to what was experienced on the run from Newcastle to St. Petersburg. The cause of the knock was the same as before; viz., weakness of valves. This defect, of course, decreased gradually as the valves were replaced by new ones of stronger pattern. There were on the "Kherson" two pumps for each four boilers. One of these pumps was kept working, while the other was kept in reserve, but always ready for use. The pump was working hard all the time, as the boilers were working at full power. Possibly, on account of the severity of the duty, the packing did not stand more than four days; by the end of that time more packing was found to be necessary, or the stuffing boxes had even to be repacked. The packing was of M. Belleville's own make. The ebonite packing rings gave no trouble during the whole voyage, indeed, they worked as well at the end as at the beginning.

Reducing Valves.—The port valve never leaked or stuck, while the starboard one stuck frequently and leaked through the gland of the stuffing box in spite of repacking. When sticking occurred only steam of a lower pressure was obtainable. The cause of the difference between the working of the port and starboard valves could not be ascertained, but it was certainly not connected with the treatment of the valves; very possibly it was on account of some fault in fitting.

The Main Separators.—The main separators, as well as the automatic blow-off valves, always began to work when the water in a separator rose about two inches above the normal level. The number of blow-offs was different, but, on an average, six to seven times every four hours, and each time for about five or six seconds; this number was increased to ten when the fires were cleaned. Only once the blow-off valve of one separator gave trouble. It happened when the spindle of the valve, which leads the water to the condenser, broke at the neck. It took two hours to fit the spindle in its place again, and during this time the separator was blown-off overboard, by hand.

DEFECTS IN THE BOILERS.

Leakage of the joints between the bottom boxes and the feed-collector orifices.—From the commencement of the steam trials this leakage was noticed, and it gave some trouble during the whole voyage, especially when there was a list—either to starboard or port. When drops of water started to run from the above named joints, the nuts of the corresponding securing bolts of the elements were screwed up; this stopped the leakage for a time, but it appeared again and again; the screwing up of the nuts did not altogether remedy the evil. We therefore took the first opportunity to replace the joint ring, which was generally found shifted to one side or broken. During the round voyage joint rings were replaced in nearly all the elements. The main cause of this trouble consisted in the material of the joint rings, although at the time this explanation did not occur to me. They were made of *steel* coated with nickel, and not of *nickel*, which the latest practice shows to be the most suitable material for the purpose.

Burst Tubes.—Four tubes were replaced during the round voyage. Three of them were found out of order when examined outside. On the surface of each of these a protuberance with a crack on the top of it was observed. These tubes were replaced during the stay in ports, and each of them required about 10 working hours to replace. The fourth tube burst on the run from Singapore to Nagasaki, on the second day's steaming of the boiler to which it belonged. The fires were just cleaned when the fireman in charge heard some noise coming from inside the furnace, and immediately after, steam began to come out so violently that it was difficult to ascertain its origin. The level of water in the gauge glass fell rapidly, and therefore the order was given to draw the fires. The tubes were black at the time, and not more than two minutes expired when it was noticed that the tubes were getting hot. The feed-valve was at once shut. When the fires had been taken out, the tubes of all the eight elements were red hot from bottom to top. Smoke-box and furnace doors were shut, and the boiler gradually cooled down. Examination on the next day showed that the second tube from the bottom was cracked on the weld for a length of 5 inches, the width of the crack in the middle being about half-an-inch. The rest of the tubes were untouched. The burst tube was replaced in Vladivostock, and the boiler worked afterwards as well as before.

Bending Tubes.—About three-quarters of the whole number of tubes were out of their original straight form when the "Kherson" returned home. After every time a boiler had been in use the tubes were measured, and without exception a change on the previous bend was found; sometimes it was worse, sometimes better. In some cases the tubes were bent upwards, but on every occasion the bend was in accordance with the list of the ship when the boilers were under steam. The largest number of tubes were bent about ⅜-inch in the middle, the smaller number of them only ⅛-inch, but a few as much as 1⅛-inches.

Brickwork.—At the end of the outward voyage the back brickwork in five boilers was found cracked, and with a convex bulge. When pulled down for re-building, it was seen that some of the girders of the back division plate of the boilers was burned out, and five of these were replaced by new ones. On the homeward voyage similar damage was done to some extent in all the boilers, and it was found necessary, on arriving at Odessa, to rebuild the back brickwork in every case and replace all the girders.

The defects just mentioned were the most important discovered in the first voyage of the "Kherson." All the repairs on the voyage were carried out by three artificers, under the supervision of an engineer, who was in charge of the boilers. To keep the boilers in condition ready for steaming required continuous work at sea for one artificer and one fireman, during two-thirds of the number of steaming days. Amongst the things which always required overhauling were the joint rings of the feed-collectors, nut couplings of the feed and water-gauge standard pipes, valves of the feed-pumps, etc. In port there was always sufficient work for three artificers, besides ten firemen who were engaged in general cleaning of the boiler tubes, fire grates, fittings, etc.

COAL CONSUMPTION.

As the members of the Institution may see from the graphic logs of the "Kherson," (page 161, Plates X., XI., XII.), the average coal consumption was from about 2·15 to 2·2 lbs. of Cardiff coal per I.H.P. per hour. I have not the indicator diagrams at hand to show what the steam consumption of the engines was, but they were working under very unfavourable conditions, at about a quarter of full power. Comparison, however, with the coal consumption of another Russian Volunteer Fleet steamer, working under similar conditions, shows the increase in coal consumption on the "Kherson' to be not less than 10 per cent.

The Chairman, Mr Robert Caird, F.R.S.E., Vice-President, observed that if time had permitted, a discussion would have been taken on Mr Gretchin's paper, but the hour was so advanced that that was impossible. At the same time, he did not see why they should deprive Mr Gretchin of the pleasure of receiving the thanks of the Institution, for his very admirable paper. Mr Gretchin's paper was an admirable one for various reasons; one in particular being its extreme frankness. The author, whose obser-

vations had been taken in the most excellent way, had given all of them a lesson in presenting the data in a full, frank, and conscientious manner. He only wished that they had some data on their side taken as conscientiously, for purposes of comparison.

On the motion of the Chairman a vote of thanks was passed to Mr Gretchin for his paper.

SOME OF THE ECONOMIC AND PRACTICAL ASPECTS OF ELECTRICAL POWER DISTRIBUTION IN FACTORIES.

By Mr Henry A. Mavor (Member).

Held as read 22nd March, 1898.

(SEE PLATE XVIII.)

During the past two years there has been in this country a decided awakening of interest in the possibilties of electric distribution of power in factories. Long distance transmission is less interesting to us because of our local conditions. Proposals have been from time to time made to turn to account such sources of power as exist for example at the Falls of Clyde, or even to use the tides for the production of electric energy for transmission to distant points. The fact that fuel is cheap and the cost of transport small, will probably militate against the realisation in the near future of such dreams. For such power using centres as we propose to discuss in the present paper, it may be taken for granted that under existing conditions the power can be produced, at or near the point where it is to be used, so cheaply, as to preclude any consideration of means for transmitting it from a distance.

A very interesting scheme is on foot in the Midland Counties of England to generate electricity at the pithead, and to transmit it to power using centres in the form of high tension alternating currents. It is anticipated that many users of power who are at present working under uneconomical conditions will find it advantageous to avail themselves of this supply, which is expected to be available at a price something like one penny per horse power per hour. It seems probable that the operation of such a scheme would only be commercially practicable in districts where the local authority does not control electric supply, because when the local authority has to be dealt with, the price obtainable from that authority would not probably exceed the rate at which they could themselves produce the power without any allowances for profit. As the local authority could, and doubtless would, avail itself of the most efficient means of power production, the only item to set-off as a possible profit to the supply company, would be the railway carriage in the coal. Unless under very exceptional circumstances, it is hardly conceivable that this margin would be sufficient to cover the very heavy capital cost of the generating plant. On the other hand, undoubtedly, there is an enormous field for the electric motor among small users of power who can obtain the electric current at a moderate rate, from supply companies or local authorities. This class of consumers form an important group by themselves.

I propose in this paper to confine attention to those factories where the total power required is upwards of 50 Horse Power, and where the power is produced on the consumer's premises.

To what extent, and in what manner in such factories, can electric power transmission be advantageously used?

The conditions as to requirements of the work to be done, and present methods of doing it, are so various that it is difficult to enter upon a useful discussion on general lines.

Two typical groups may be chosen for discussion :—

Group 1.—Factories where the power is delivered from one main engine through gearing, belting, or ropes, to line shafting, which is in turn belted or geared to machinery closely grouped round the source of power. This includes most factories where the machinery runs at a constant speed on a fairly steady load; as in spinning and weaving factories.

Group 2.—Where the nature of the work is such that the power must or ought to be delivered direct from the prime mover at the point where it is applied to the work. This includes factories where the machines to be driven are widely divergent in character, are widely spaced, and run at different and varying loads and speeds; as in paper mills, printfields, chemical works, steel works, foundries, shipyards, and many engineering establishments where work of a varying character has to be accomplished.

This group affords by far the most promising field for the electrical engineer.

In the first group, advantage can, to a large extent, without the use of electric transmission, be taken of the direct economies to be gained by the centralisation of power production, and the electrical engineer must, as a rule, base his argument in favour of the adoption of electric transmission rather on such points as saving of space and cost of construction, absence of noise, and additional convenience, than on any claim for direct economy in coal consumption.

Of course there are very many cases where an enormous saving could be accomplished, even in such factories, by the introduction of a good modern electric equipment; but, generally speaking, an equivalent saving could be gained by more direct means. There are, however, important advantages gained where electric motors can be applied directly to the working of machinery of production. No matter how well engineered the arrangements may be in the first instance, all systems of transmission by rope or belt are subject to increasing and varying slip, and, apart altogether from the loss of power arising from this cause, this has the very serious result of reduction in speed of the machinery of production. Thus, a slip in the belt or rope driving a machine or group of machines reduces the output in direct proportion to that slip, while the total expense of production remains the same. It is quite certain that this is a frequent source of loss even in the best managed factories. The electric motor can be arranged to run at constant speed if the electric pressure be maintained constant, and this can be, and is easily regulated, observed, and recorded automatically if necessary, and the speed may be maintained constant within any desired range.

While, as a general rule, in such factories it appears that the case for electricity is not strong enough to warrant any very great capital expenditure, with a view to direct economy in fuel, it by no means follows that there may not be exceptions to the rule. Such exceptions would probably be found in factories where the nature of the machinery and transmission is such, that after the best that gearing and straps can do, has been done, there remains a loss between the prime mover and the producing machinery of more than 25 per cent.; or, in factories where the machinery is used in an intermittent manner, and where a saving could be made by stopping the shafting along with the machines. There are very many such cases.

Looking at the matter from the standpoint of comparing the best that can be done by shafting with the best that can be done with electric transmission, it may be taken that where there are more than five steps between the shaft and prime mover and the point of final application of the power, it is possible to gain a higher efficiency by electric than by mechanical transmission.

For example, starting from the engine shaft, a belt or rope is taken to a main shaft—step one; to a countershaft on another floor—step two; across a room—step three; to the machine countershaft—step four; to the machine itself—step five. The total loss in transmission under favourable circumstances would probably be not less than 5 per cent. for each step, or say 25 per cent. in all.

The loss by electric transmission could certainly be reduced below this amount, and economy in working expense would result, even where the machinery is in constant use in both cases. Any irregularity in or interruption to the use of the power at the point of application, would tell in favour of electric transmission, because the loss is nearly proportional to the load in the electric, while in the mechanical transmission it is approximately constant, and independent of the load.

On the other hand, the capital cost of electric transmission in factories of this class is usually greater than that of mechanical transmission.

The problem of calculating for any special case is a comparatively simple one, because where the power is centralised it is not difficult to arrive at any required data for the calculation. The power required is easily ascertained, and the loss in transmission is easily estimated.

The best proof of the value of electric transmission in factories of this class is the fact that growing experience of its use is leading to its enormous extension, notwithstanding its greater first cost. The electrical engineer's best argument is appeal to experience of convenience, which cannot be directly valued in figures.

Group 2 differs in many essential respects from Group 1.

In nearly all such cases electric transmission compares favourably in first cost, and still more favourably in working cost, with any other system of transmission. Its only serious competitor in some cases is hydraulic transmission, and this generally is more of a useful coadjutor than a rival.

In this group, however, the whole question of comparison bristles with difficulty.

In the first place, it is extremely difficult to arrive at any approximation to accuracy in determining the amount of power actually required to perform the various operations usually performed by steam engines.

As a general rule such factories as those instanced in Group 2 use steam engines worked with low pressure steam. These engines are rarely kept in perfect repair, and the indicator diagram gives little information as to the effective power. It is not usual to make provision for indicating such engines, and there are many gateways for the escape of heat.

The best way to arrive at the actual power is to apply an electric motor to the work and record the measurement of power thus obtained. While in many cases such results accord very closely with skilled guesses at the actual power, there are many surprising differences.

Another very important element is the fact that in many such factories, for example, in paper mills, calico printfields, chemical works, and dye houses, there is a large quantity of steam required for heating purposes, and this has a most important bearing on any proposal to substitute electric motors for the small steam engines. Not only does such substitution involve the use of a steam distribution independent of the power distribution, but it complicates the calculation of efficiency ; because, in the case of a paper machine, for example, if the whole of the exhaust steam from the driving engine be used for heating the rolls, then the efficiency of the engine ceases to be of any importance whatever. The engine will exhibit its inefficiency by rejecting heat which is afterwards profitably utilised elsewhere.

Hence arises the custom so puzzling to one who wishes to compare the power efficiency of factories of different kinds, of checking the efficiency by equating the coal consumption to the output of the manufactured product. This after all is the real test as between one factory and another, but it altogether conceals the factors in the calculation which enable one to localise the losses.

Even in the case where this complication of heating does not exist, there is usually in such factories so constant a variation of load that it is almost impossible to arrive at accurate data of the actual power used.

Notwithstanding these difficulties, the case is so good for electric transmission of power, under such conditions, that it is not difficult to prove its superior economy in nearly every case falling under the description of Group 2.

Even in cases where the whole of the exhaust steam is profitably used and the efficiency of the engines themselves is of no importance, there is a serious loss of heat between the boiler and the engine. Every gallon of water sent to waste through the steam traps and drain cocks, represents a pound of coal uselessly burnt. Even when the pipes are well covered and perfectly steam tight this loss is considerable.

Last year, in response to questions addressed to users of power in England, Scotland, and Ireland, the answers compiled in tables A and B were obtained by the courtesy of about twenty out of one hundred factory owners. While, of course, it is impossible that these results as a whole can be quantitatively correct for scientific purposes, they possess a great value as a qualitative analysis of this important element of manufacturing cost.

These tables show very clearly that in all cases where there are many small engines the cost of power is a maximum. There is a decided tendency to exaggerate the power of small engines, and if this be taken into consideration in addition to their well known inefficiency, the result comes out much more seriously against them than is indicated by the figures in the tables.

We have the authority of a famous firm of engine builders, which has perhaps given as careful attention to the subject of steam economy in small engines as any in the world, for saying that, *all small engines, however well made and designed, are wasteful of steam in regular working.*

It is perhaps hardly necessary to enlarge on this point, but it may be amusing as well as instructive to look at a set of indicator diagrams Plate XVIII., taken from steam engines, together with the water consumption calculated from those diagrams. The engines referred to have been at work for about twenty years, and are still dragging out their miserable existence. They are in a factory where the main engines are working on a consumption of about 14 lbs. of steam per I.H.P. per hour.

Anyone who has looked at this subject at all, knows that they are not the only wasteful engines running in this country. The record of coal consumption given in the Tables A and B, for engineering workshops, would seem to indicate that there is a family resemblance traceable with those in use in those homes of engineering science, and that the "Blacksmith's Mare" is not alone in her limping inefficiency.

It is difficult indeed to put a figure on the saving to be obtained by the abolition of such engines and the centralisation of power production in efficient engines of large size, but no one can doubt that it is the right thing to do. It may be broadly stated that by the aid of electric transmission the worst cases in Group 2, Table B, could be brought within the region of economy which is already attained in Group 1, Table A. A loss of 30 per cent., which is a liberal allowance for electric transmission, is a mere bagatelle when compared to the awful waste shown in several of those cases.

In compiling these tables, the actual answers given by the factory owners are embodied in Tables A and B. In most cases the data were given in a sufficiently complete form, but in others exact information was not obtainable. In calculating Table C it was therefore necessary to make some assumptions. None of the assumptions are pure guesses, but they are all indicated in the Table by being marked *a*.

It may be objected that the number of cases taken is not sufficient on which to base estimations of averages, but they may serve as an indication to manufacturers, of the very great importance of keeping scientifically accurate records of so outstanding an element in manufacturing cost.

Such records are constantly kept in ships at sea, and it would certainly not be more difficult to keep them in factories on land.

It is abundantly evident from Table C that cheap coal is dear coal.

Another point is brought out fairly well, namely, that the use of mechanical stokers does not materially reduce the wages bill.

If those figures be accepted as fairly representing qualitatively the case of Group 2, no other argument should be necessary if it could be established. Electric transmission can bring about a state of affairs corresponding to Group 1.

Experience only can accumulate sufficient data for demonstration of the fact, of which the writer has no doubt.

Even when the change has been made and the advantage is evident, it is not always easy to arrive at the result in pounds, shillings, and pence. Few factories maintain the same conditions long enough to permit of a direct comparison being made. It is, therefore, satisfactory to be able to produce a case where a change has been made from the old to the new system of working, and to give the results. Still more satisfactory is it to be able to say that this factory is in Glasgow.

In this case a direct and accurate comparison can be made. Two periods are taken at an interval of six years, during which the alterations were carried out. The output of manufactured product and the work done in each period was the same.

In 1890, the coal burned for power during the month chosen for example, was....................566 tons dross.

Between that year and 1897, nineteen small engines were removed, and replaced by one large gas engine driving a set of hydraulic pumps and a dynamo, the power being about equally divided between them. There are seven electric motors, of from 3 to 35 H.P. The hydraulic gear works lifts, cranes, and testing apparatus. The electric gear works cranes, elevators, machine tools, and special turning machinery. In addition, it lights a large portion of the works, which were formerly lighted by gas and oil, the value of which is not known, and is not credited to the new apparatus. The average power developed is not known, but the maximum is 120 I.H.P.

For the corresponding period in 1897 the consumption was..227 tons dross,
and 26 ,, an'cite.

It would thus appear that the nineteen engines which have been displaced were responsible for a consumption of 339 tons of dross per month, of 390 hours. The maximum I.H.P. necessary for the work is now proved to be 120, therefore the consumption of coal per I.H.P. in 1890 was not less than 16 lbs. per I.H.P. hour, even if it be assumed that the engines were always working at their maximum load. The actual rate of consumption was probably not less than double this quantity.

The same work is now being done for 1·32 lbs. I understand that test results on this engine have been got down as low as ·8 lbs. of anthracite per I.H.P. per hour.

The cash saving is about £60 per month in cost of coal alone, and the total saving in working expenses is probaby not less than £80 to £100 per month.

The electric machinery has been running for upwards of 2½ years, and the total cost of repairs and renewals has been £7 11s 7d, or an average of 60/- per annum. The plant is at work in an iron foundry where it is subjected to exceptionally severe conditions of working.

It is not surprising that an onslaught is now being made on the 227 tons dross which are still being consumed. The ultimate result will be the total abolition of the cheaper fuel, a cessation of the procession of the coal trucks into the premises, and a total consumption of fuel of about 45 tons per month at a cost of £28, as against 566 tons at a cost of £127. These are not hypothetical calculations; they are extracts from business books.

This installation is doubly interesting, because it is one of the first cases where so large a gas engine has been successfully used in this country. Owing to the higher cost of fuel, there is no direct economy in the absolute cost of fuel due to the gas engine. Equally good results, economically, might have been obtained from a steam engine. In this connection, a digression may be made to plead for a more universal adoption of condensing engines.

Up till quite recently, in this country, the use of condensers on land engines of small power was limited to cases where a plentiful supply of water could be had for the pumping. Within the last few years there has been a decided awakening to the use of ejector, jet, and air condensers, with simple and efficient cooling apparatus.

It would be out of place to enlarge too much on this point here, but, as it has a very important bearing on the cost of power production when the production is centralised—as, it is now argued, it should be—a short description may not be out of place.

The writer is at present associated with Messrs Körting Bros. in supplying the condensing apparatus for the Electricity Supply Station of the Cheltenham Corporation. The condenser is of the usual ejector type which is well known in Glasgow, having been originally invented, I believe, by Mr Alexander Morton of this city. The water is returned to the tanks, which are comparatively small, by electrically driven centrifugal pumps throwing the water through spraying nozzles; the water is thus cooled by being passed through the air in a finely divided state, and reaches the tank quite cool enough to be used again. The temperature of the water in the tank is not allowed to rise above about 70° Fah. The total quantity of water required to be stored is from about ten to twenty minutes' supply for the condenser, and the loss of water by evaporation is about from 3 to 4 per cent. This is a very cheap and efficient arrangement, the capital cost per I.H.P. being only about from 20/- to 30/-. The suitability or otherwise of using such a system of condensing depends, of course, on the price of coal.

It will probably be admitted here, without further argument, that the general propositions laid down above are sound, and that in laying out a new factory they ought to have full effect.

There remains, however, the important problem of dealing with existing conditions in Factories already in operation. This problem is so wide in its ramifications that we shall find that it is impossible to discuss it to any profit, unless we confine our attention at least to one class of factory at a time. To this Institution, of course, the case of engine works and shipyards will be most interesting. It has already been pointed out that such factories are, as a rule, most conspicuously uneconomical. There are many good reasons for this. Among others, may be mentioned the following:—

The cost of power bears a small proportion to the total cost of production, and is therefore less important than in many other industries.

Up till quite recently there has been no better method of driving tools in isolated positions than by small steam engines, which, in the very nature of things and in themselves, are uneconomical.

The very facility with which steam power can be applied and used in an engineering establishment leads to the adoption of wasteful expedients for arriving quickly at the desired results. The hastily devised apparatus, having served its first purpose, remains available for similar requirements in the future, and, wasteful as it is, it is much "better than nothing." It is often really cheaper to use a piece of apparatus which is directly wasteful, because of indirect economies resulting from its use.

The engineer, therefore, who sets about changing the existing condition of things has to face not only an initial expenditure for the new plant, but he has to write off the capital value of the displaced appliances. It is fortunate that the possible saving is enormous, otherwise his case would be hopeless. These points are, however, too often completely ignored by the youthful enthusiast in electrical engineering, and too frequently he does permanent damage to the industry by talking nonsense about the economy resulting from a clean sweep of the old arrangements. This damage is most serious when he is able to impress his misguided enthusiasm on his unsuspecting customer, who finds out at the end of the first year that he has spent his money for that which does not bring any adequate return.

The capital expenditure involved in the introduction of electric driving to a shipyard or engineering works is always a considerable item, but if the expenditure be wisely arranged the result will invariably justify the cost.

The great flexibility of electric arrangements renders it possible to treat the problem in such a manner as to show a good return for capital expenditure, from the start.

This desirable result is best attained by attention to the following points.

Any such drastic change as the substitution of electric transmission for steam distribution should proceed on the basis of making the new plant thoroughly up to date, that is to say, the boilers, engines, and dynamos, should be the most efficient obtainable for money. It is better to have a partial equipment of an efficient plant than a cheaper and larger equipment which is less efficient. It is a mistake to put new wine into old bottles, or to drive a new dynamo from old low pressure engines and boilers.

Shaft transmission should be left undisturbed till the last. Old engines which are working at fair efficiency should be left until all the notoriously wasteful engines have been shut down.

These may appear to be truisms, but cases have been known in which a dynamo has been attached to old line shafting to drive motors doing the work formerly done by extensions belted from the same shaft, and retaining the old engines and boilers; thus simply substituting electric losses in dynamo and motors for frictional losses in shafting and belting, and gaining no economy whatever; whereas, the same money spent on a smaller plant, including boiler, engine and dynamo, and applied to the work of small engines in the same premises, would have resulted in an economy more than sufficient to warrant the capital expenditure. When all the isolated engines have been displaced by electric motors, and the resulting economy proved, it may then be calculated on safe grounds, whether it will be right to break up the work of the larger engines and stop down the line shafting in sections, and to drive the whole place by electricity.

While thus advocating a gradual introduction into existing factories, I must by no means be understood to throw any doubt upon the practicability of making an immediate sweeping change on any other ground than that of economy. It is safer to trust to electric transmission than to steam transmission.

The argument may be illustrated from another point of view. Let us assume for the moment that electric transmission costs £20 per horse power for boiler, engine, dynamo, cables and motors; that we assume that the displaced engines, piping, etc. have been written down to their scrap value; and that the new plant is charged with interest and depreciation at the rate of 10 per cent per annum.

Then the old engine must waste £2 per horse power per annum, otherwise it should continue to run until it breaks down, or until all other more wasteful engines on the premises have been wiped out.

It will be seen that the efficiency of the existing engine is not the only element in the case. We must also inquire how many hours per annum it is at work before we give it the bad prominence which will condemn it to death.

The price of coal is also a factor in the consideration. Where coal is cheap it costs less to waste it.

These last paragraphs are written in the spirit of one who, desirous of cleansing through and through the foul body of this infected world, wishes to best use his time by attending first to t urgent cases, leaving the fancy surgery for later attention. The is now no disposition on the part of the patients to hang back fro the cure, and this word of restraint as to the direction of operatio may not be out of place.

This view of the problem need not deter any one from gleani the last straw of economy in working, but it may prevent some fro gathering straws in one corner of the field while the harvest is goi off in smoke at the other.

Discussion.

The discussion on this paper took place on 26th April, 1898.

Mr ANDREW S. BIGGART (Member) said the author had de with a subject of great and increasing interest, especially engineers. Quite recently his firm had decided on some ext sions, and it had been arranged to put down a non-condensing ste engine of about 200 horse-power to drive the machinery throu shafting without the intervention of electric motors. He thoug a *resumé* of the reasons which led to that decision might serve as quota to the discussion of the paper. At the risk of a slight div sion he would like to refer to gas driving. The best gas engi working in ordinary practice consumed about 20 cubic feet of per brake horse-power per hour. This he had been able to che from a good many sources, and even from remarks made by Mavor. In such an engine, the cost for gas per brake horse-po per hour came to a ½d when the gas was charged at 2s 1d per 1,0 cubic feet. If that cost was transferred to the value of coal, say 6s per ton, then the equivalent quantity of coal would be about lbs. per brake horse-power per hour. With a large installation t was a prohibitive price, and they must look to some other source reduce the cost of power. Mr Mavor had referred in his paper the consumption of gas, when such was produced in the Dowson producer, and instanced a coal consumption of 1.32 lbs. per br horse-power per hour. He had ascertained that in an installat as large, if not larger than that referred to by Mr Mavor, the wei

h	i	k
Thread mill	Tweed mill	Tweed mill
coal	coal	both
5/ to 5/6	7/	11/6
—	9/6	—
—	—	—
26	one two	two
30′ × 7′	30′ × 8′, 24′ 6″ × 7′ 6″	30′ × 8′
Lancashire	Lancashire	Lancashire, with Galloway tubes
—	two	two
6000 H.P.	26″ and 30″	—
compound beam and horizontal	beam M'Naught coupled	comp. tandem and beam comp.
70 to 100 lbs.	68 lbs.	80 lbs.
yes	yes	no
no	no	no
yes	yes	yes
yes	yes	yes, 196 pipes
2800	2900	5800 hours
6000	340	day 226, night 80 HP.
5500	irregular	—
—	cannot answer	65 H.P.
5 per cent.	—	—
£1 15/	—	—
including everything, except depreciation	—	—
—	£1500, incl. heating, lighting and dyeing processes	cannot answer
—	£25	
—	£60, including repairs	—
—	—	—
—	£210	—
—	£95	—

P., 1

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		g			*h*
		Sugar Refinery			Paper mill
co		coal			coal
		6/3			5/6
		—			—
		—			—
	1	3			8
4'.P.,	188 H.P.	26' × 8'			30' × 8'
ock	Babcock				Lancashire
bs.	100 lbs.				
	1	1	1	1	about 20, sundry sizes and types
30",	12" × 24"	14" × 15",	18" × 30",	15" × 36"	
'tal	horiz'tal	6900 hrs.	3500 hrs.	6900 hrs.	
		horiz'tal	horiz'tal	beam	
0	100	45			100
es		did, but put them out			yes
es		no			no
s		no			yes
r		yes			no
		6900 hours			7000
		about 100 H.P.			1000
		about 60 H.P.			900
		50 H.P. *(evidently for machinery driven by shafting)*			—
		2 lbs.			—
		impossible to say, as a considerable quantity is used for boiling sugar			—
					£3700 including heating
		£107			£180
		£50			—
		nothing except cost of pumping			cost of pumping unknown
		£130			£815 for power& £215 heating.
		£85			£334

i Tweed												
Average	—	—	—	5/5 per ton	3·1	·09	—	20·0	·028	—	·011	·13
Group II.												
a Paper	5120	25,500	11/3	£6433	5·0	·3	£545	11·4	·025	£200	·01	·335
b Paper	2400	11,200	4/	1000	4·65	·1	400	19·2	·04	150[a]	·015	·155
c Chemical	2400[a]	12,200	5/6	1500	5·0	·146	200	8·8	·02	25	·002	·192
d Paper	4690	18,000[a]	4/6	1800	3·85	·093	625	18·6	·032	200[a]	·01	·135
e Engineering	200	5,570	2/11	360	27·85	·435	150	14·6	·18	25	·03	·456
f Engineering	540	10,000[a]	4/	890	18·5	·4	200	10·9	·09	70[a]	·03	·52
g Sugar Refining	320	4,500	6/3	625	14·0	·47	215	25·75	·16	157	·012	·642
h Paper mill	6300	31,000	5/6	3700	4·9	·144	1364	23·5	·052	300[a]	·011	·207
Average	—	—	—	6/4 per ton	5·3	·18	—	14·2	·034	—	·01	·224

[a] Estimated from other data.

taken over a long period represented a consumption of 2 lbs. per brake horse-power. The cost of the coal in that case, however, was 14s per ton, which, if reduced to the same level as the coal he had already referred to, at the price of 6s per ton, would give 4⅔ lbs. of coal per brake horse-power per hour to work upon. He ventured to say that any good non-condensing compound or triple-expansion engine was perfectly capable of working with a consumption of coal less than that. The great advantage a steam engine had over the gas engine was, that the steam engine would run from one year's end to another with practically no trouble whatever. With a gas engine, however, of 200 horse-power or two gas engines each of 100 horse-power, driven by gas produced in a Dowson or other similar producer, the case was different. Mr Mavor had appealed to practical experience, and he would do the same. In passing some time ago through a large engineering work, not far from Glasgow, where one of the principal manufactures was gas engines, the gentleman who accompanied him pointed to a gas engine driving the principal portion of the works and using gas from the town's main — the reason given for this being, that the engine was a continual source of trouble when driven by gas made in producers on the premises, and it had been found cheaper to pay the extra price for the town's gas. In addition, he volunteered the information that if he had to put down an engine again, he would have one to be driven by steam. A few days ago he visited one of the most recent and largest gas-driven installations in Glasgow having its own gas producer. There, so long as the producer was working steadily and well, with little variation in the load, little trouble was experienced, but immediately a steady range of production was departed from, troubles began. To give good results, a producer must be kept going continually, and, as in engineering works, a run of more than three hours on end was rare, to avoid trouble, the producer had to be kept running constantly, even at the expense of blowing the gas into the air during the meal hours. Sooner or later, no doubt, that difficulty would be overcome, and when realized in ordinary practice it would probably be found that

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the use of gas would forge rapidly ahead. With regard to the question of capital cost, the steam engine and boiler were far more economical than the gas engine and producer. There was no doubt a large field for electric driving. His firm, many years ago, adopted it in special work, and found it to be of great advantage. Some time ago he visited works on the north-east coast where a large electric power installation had been recently laid down. The central power station contained two engines in duplicate, each of about 400 horse-power. That plant had replaced a large number of low pressure steam engines with boilers supplying steam at a pressure of from 40 to 50 lbs. per sq. in. None of the engines were condensing, and in a good many cases the steam had to be carried for a considerable distance. The original half-dozen boilers were replaced by one boiler close to the new engines, which were compound and condensing. The result of the change was not only the reduction of the number of men employed, but also a saving in the coal bill of one half. All isolated drives were expensive, and there was no doubt that electromotors in many such cases were advantageous from the point of economy, as well as from the point of convenience. The engine his firm was about to lay down was non-condensing, and would be supplied with steam at a pressure of 150 lbs. per square inch. It would drive direct to the main shaft, from which the whole power would be taken off in a length of about 100 lineal feet. Several of the heavy machines would be driven by belts direct from the main shaft, without the intervention of counter shafts. If a dynamo and motor had been installed between the engine and the machines, additional counter-shafts would have been required of a greater total length than that of the main shafting, so that the loss of about 20 to 25 per cent., due to electric transmission, would have been gratuitous and without any compensation whatever. He had in his mind an installation he had seen some years ago, which would come under Mr Mavor's Table A. It was a large spinning mill, in the centre of which was a large compound condensing engine. The engine drove the mill off the fly-wheel by ropes leading direct to the main shaft in each flat. He believed there was nothing more than a

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counter-shaft between it and the machines in almost every instance. In a case of that kind it was difficult to see where any economy could ever be attained by electric transmission. For all practical purposes, the steam engine, as a prime motor, was still first by a considerable lead.

Prof. W. H. WATKINSON (Member) said this paper had been brought forward at a most opportune time, as most people who had a number of small wasteful steam engines scattered about their works were now considering whether they could not get rid of them. At the end of the paper the author showed a number of indicator diagrams, illustrating the bad conditions under which small steam engines usually worked. He (Prof. Watkinson) had put upon the board other diagrams, which he had taken himself from engines working in Glasgow, and which illustrated some of the same points referred to by Mr Mavor. In one of those cases the consumption of steam was at the rate of 120 lbs. per I.H.P. per hour. All those engines were now being replaced by electro-motors. In the last paragraph on page 317, Mr Mavor referred to the case of paper mills and calico printing works, where a large quantity of steam was required for drying purposes, and he stated that in those cases the consumption of steam by the engines was practically immaterial, because a large amount of steam was required, at any rate, for the drying calenders and other purposes. He thought the consumption of steam by the engines was very material, even in such cases, and in all others that he had to deal with. In works of that kind the majority of the machines could be driven by electro-motors, and the exhaust steam from the main engine, or engines, could then be superheated before being sent to the drying cans, etc. By that arrangement high-temperature steam at little more than atmospheric pressure was available for drying purposes, and not only were the difficulties connected with the stuffiing-boxes of the drying cans reduced, but the cans, and the printing machines connected with them, could be driven at a greatly increased speed. In that case much less steam would be required for drying purposes, and the output of the plant could be greatly increased.

Mr W. B. Sayers.

Mr W. B. SAYERS (Member) thought Mr Biggart's mention of the relative values of gas and steam engines was rather away from the subject matter of the paper, but he would like to say a word or two on the points Mr Biggart had raised. Mr Biggart said that the Dowson gas plant would work very well if the load were constant, but troubles arose on a variable load. He knew of a Dowson gas plant which had been in operation for some years, and which was used exclusively for electric lighting, and there could be no doubt that the load was a most variable one. The plant he referred to consisted of two 250 horse-power sets. During the first year or two the cost of fuel per electrical unit delivered was ·2d. During the period from June, 1896, to July, 1897, the cost was ·13d per unit delivered, which was pretty low. An electrical unit was equal to 1000 watts, as compared with 746 watts for one horse-power, therefore, when allowing an efficiency of only 75 per cent. for the electric motor it might be considered that ·13d represented the cost per horse-power. The power obtained from a given quantity of steam was very variable, depending on the engine used; whereas, if an electric motor wasted more than say 25 per cent. it would probably burn out. Usually only 10 per cent. or 15 per cent. would be wasted, except in very small motors. Using coal gas, in the engines he had referred to, at 2s 3d per 1000 cubic feet, the cost per unit delivered was 1·2d.

Mr JOHN BARR (Member) considered that Mr Mavor had made out a very good case for electric driving. He knew the instance alluded to by the author in his paper, and thought a great deal of its success was due to the fact that there was a judicious admixture of hydraulic and electric power. The manager's abilities were shown when he laid out his place to get a mixture of drives to suit the various operations to be performed. It might be that a gas or oil engine would best suit one situation, hydraulic power another, and electric power a third. There was no doubt at all that where considerable distances had to be considered, there was nothing to beat an electric drive. A new shop was being erected at the works with which he was connected, and, as no shafting was near the place, Mr John Barr.

it had been decided, on the grounds of efficiency and economy, to put down a dynamo driven by an existing engine, and to lead a wire to the new shop capable of carrying about 27 horse-power. It would be found that for first cost electric driving was highest, but first cost was not always what ought to be considered. Where an installation was fairly large, the old-fashioned steam engine would still hold its own.

Mr ROBERT T. NAPIER (Member) asked if with a motor working intermittently there was any extra risk of burning the connections, or causing injury when started suddenly; also, if, with a motor running continuously under a varying load, the speed could be kept as well under control as in the case of a steam engine?

Mr F. J. ROWAN (Member) inquired whether in the installation of gas engines worked from Dowson producers, referred to by Mr Biggart, gas-holders were included, because, in the absence of gas-holders, one could understand the fluctuations in the quality of gas from hour to hour, but where a complete installation of that sort was erected, there was usually a gas-holder which contained several hours supply of gas for the engine, so that it was not very apparent why there should be rapid fluctuations of the quality. He thought with Mr Sayers that it was a pity that the discussion had taken the course of comparing the relative values of steam and gas engines, because, in any case, with an electric system of transmission there must be a prime mover, and no doubt the best and most economical prime mover for working a dynamo in a given locality would be selected. Whether it should be steam, gas, or water-power was an open question, but the idea which many people held, that they could not have an economical electric installation for power transmission unless they had a natural source of power—a fall of water—for their prime mover, was a mistaken one. The cost of the Board of Trade electrical unit, as worked out at Niagara, was given to him recently by an electrical engineer—it was ·125d. With economical condensing steam engines and boilers, and with coal at 5s per ton for firing the boilers, the cost of the same unit worked out at ·110d, and with coal at 6s per ton the cost came out at the figure which had already been mentioned; viz., ·131d; so that there was not very much difference between the cost of an electrical unit starting from a natural source of power, such as a large mass of water in motion, and where good steam engines and boilers could be employed. What would be the cost with gas engines for prime movers was a little doubtful, because up till now large gas engines had not been made to work economically, although on trial small engines had given the result which Mr Mavor had mentioned; viz., ·8 lb. of coal per indicated horse-power per hour. He did not think that had been realised in practice on a large scale. Mr Mavor said that gas engines had been made of 120 horse-power, but when power had to be transmitted over a considerable area in large works it was evident that that would be only a small unit.

Mr JAMES COATS (Member) observed that the majority of the speakers had lost the point on page 322, where the author said, "Equally good results, economically, might have been obtained from a steam engine." Respecting the losses in shafting, he, upon a certain occasion, wished to ascertain the power required to drive 2000 lineal feet of shafting, and found that when the works were in full swing the total indicated horse-power of the engine was 70. When work was stopped, the indicated horse-power of the engine was 42, at the same revolutions, proving that there was about 60 per cent. taken up through friction. That was a case where a distribution of small motors would have saved a good deal of the lost power. There was one thing about all large gas engines, one had his eggs all in one basket in the case of a breakdown, and it would be better to have duplicates with smaller capabilities.

Mr MAVOR, in reply, said, with regard to Mr Biggart's remarks, he thought that his paper stated very clearly that in this district there was no direct advantage on the score of economy in using a gas engine, as against a steam engine; that was to say, that no person would, for economy alone, use a large gas engine in preference to a steam engine, if he knew what he was about. He might do so for other reasons than for economy; that happened to be so in the special case referred to in the paper. The reason why gas engines were used in the first instance and the installation increased by another engine of a larger size was, that the gas engine took up less space than the steam plant. At the same time, he could not agree with Mr Biggart's remarks as to the unsatisfactory working of gas engines up to the size mentioned. It was quite true that the gas engine had not been developed; but there was no doubt that the troubles which arose in such cases were the result of inexperience on the part of the operator rather than from defects in the apparatus. That had been clearly proved in many cases where much trouble had been found in the first three or four months, and then, without any change in the apparatus, it had continued to work for years without any trouble. The most of the troubles which he referred to arose from the admission of air through the fire in the gas producer; that was the most fruitful cause of trouble in the engine room; another source of trouble was, insufficient storage capacity for the gas. If the fire was kept properly attended to, and no air admitted, and if there was a reasonable margin of storage for the gas, there was no reason why gas should not be as worthy of reliance as steam. It had been proved that it was quite satisfactory. Mr Biggart's comparison of costs between gas and steam was misleading. The cost of gas from producers was not 2s. 1d. per thousand cubic feet, and if he wished to compare the cost of coal, the simplest method was to take the weight of anthracite coal used for the gas engine, and compare it with the weight of coal for producing the horse power in the most economical steam engine. The steam engine took rather more than double the weight of coal at about half the price per ton, and any difference arose from variations in the cost of handling the different quantities of coal. In his opinion there was nothing to choose between the two methods of driving in Glasgow as a question of economy. On the other hand, where steam coal was high in cost as compared with coal for gas producers, the gas engine became preferable on the score of economy. It was quite true that with ordinary engineers they were less likely to have trouble arising from faults of inexperience than with the steam engine.

Mr BIGGART—If Mr Mavor had been led to believe that 2s. 1d. was

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the price of the gas produced in the Dowson producer, he would like to correct that impression. He meant that 2s. 1d. was the price of the gas produced by any ordinary corporation and sold as lighting gas. The Dowson was very much cheaper.

Mr MAVOR—Mr Biggart had raised an interesting question as to the possibility of distributing power through a factory by means of gas engines. That at first sight was very attractive, but if one only compared the working engine and working electro-motor it would be seen that there was a very large amount in favour of the motor as regarded supervision. There were no valves to clean and nothing to do but oil the machine once a week, and if it was properly attended to once a day, and got a careful overhaul once a week, it was all that was required. Although the distribution of gas pipes throughout a factory was much simpler than the distribution of steam pipes, the distribution of electric conductors was easier than either. Mr Biggart had mentioned the case of a 200 horse power engine driving a single line shaft in its immediate vicinity, and he would refer him to his paper where it was stated that there was no advantage to be gained by the substitution of an electric drive in such an instance, and where he pointed out that in some such cases this had been done by misguided enthusiasts and the money spent upon it entirely wasted. The profitable utilisation of waste steam was a point to which he had given some attention. The steam that was rejected by small engines in paper mills was not all wasted. Looking at the point broadly, he took the view that an inefficient steam engine was inefficient because it rejected heat, and if the rejected heat was afterwards fully utilised, the money spent on coal to produce it was not lost. There were other matters, however, which came in, as Professor Watkinson pointed out, that it was possible with high temperature steam to drive the drying cans faster, and these, and other points, were important, but he thought the facts were as he stated, that the efficiency of engines, purely from the coal consumption standpoint, was not of any importance in such factories where the whole of the exhaust steam was required for heating, and where all the heat rejected by the engine was economically used afterwards. There was no direct loss to put against the cost of a system of electric transmission. Anyhow he had not met with a case. In most factories where wasteful engines were in use, steam might be seen blowing into the air in large quantities, and this usually indicated an opening for the electrical engineer. Mr Barr spoke of a judicious mixture of hydraulic and electric power, and the writer thought he had indicated the danger of rushing into electric transmission without really considering the question. It was quite possible to waste money on electricity as it was on anything else if injudiciously applied; and there was no doubt that for many purposes hydraulic transmission was much superior to electric transmission. There were also purposes for which a steam engine was a superior article to an electro-motor. He wished to express his great delight, as an electrical manufacturer, as well as an engineer, to find that the people in this neighbourhood were waking up to the benefits of electric driving. He would point out that engineers here were becoming convinced that electric motors were more suitable than any other means for operating overhead travelling cranes. Not only so, but they found that electricity was a much more convenient and simple thing than they had any idea of, and the installation which was originally adopted for working a crane had been multiplied and was driving other things as well. Regarding the loss in shafting, it was very difficult to discuss a case of that kind without knowing the particulars. Where the loss in shafting exceeded 25 per cent., it was worth while to consider electric driving, remembering, at the same time, that where coal was cheap it cost little to waste it. In the case adduced by Mr Coats, the percentage of loss was not so high as he said—the total horse power being 70, the actual work being 28, the difference being 42. Of course a large proportion of that was due to the loss in the engine itself, and not entirely to the shafting. Probably 15 horse power might be lost in the engines without anything being wrong, and that might be increased to 20 or 25 without making the engines squeak. Another matter was mentioned, about the disadvantage of having all one's

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eggs in one basket. He had become convinced that this fear was a groundless one. Why put them in three or four baskets if one could carry them? We crossed the Atlantic in a steamer with one engine, and we drove a cotton mill with one engine, and an express train with only one locomotive at a time, and why should we have two electric driving dynamos to work one factory? Of course all human constructions were liable to break down and stop, but he thought that those who had used electric plant would agree with him in saying that a dynamo was as little likely to break down as a steam engine. In conclusion, he wished to say that while his paper might seem to be rather a restraining one, he thought the members would give him credit for disinterestedness in making it so; because it was clearly an advantage to the electrical engineer that as much should be done as possible, but it was to his highest interest that what was to be done should be done properly. Mr Napier had asked whether motors were suitable for intermittent work. These were the best cases for electric driving.

Mr NAPIER—But about the burning out?

Mr MAVOR—Perhaps Mr Napier had in his mind a sudden stopping and starting. It was not practicable to suddenly stop and start without breaking something, unless they had a machine designed for the purpose which would stand sudden shocks, but it was easy to make an electric motor which would do so better than the steam engine, because in the former there was no reciprocating parts, and it was only the inertia of rotating parts that had to be overcome.

On the motion of the President, Mr Mavor was awarded a vote of thanks for his paper.

THE "JAMES WATT" ANNIVERSARY DINNER.

THE Annual "James Watt" Dinner took place in the Windsor Hotel, St. Vincent Street, Glasgow, on Saturday, the 22nd January, 1898. The meeting was attended by upwards of 260 Members and distinguished guests, which was the largest company ever present at any previous annual function of the sort held under the auspices of the Institution. Mr George Russell, President, occupied the chair, and was supported by the Right Hon. Lord Kelvin, the Hon. Lord Provost Richmond, Sir William Arrol, LL.D., M.P., Deacon-Convener Miller, Sir W. H. White, F.R.S., LL.D. (Assistant Controller and Director of Naval Construction), Rev. Dr John Macleod, Dr John Inglis, Mr Henry Murray, Mr Joseph Naismith, Lieut.-Colonel Archibald Denny, and Prof. Archibald Barr, D.Sc.

The croupiers were Mr William Foulis and Mr Robert Caird, F.R.S.E., Vice-Presidents of the Institution.

The loyal toasts were proposed from the chair, and cordially pledged by the company.

Mr ROBERT CAIRD, F.R.S.E., submitted the toast of "The Navy, Army, and Reserve Forces." In doing so, he remarked that perhaps they, as engineers and shipbuilders, might scarcely be considered disinterested ratepayers. At any rate, a spirited naval policy was not without contingent advantages to them; to some of them it brought financial advantages; to others, it brought what moralists loved to tell them was better than riches—experience—and they certainly ought to be grateful to the Admiralty for having given them the opportunity of gaining it at whatever sacrifice of time and money. No one could look back upon the course of international politics during the last few years without a feeling of deep thankfulness that our navy was strong. There was probably no more potent factor making for peace in these troublous times than the manifestly pre-eminent strength and efficiency of the British Navy. Our army numerically was small, but it was exceedingly rich in traditions and heroism, and the volunteers would be ready, when called upon, to do their duty.

Sir William White, F.R.S., LL.D., replying for the Navy, remarked that there had been times when the naval officers of Britain had had to venture into action against unequal odds, when victories had been won by their skill and courage against immense odds, when the ships they commanded were distinctly inferior to those in which their foes fought. But because such things had been, there was no reason that such things should be. It was only fair to the officers that they should not be asked to face unequal odds. Nelson, who in his day thought no odds too great to face, but who dared what no other living man at the time dared to do, was the man of all others who said that he should not be called upon to fight except he had a preponderating force. We should not overlook the fact that, for the command of the sea we must find the finest *personnel* which breeding and training could produce embarked in the finest *matériel* which the skill of this country could furnish. It was not for him to say what the *matériel* was which they now possessed; but they had, if foreign critics were to be the judges, not merely the finest *personnel* in the world, but the most magnificent *matériel* that had ever floated on the sea.

Colonel Chermside replied for the Army, and Lieut.-Colonel A. Denny for the Reserve Forces.

The Chairman said that was the eleventh occasion on which the Institution had celebrated the "James Watt" anniversary. He thought the present occasion was unique, for the toast of the evening was to be proposed by the very successor of Prof. John Anderson, the friend of Watt. He had much pleasure in calling upon Lord Kelvin to propose "The Memory of James Watt."

Lord Kelvin, who was received with enthusiasm, assured the meeting that he felt very keenly the honour of being allowed to propose the toast. Belonging to the apparatus collection of the Natural Philosophy class of the University, but now handed over to the Hunterian Museum, there was the model which Watt was employed by the University to repair in some minor details. In studying this he saw not only what had to be mended, but some of the principles which it realised, and he was led on from that small beginning to the great work which they commemorated that night; the work which had made the nineteenth century in the eyes of the engineers, and, if in the eyes of the engineers, he thought he might safely say in the eyes of the whole world, the century of James Watt. There had been engineers before James Watt. Happier than the brave men who lived before Agamemnon, their memory was not lost in obscurity for want of the sacred prophet, poet, and historian to commemorate their deeds. Tubal Cain was a great mechanical engineer, whose name was a household word in Scotland in the end of the nineteenth century. Poets and historians had chronicled the work of Archimedes. Skipping twenty centuries, they came to Smeaton, a great man who preceded Watt by not very many years, a man who led up towards the mechanical developments which Watt perfected. But Watt! What had he done for the world? Of all the sixty centuries of recorded human history, no century had been so great as the nineteenth century in engineering, in the work of the engineers who applied the laws of matter to the principles of science for the benefit of mankind. Indeed, they almost forgot that there was engineering before the beginning of this century when they remembered that steam navigation first came into existence on Dalswinton Loch, and that Symington's boats, a few years after their first trial on Dalswinton Loch, in 1798, were placed on the Forth and Clyde Canal. There was the beginning of marine engineering. And what was marine engineering now? It had covered the whole world with the works of English engineers. By England he meant, he always meant—England, Scotland, Ireland, India, Canada, and the other British colonies. Engineers, he went on, connected other names than the name of James Watt with the nineteenth century. Faraday, Carnot, Joule—they had done great things to make the latter end of the nineteenth century worthy of its beginning under James Watt. The steam engine of James Watt—was it to be the engine of the nineteenth century or the

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engine also of future centuries? The latter part of the nineteenth century opened new vistas, vistas of the application of Watt's science, led up to by Watt and Carnot, and Regnault and Joule—the application of fuel to produce power. No man would be readier than Watt himself, were he alive, to see the possibilities of other modes of developing power by steam. Lord Kelvin believed if Watt could look back upon the nineteenth century, steam, electricity, and the means of developing power on which electricity depends, not thought of in the beginning of the century, would have engaged his attention and his admiration, and if he could be living here now, would have engaged his attention for the promotion of anything that could be done to improve upon the steam engine. But he must not speak of anything so chimerical as the doing away with the steam engine. He believed they would have steam engines driven by steam power for at least 100 years. As long as their coal supply lasted steam power would still keep alive directly the results of the labours of James Watt. He would not prophesy that in any respect, even for land use, even for the generation of electricity, the twentieth century would be the century of oil and gas and internal combustion engines. It might or it might not. Engineers were all interested in the question. Was the internal combustion engine in any shape going to supersede, for a large variety of applications, the steam engine? Whether it did or did not supersede the steam engine for any larger application than that for which they now saw the gas engine applied, still they would have no less reason to be grateful to James Watt for what he had done for them than they had just now; and Lord Kelvin could venture to prophesy, that at the end of the twentieth century the name of James Watt would be as fresh and as much honoured and as much respected, and received with as deep feelings of gratitude, as it was now at the end of the nineteenth century. In pure science, Watt was a leader. Lord Kelvin well remembered, under his great master in physical science, Regnault, *la loi de* Watt was always on his lips—the law which Watt gave with reference to the latent heat of steam. Watt in many, in all branches of science, showed himself a man of most penetrating genius, and it was a matter of great joy and perpetual pleasure to the University of Glasgow that it had the honour and credit of having given a home to Watt in the early days of his struggle, and that in Watt's workshop in the University of Glasgow a true scientific society, a philosophical society, a physical society came into existence which had been the parent of many similar societies all over the British dominions. They knew what tremendous benefits he had given to mankind. Let them think of life in the end of the nineteenth century and compare it with life 100 years ago. Some people asked the question, were they made happier, were they made better, or were they better in virtue of those wonderful advantages that they had? People were happy and people were good, and sometimes neither happy nor good, during the sixty centuries of human history that preceded Watt; but they had social advantages that no human being had before 1800. The being kept continually in touch with friends at a distance, not merely hearing from them rarely by letter, but being able to shoot away and see them with little loss of time or comfort. Was not that a great social advantage? Engineers did not look upon the applications of their grand work merely from the mechanical point of view. They knew very well that their steamers and their railways were a true benefit to humanity, a blessing, and a good. Let them take the telegraph, again. He had in his pocket a telegram he had received from India that morning describing an eclipse. The telegram was—"Eclipse well seen; also red flames and Baily's beads. Some very fair photographs. The whole party well satisfied." This telegram, through the Eastern Telegraph Company, had reached him before noon that day, and it was sent by a man of over eighty, who went all the way to India, taking his implements with him, to observe the eclipse and to try and contribute something to the sum of knowledge. There was a benefit from James Watt all over the fields of science. The power of seeing our friends and keeping up social intercourse was a great blessing; the power of doing things that were interesting to the human intellect was an exceedingly great benefit conferred on the world by engineers. The telegraph was not steam power, but

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without steam power the laying of an ocean telegraph would have been absolutely impossible, so that he looked upon the electric telegraph as one of the blessings resulting to the world from the great work of James Watt. He was sure that every human being that thought of the subject, that knew what the meaning of language was, would say that the world this day was happier and better in every respect for the works of James Watt. He asked them to drink to "The Memory of James Watt."

The remaining toasts were—"The City of Glasgow," proposed by Sir William Arrol, LL.D., M.P., and responded to by Lord Provost Richmond; "Our Guests," proposed by Deacon-Convener Miller, and acknowledged by Dr Freeland Fergus; and "The Institution of Engineers and Shipbuilders in Scotland," proposed by Dr Ebenezer Duncan, and replied to by the President.

MINUTES OF PROCEEDINGS.

FORTY-FIRST SESSION.

THE OPENING MEETING was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 26th October, 1897, at 8 P.M.

Sir WILLIAM ARROL, LL.D., M.P., introduced the new President, Mr GEO. RUSSELL.

Mr RUSSELL acknowledged the honour of having been elected President, and took the Chair.

The Minutes of the Annual General Meeting, held on the 27th April, 1897, were read, confirmed, and signed by the President.

The PRESIDENT delivered his Inaugural Address.

On the motion of Sir WILLIAM ARROL, LL.D., M.P., a vote of thanks was awarded the President for his Address.

The awards made at the Annual General Meeting of April 27th, 1897, were presented as follows, viz. :—

The Marine Engineering Gold Medal

To Mr ROBERT CAIRD, for his paper on "Propeller Diagrams."

Premiums of Books

To Mr ROBERT SIMPSON, B.Sc., for his paper on "Tunnelling in Soft Material, with Special Reference to the Glasgow District Subway;"

To Mr J. G. STEWART, B.Sc., for his paper on "The Manufacture of Welded Iron and Steel Pipes;" and

To Mr JOHN INGLIS, Past-President, for his paper on "Rates of Speed and Rates of Freight."

A paper on "The Proell-Corliss Engine and the Proell Valve Diagram" was then read by Mr HERMANN KÜHNE, of London. The discussion on this paper was begun and adjourned.

On the motion of the President Mr KÜHNE was awarded a vote of thanks for his paper.

Thereafter a paper on "Water-Tube Boilers" was read by Mr F. J. ROWAN.

Mr F. P. PURVIS exhibited several models of Ship Carpentry and Ship Joinery, made by students of the City and Guilds of London Institute.

The President announced that the following Candidates had been elected; viz.:—

AS MEMBERS:—

EDWARDS, CHARLES, Draughtsman, 5 Minard Ter., Partickhill, Glasgow.
HALKET, JAMES P., Engineer, Glengall Iron Works, Millwall, London, E.
LAWS, BERNARD COURTNEY, A.R.C.Sc., Ship Draughtsman, Ship Department, Fairfield Works, Govan.
M'LACHLAN, JOHN, Engineer, Saucel Bank House, Paisley.
MATTHEY, C.A., Engineer, 22 Melville Street, Pollokshields, Glasgow.
MUIRHEAD, WILLIAM, Iron and Steel Manufacturer, 37 West George Street, Glasgow.
MURRAY, RICHARD, Mechanical Engineer, 228 Central Chambers, Hope Street, Glasgow.
STEVEN, JOHN, Brassfounder, 32 Elliot Street, Glasgow.
WYLIE, ALEXANDER, Engineer, Kirkfield, Johnstone.

AS MEMBERS FROM GRADUATES' SECTION:—

BORROWMAN, WILLIAM C., Engineer, Stobcross Engine Works, Finnieston, Glasgow.
CONNER, BENJAMIN, Civil Engineer, 196 St. Vincent Street, Glasgow.
HOMAN, WILLIAM M'L., Assistant Engineer, Orange Free State Railways, Kroonstad, Orange Free State, South Africa.
TAYLOR, WILLIAM, Engineer, 10 Broomhill Avenue, Partickhill, Partick.
WELSH, JAMES, Engineer, 3 Princes Gardens, Dowanhill, Glasgow.

AS ASSOCIATES:—

BAIN, ANDREW, 17 Athole Gardens, Glasgow.
DODDRELL, ED. E., Machinery Agent, 11 Bothwell Street, Glasgow.
STRACHAN, G., Secretary, Fairfield Works, Govan.

AS GRADUATES:—

ARNOTT, HUGH STEELE, Draughtsman, 16 Fitzroy Place, Glasgow.
BENNETT, DUNCAN, Apprentice Engineer, c/o Mills, 91 Kent Road, Glasgow.
BOYD, GUY W., Draughtsman, 2 Queen Margaret Crescent, Glasgow.
BROWN, ALEXANDER TAYLOR, Draughtsman, 2 Parkgrove Ter., Sandyford, Glasgow.
FRANCE, JAMES, Apprentice Draughtsman, 8 Hanover Terrace, Kelvinside, Glasgow.
HORN, PETER ALLAN, Draughtsman, 201 Kent Road, Glasgow.

Houston, William C., Assistant Lecturer in Engineering, 4 Abbotsford Place, Glasgow.

Inglis, John F., Shipbuilder, Pointhouse Shipyard, Partick.

Kirkwood, William D., Draughtsman, 30 Queen Mary Avenue, Glasgow.

M'Ewan, John, Apprentice Draughtsman, 211 Dumbarton Road, Glasgow.

Macfarlane, Duncan, Jr., Draughtsman, 25 St. Andrew's Drive, Pollokshields, Glasgow.

M'Gillivray, John A., Assistant Lecturer in Engineering, 167 Broomloan Road, Govan.

Morton, W. Reid, Draughtsman, 8 Ardgowan Terrace, Glasgow.

Mowat, Magnus, Apprentice Engineer, 480 Springburn Road, Glasgow.

Portch, Ernest C., Draughtsman, 2 Park View, Langside, Glasgow.

Ritchie, James, Draughtsman, 1 Westbank Place, Hillhead, Glasgow.

Sibbald, Thomas Knight, Draughtsman, 162 Queen's Drive, Glasgow.

Smith, George F., Apprentice Engineer, 11 Woodside Terrace, Glasgow.

Stewart, Henry, Draughtsman, 26 Evelyn Avenue, Bloomfield, Belfast.

Wharton, Fred., Draughtsman, 2 Park View, Battlefield Road, Langside, Glasgow.

Wright, Robert, Apprentice Engineer, c/o Mrs Arnott, 552 St. Vincent Street, Glasgow.

The Second General Meeting was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 23rd November, 1897, at 8 P.M.

Mr George Russell, President, in the Chair.

The Minutes of the General Meeting, held on the 26th October, 1897, were read, confirmed, and signed by the President.

The Treasurer's Annual Financial Statement was presented and held as read. On the motion of the President, votes of thanks were awarded to the Auditors, Messrs. P. Stewart and W. A. Charlton.

The President announced that the Council had agreed to ask the Members to elect Mr R. E. Froude, F.R.S., an Honorary Member, and that his name would appear on the next ballot paper.

The adjourned discussion on Mr Hermann Kühne's paper, "The Proell-Corliss Engine and the Proell Valve Diagram," took place, and was terminated.

The discussion on Mr FRED. J. ROWAN'S paper, "Water-Tube Boilers," was begun and adjourned.

Thereafter Mr ROBERT CAIRD read a paper, entitled, "A Graphic Log."

The President announced that the following Candidates had been elected; viz. :—

AS MEMBERS :—

ALLEY, STEPHEN E., Engineer, Langside House, Langside.
FERGUSON, J. STRATHEARN, Chief Draughtsman, 154 Comelypark Street, Dennistoun, Glasgow.
GALE, EDMUND WILLIAM, Ship Draughtsman, 4 Rosebery Place, Clydebank.
HORNE, JOHN, Mechanical Engineer, Rokeby Villa, Carlisle.
MATTHEWMAN, F. A., Departmental Manager in Steel Works, 7 Gardenside Terrace, Uddingston.
PAUL, FRED. W., Steel Works Manager, Blochairn Steel Works, Glasgow.
STEWART, J., B.Sc., Manager and Secretary of the Haythorn Tubulous Boiler Company, Limited, Stanley Villa, Langside, Glasgow.
TULLIS, DAVID K., Engineer, Kilbowie Iron Works, Kilbowie.
TULLIS, JAMES, Engineer, Kilbowie Iron Works, Kilbowie.

AS MEMBER FROM GRADUATES' SECTION :—

FLETCHER, J., Engineer, 11 Ibrox Place, Whitefield Road, Govan.

AS ASSOCIATES :—

HOLLIS, H. E., Agent, 40 Union Street, Glasgow.
HOLLIS, JOHN, Agent's Assistant, 40 Union Street, Glasgow.
WEBSTER, J. A., Steel and File Manufacturer, Clydesdale Works, Sheffield.

AS GRADUATES :—

ALBRECHT, J. AUGUST, Engineer, 159 Buccleuch Street, Glasgow.
CRICHTON, J., Draughtsman, 117 Ardgowan Street, Glasgow.
JONES, T. C., Draughtsman, Rose Cottage, Langlands Road, Govan.
KNOX, ALEX., Draughtsman, 12 Westbank Terrace, Hillhead, Glasgow.
MITCHELL, R. M., Draughtsman, 24 Howard Street, Bridgeton Glasgow.
MORRISON, A., Draughtsman, Alt-na-craig. Greenock.
TURPIN, C., Draughtsman, 874 Govan Rd., Govan.
TAYLOR, J. F., Draughtsman, c/o Young, 300 Duke Street.
YOUNG, JOHN, Jr., Draughtsman, 9 Dover Street, Glasgow.

THE THIRD GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 21st December, 1897, at 8 P.M.

Mr GEORGE RUSSELL, President, in the Chair.

The Minutes of the General Meeting, held on the 23rd November, 1897, were read, confirmed, and signed by the President.

The discussion on Mr FRED. J. ROWAN'S paper, "Water-Tube Boilers," was resumed and again adjourned.

The discussion on Mr ROBERT CAIRD'S paper, "A Graphic Log," was postponed.

Mr T. R. MURRAY, Wh.Sc., read a paper, entitled, "The Theory and Practice of Mechanical Refrigeration."

A paper by Mr C. E. STROMEYER, on "Basic Refined Steel on the Continent," was held as read.

The President announced that the following Candidates had been elected; viz.:—

AS AN HONORARY MEMBER:—

R. E. FROUDE, F.R.S., Admiralty Experiment Works, Gosport.

AS MEMBERS:—

BROWN, WILLIAM S., Jr., Spring Manufacturer, 67 Washington Street, Glasgow.

BRUCE-KINGSMILL, J., Captain, Royal Artillery, Newton House, Newton.

COATS, JAMES, Talara, Katharine Drive, Govan.

MARR, JAMES BROWN, Engineering Draughtsman, c/o Mrs Casey, 229 North Street, Charing Cross, Glasgow.

MUIR, ROBERT WHITE, Engineer, 97 St. James Road, Glasgow.

RAMSAY, CHARLES, Engineering Draughtsman, 14 Walmer Terrace, Paisley Road, W., Glasgow.

RICHMOND, The Hon. DAVID *(Lord Provost of Glasgow)*, Iron Tube Maker, North British Tube Works, Govan.

SUTHERLAND, SINCLAIR, Iron Tube Maker, North British Tube Works, Govan.

TURNBULL, WM. GEORGE, Mechanical Engineer, Hallside Steel Works, Newton.

HALLEY, WILLIAM LIZARS, Brassfounder, Lennoxlea, Dumbarton.

WORKMAN, HAROLD, B.Sc., Engineer, Dunluce, Dullatur.

AS MEMBERS FROM GRADUATES' SECTION:—

CRAIG, JAMES, Surveyor, Lloyd's Register, 6 Edelweiss Terrace, Partick.

MILLAR, SIDNEY, Chief Draughtsman, 32 Annette Street, Crosshill, Glasgow.

AS ASSOCIATES :—

BROWN, Capt. A. R., Consul for Japan, 24 George Square, Glasgow.

GOODRICH, WALTER FRANCIS, Engineer, 101 St. Vincent Street, Glasgow.

HALLIDAY, GEORGE, Teacher of Engineering, 23 Alfred Place, Bedford Square, London, W.C.

ANDREWS, HENRY W., Representative, Messrs Galloway's, Ltd., Manchester, 128 Hope Street, Glasgow.

AS GRADUATES :—

GOUDIE, WILLIAM J., B.Sc., Engineer, 29 Albert Drive, Crosshill, Glasgow.

DUNLOP, ALEX., Draughtsman, 14 Derby Terrace, Sandyford, Glasgow.

LLOYD, HERBERT J., Student, West of Scotland Technical College, c/o Wessenberg, 4 Cromwell Street, Glasgow.

M'WHIRTER, ANTHONY C., Electrical Engineer, 214 Holm Street, Glasgow.

MACDONALD, JOHN F., Engineer, 36 Willowbank Street, Glasgow.

MACKIE, WILLIAM, Draughtsman, 29 Thomson Street, Govan.

NOWERY, WILLIAM, Engineer, 37 Derby Street, Glasgow.

SCOTT, JOHN R., Engineer, 51 Love Street, Paisley.

WELSH, GEORGE MUIR, Apprentice Engineer, 3 Princes Gardens, Dowanhill, Glasgow.

THE FOURTH GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 25th January, 1898, at 7-30 P.M.

Mr GEORGE RUSSELL, President, in the Chair.

The Minutes of the General Meeting, held on the 21st December, 1897, were read, confirmed, and signed by the President.

The adjourned discussion on Mr FRED. J. ROWAN'S paper, "Water-Tube Boilers," took place and was terminated. On the motion of the President, a vote of thanks was accorded to Mr ROWAN for his paper. Prof. W. H. WATKINSON and Mr F. R. RAINEY exhibited models of various Water-Tube Boilers in action, and each was awarded a vote of thanks.

The discussion on Mr C. E. STROMEYER'S paper, on "Basic Refined Steel on the Continent," was begun and concluded.

On the motion of the President, a vote of thanks was accorded to Mr STROMEYER for his paper.

The discussion on Mr ROBERT CAIRD'S paper, "A Graphic Log," was postponed.

The discussion on Mr T. R. MURRAY'S paper, "The Theory and Practice of Mechanical Refrigeration," was postponed.

A paper on "The Causes of Collapse in Marine Boiler Furnaces," by Mr W. R. AUSTIN, was held as read.

The President announced that the following Candidates had been elected; viz.:—

AS MEMBERS:—

AILSA *(The most Honourable the Marquis of)*, Shipbuilder, Culzean Castle, Maybole.
ALLAN, J. R., Shipbuilder and Engineer, Bintang, Dumbreck, Glasgow.
BALDERSTON, JAMES, Manager, Anchor Mills, Paisley.
BARCLAY, GEORGE, Engineer, Vulcan Works, Paisley.
BENNIE, H. OSBOURNE, Engineer, Clyde Engine Works, Polmadie, Glasgow.
BOST, W. D. ASHTON, Engineer, Adelphi House, Paisley.
BROADFOOT, WILLIAM R., Admiralty Contractor, Inchholm Works, Whiteinch.
CALDERWOOD, WILLIAM T., Engineer, 88 Sinclair Drive, Langside, Glasgow.
COCKBURN, ROBERT, Engineer, 14 Kelburn Avenue, Dumbreck, Glasgow.
CRAIG, ARCHIBALD FULTON, Engineer, Dykebar House, Paisley.
CROW, JOHN, Engineer, 236 Nithsdale Road, Pollokshields, Glasgow.
FISHER, ANDREW, Engineer, St. Mirren's Engine Works, Paisley.
FLEMING, WILLIAM, Assistant Manager, Atlas Locomotive Works, 10 Heathfield Terrace, Springburn, Glasgow.
GLASGOW, JAMES, Engineer, Fernlea, Paisley.
GRAHAM, JOHN, Chief Draughtsman, 60 Cambridge Drive, Kelvinside, Glasgow.
GRETCHIN, G. L., Engineer, Russian Volunteer Fleet, c/o The Clydebank Engineering and Shipbuilding Co., Clydebank.
GRIEVE, JOHN, Engineer, Motherwell.
HOUSTON, JAMES, Jr., Marine Engineer, Brisbane House, Bellahouston.
LANG, ROBERT, Engineer, Quarrypark, Johnstone.
LOUDON, GEORGE FINDLAY, Machine Tool Maker, 10 Claremont Terrace, Glasgow.
MACDONALD, THOMAS, Mechanical Engineer, 180 Hope Street, Glasgow.
MACLEAN, WILLIAM DICK, Superintending Engineer, Glasgow District Subway, 173 Scotland Street, Glasgow.
M'GEE, WALTER, Engineer, Stoney Brae, Paisley.
M'KENZIE, JOHN, Manager Engine Works, Speedwell Engineering Works, Coatbridge.
M'KIE, J. A., Marine Engineer, Copland Works, Govan.
MITCHELL, GEO. A., F.R.S.E., Coalmaster, 5 West Regent Street, Glasgow.
PATRICK, ANDREW CRAWFORD, Engineer, Johnstone.

PENMAN, ROBERT REID, Boilermaker, 16 Annfield Place, Glasgow.

PENMAN, WILLIAM, Boilermaker, Springfield House, Dalmarnock, Glasgow.

REDFEARN, WALTER MAURICE, Engineer, 42 Dixon Road, Govanhill, Glasgow.

REID, JAMES, Engineer, 3 Cart Street, Paisley.

RUSSELL, FREDERICK ALEXANDER, Mechanical Engineer, 132 West Regent Street, Glasgow.

SMITH, HUGH WILSON, Engineer, 2 Knowe Terrace, Pollokshields, Glasgow.

SMITH, JAMES, Mechanical Engineer, 24 Melrose Gardens, Glasgow.

TANNETT, JOHN CROYSDALE, Engineer, Vulcan Works, Paisley.

THOMSON, ROBERT, Mechanical Engineer, Manager, c/o Barr, Thomson & Co., Ltd., Engineers, Kilmarnock.

TURNBULL, ALEXANDER POTT, Mechanical Engineer, 264 Maxwell Road, Pollokshields, Glasgow.

WATT, ALEXANDER, Engineer, Inchcape, Paisley.

WILSON, MATTHEW G., Founder, 43 Oxford Street, Glasgow.

AS MEMBER FROM ASSOCIATES' SECTION :—

BARR, JOHN, Secretary Glenfield Company, Kilmarnock.

AS MEMBERS FROM GRADUATES' SECTION :—

ROBIN, MATTHEW, Engineer, 15 Clifford Street, Glasgow.

RUSSELL, JAMES, Engineer, 15 Kyle Park, Uddingston.

RUSSELL, JOSEPH WILLIAM, Brass Founder and Engineer, 158 Milton Street, Glasgow.

AS ASSOCIATES :—

BAILLIE, ARCHIBALD, Iron and Steel Merchant, 2 Balmoral Terrace, Glasgow.

GUTHRIE, ALLAN, Mechanical Engineer, 2 Whittingehame Drive, Kelvinside, Glasgow.

M'MILLAN, ARCHIBALD, Secretary, Clydebank Shipbuilding and Engineering Co., Rosebery Place, Clydebank.

TAYLOR, JOHN, Marine Superintendent, Stanley House, South Avenue, Govan.

WEIR, ANDREW, Shipowner, 102 Hope Street, Glasgow.

WREDE, FREDERICK LEAR, Shipowner, 25 Bentinck Street, Greenock.

AS GRADUATES :—

BOYLE, EDWARD S. S., Apprentice Civil Engineer, 9 Arlington Street, Glasgow.

GIBSON, ROBERT E., Apprentice Civil Engineer, Engineer's Office, St. Enoch Station, Glasgow.

Johnstone, Alexander C., Mechanical Draughtsman, 7 Blackburn Street, Paisley Road, West, Glasgow.
Morton, Charles C., Apprentice Engineer, Ingleside, The Park, Waterloo, Liverpool.
Mitchell, Charles, Mechanical Draughtsman, 1 Cambridge Terrace, Pollokshields, Glasgow.
Newton, Charles A., Electrical Engineer, c/o Miss Davison, 51 Grant Street, Glasgow.
Roy, William, Mechanical Engineer, 14 Wilton Drive, Kelvinside, Glasgow.
Sloan, John Alexander, Engineer, 11 Rose Street, Garnethill, Glasgow.

The Fifth General Meeting was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 22nd February, 1898, at 8 P.M.

Mr George Russell, President, in the Chair.

The Minutes of the General Meeting, held on the 25th January, 1898, were read, confirmed, and signed by the President.

Prof. E. J. Mills, D.Sc., F.R.S., read a paper on "Photo-Surveying."

Mr C. A. Matthey showed some experiments relative to circulation in Water-Tube Boilers, and was awarded a vote of thanks.

The discussion on Mr Robert Caird's paper, "A Graphic Log," took place and was terminated.

On the motion of the President, a vote of thanks was awarded to Mr Caird for his paper, and to Mr Gretchin for his contribution to the discussion.

The discussion on Mr T. R. Murray's paper, "The Theory and Practice of Mechanical Refrigeration," was begun and adjourned.

The disçussion on Mr W. R. Austin's paper, on "The Causes of Collapse in Marine Boiler Furnaces," was postponed.

A communication from Mr G. Gretchin, on "Notes on the Belleville Boilers of the T.S.S. 'Kherson,'" was held as read.

The President announced that the following Candidates had been elected; viz.:—

AS MEMBERS:—

Bennie, John, Engineer, Auldhousfield, Eastwood, Pollokshaws.
Beveridge, Richard James, Lloyd's Surveyor, 342 Argyle Street, Glasgow.

CHAMEN, W. A., Chief Electrical Engineer, Glasgow Corporation, 75 Waterloo Street, Glasgow.

CHRISTISON, GEORGE, Engineer, 68 Cambridge Drive, Glasgow.

CLARK, WILLIAM GRAHAM, Naval Architect, 27 Lawton Road, Waterloo, Liverpool.

DEMPSTER, JOHN, Mechanical Engineer, 49 Robertson Street, Glasgow.

EASTON, WM. CECIL, B.Sc., Civil Engineer, City Engineer's Office, Glasgow.

HOWAT, WILLIAM, Engineer, 121 Raeberry Street, Glasgow.

KERR, JAMES, Lloyd's Surveyor, 342 Argyle Street, Glasgow.

KINCAID, JOHN G., Marine Engineer, Oakfield, Greenock.

SOMERVILLE, THOMAS A., Engineer, 264 Maxwell Road, Pollokshields, Glasgow.

WILLIAMS, LLEWELLYN WYNN, B.Sc., Mechanical Engineer, Cathcart, Glasgow.

WILSON, W. H., Mechanical Engineer, 45 Scotland Street, Glasgow.

AS MEMBERS FROM ASSOCIATES' SECTION :—

M'KINNEL, WILLIAM, Founder, 234 Nithsdale Road, Pollokshields, Glasgow.

SMILLIE, SAMUEL, Founder, 71 Lancefield Street, Glasgow.

AS MEMBERS FROM GRADUATES' SECTION :—

SHUTE, T. S., Lloyd's Surveyor, Heath House, King's Road, N. Ormesby, Middlesbrough.

HARRISON, J. E., Civil Engineer, 160 Hope Street, Glasgow.

ELLIOTT, ROBERT, B.Sc., Lloyd's Surveyor, Greenock.

BRUHN, JOHANNES, Lloyd's Surveyor, 49 Sydenham Park, Sydenham, London, S.E.

AS ASSOCIATES :

MORTON, ALFRED, Iron and Steel Merchant, 8 Prince's Square, Glasgow.

MOWBRAY, ARCHIBALD H., Secretary of Rolling Mills and Galvanizing Co., c/o Messrs Smith & M'Lean, Mavisbank, Glasgow.

SMITH, JOHN, Cashier, The Crown Iron Works, 13 Gt. George St., Hillhead, Glasgow.

AS GRADUATES :—

CRAIG, JAMES, Apprentice Draughtsman, Netherlea, Partick.

EDMISTON, ALEXANDER A., Mechanical Draughtsman, Ibrox House, Govan.

INNES, W., Apprentice Electrical Engineer, 11 Walmer Terrace, Glasgow.

MACKAY, HARRY J. S., Draughtsman, 1 West Bank Place, Hillhead, Glasgow.

POLLOK, JOHN, Apprentice Civil Engineer, Portland Park, Hamilton.

THOMSON, GRAHAM H., Jun., Mechanical Engineer, 2 Marlborough Terrace, Glasgow.

TOD, WILLIAM, Assistant Foreman Engineer, c/o Miss Granger, 24 St. Vincent Crescent, Glasgow.

THE SIXTH GENERAL MEETING was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 22nd March, 1898, at 8 P.M.

Mr ROBERT CAIRD, F.R.S E., Vice-President, in the Chair.

The Minutes of the General Meeting, held on the 22nd February, 1898, were read, confirmed, and signed by the Chairman.

The Chairman intimated that a Summer Meeting would be held in Sheffield on the 15th, 16th, and 17th of June, 1898.

The discussion on Mr T. R. MURRAY'S paper, "The Theory and Practice of Mechanical Refrigeration," was resumed and concluded.

On the motion of the Chairman Mr MURRAY was awarded a vote of thanks for his paper.

The discussion on Mr W. R. AUSTIN'S paper, on "The Causes of Collapse in Marine Boiler Furnaces," was begun and terminated.

On the motion of the Chairman, a vote of thanks was accorded to Mr AUSTIN for his paper.

The discussion on Prof. E. J. MILLS' paper, on "Photo-Surveying," was commenced and concluded.

A vote of thanks was awarded to Prof. MILLS for his paper, and to Mr GRETCHIN for his communication on "Notes on the Belleville Boilers of the T.S.S. 'Kherson.'"

A paper on "Some of the Economic and Practical Aspects of Electrical Power Distribution in Factories," by Mr HENRY A. MAVOR, was held as read.

The Chairman announced that the following Candidates had been elected; viz.:—

AS MEMBERS:—

BLACK, DAVID, Engineer, 12 Huntly Terrace, Shettleston.

CAMPBELL, GEORGE, Board of Trade Surveyor, Albany Villa, Kilmailing Terrace, Cathcart, Glasgow.

DIMMOCK, JOHN WINGRAVE, Lloyds' Surveyor, 2 Grantly Gardens, Shawlands, Glasgow.

HAYWARD, THOMAS ANDREW, Mechanical Engineer, 18 Carrington Street, Glasgow.

HUTCHESON, JOHN, Mechanical Engineer, 37 Mair Street, Plantation, Glasgow.

JOHNSTON, ROBERT, Chief Draughtsman, Glenfield Co., Ltd., Kilmarnock.

SMART, LEWIS A., Mechanical Engineer, Leven Shipyard, Dumbarton.

AS A MEMBER FROM ASSOCIATES' SECTION :—

LEMKES, C. R. L., Engineer, 194 Hope Street, Glasgow.

AS A MEMBER FROM GRADUATES' SECTION :—

LEE, ROBERT, Brassfounder, 158 Milton Street, Glasgow.

AS ASSOCIATES :—

MILLAR, THOMAS, Shipowner, Hazelwood, Langside, Glasgow.

RITCHIE, JAMES, Engineering Agent, 40 St. Enoch Square, Glasgow.

AS GRADUATES :—

HARVEY, ERNEST RIVERS, Apprentice Civil Engineer, c/o Mrs Haywood, 63 Great Western Road, Glasgow.

PATERSON, JOSEPH BARR, Apprentice Civil Engineer, 15 Eldon Street, Glasgow.

THE ANNUAL GENERAL MEETING was held in the Hall of the Institution, on Tuesday, 26th day of April, 1898, at 8 P.M.

Mr GEORGE RUSSELL, President, in the Chair.

The Minutes of the General Meeting, held on the 22nd March, 1898, were read, confirmed, and signed by the President.

The President intimated that the Council had already offered its congratulations to Mr John Inglis, Past-President, on the occasion of his having received the Honorary Degree of LL.D. from the Senate of the Glasgow University. He thought he was expressing the pleasure of the Meeting, that the Institution should congratulate Dr Inglis on receiving such a recognition of his merits as an eminent shipbuilder and a literary man.

The election of Office-Bearers then took place.

On the motion of Mr Robert Caird, F.R.S.E., Vice-President, seconded by Mr David C. Hamilton, Mr JAMES GILCHRIST was unanimously elected a Vice-President.

On the motion of Mr William Foulis, Vice-President, seconded by Professor Archibald Barr, D.Sc., Professor W. H. WATKINSON was unanimously elected a Vice-President.

By a majority of votes the following gentlemen were elected Members of Council:—Messrs ARCHIBALD DENNY, WILLIAM FOULIS, MATTHEW HOLMES, JOHN F. M'INTOSH, and MATTHEW PAUL.

On the motion of Mr Henry A. Mavor, seconded by Mr James Weir, Messrs PETER STEWART and W. A. CHARLTON were elected Auditors of the Annual Accounts.

The following awards were made for papers read at the ordinary meetings during the Session 1896-97 :—

1. A Premium of Books to Mr AEXANDER MORTON, for his paper on "The Maximum Elasticity and Density of Steam."

2. A Premium of Books to Mr NISBET SINCLAIR, for his paper on "Notes on the Estimation of the Power of Steamships at Sea, and of Feed and Circulating Water at Sea."

The discussion on Mr HENRY A. MAVOR'S paper, on "Some of the Economic and Practical Aspects of Electrical Power Distribution in Factories," was proceeded with and concluded. The Author was awarded a vote of thanks on the motion of the President.

Mr Andrew S. Biggart moved, and Mr James Mollison seconded, "That a Report of the Council be in future presented with the Annual Financial Statement."

The President announced that the following Candidates had been elected; viz :—

AS MEMBERS :—

ALLAN, ROBERT, Engineer and Shipbuilder, Singapore, S. Settlements.
COLLIE, CHARLES, Boilermaker, 19-21 Eaglesham Street, Plantation, Glasgow.
FERGUSON, DANIEL, Engineer and Marine Surveyor, 27 Oswald Street, Glasgow.
JARDINE, JOHN, Mechanical Engineer, Dalzell Steel and Iron Works, Motherwell.
M'ARTHUR, JAMES D., Engineer, 7 Westbank Place, Hillhead, Glasgow.
M'GECHAN, ANDREW, Manager, 232 Paisley Road, West, Glasgow.
WYLIE, WILLIAM, Engineer, 36 Maxwell Drive, Pollokshields, Glasgow.

AS AN ASSOCIATE :—

M'GECHAN, ROBT. K., Engineering Agent and Contractor, 17 Oswald Street, Glasgow.

AS GRADUATES :—

JOHNSTONE, ROBERT, Engineer Draughtsman, 10 Hayburn Crescent, Partick.
LAW, ALEXANDER, Mechanical Engineer, 44 Dowanhill Street, Partick.
M'LEAN, JOSEPH M., Draughtsman, 1 Bloomfield Terrace, Govan.
PRENTICE, HUGH, Mechanical Draughtsman, Millbank, Yoker.

TREASURER'S

INCOME AND EXPENDITURE ACCOUNT

GENERAL

ORDINARY INCOME.

			1896-97.	*1895-96.*
I. *Annual Subscriptions received—*				
530 Members	at £1 10 0	£795 0 0		*£608 10 0*
202 Graduates	„ 0 10 0	101 0 0		*90 0 0*
45 Associates	„ 1 0 0	45 0 0		*27 10 0*
			£941 0 0	*[726 0 0]*
II. *Arrears of Subscriptions received—*			44 0 0	*94 15 0*
III. *Sales of Transactions,*			10 8 8½	*2 19 0*
IV. *Interests and Rents—*				
Interest on Clyde Trust Mortgage for £300, less tax, ...		£9 8 6		*9 8 6*
Do. £35, proportion of Glasgow Corporation Mortgage for £750, less tax, ...		0 18 1		*1 0 4*
Students' Institute C.E., for use of Library, ...		11 18 0		*13 16 0*
Interest on Deposit Receipts, ...		2 3 7		*0 0 0*
				0 0 0
			24 8 2	*[24 4 10]*
			£1019 16 10½	*£847 18 10*

EXTRAORDINARY INCOME.

		1896-97.	*1895-96.*
Surplus of Ordinary Income brought down, ... —	£12 8 8½		*£61 7 0*
Do. from James "Watt Dinner,"	2 5 10		*3 17 8*
Balance, being Deficiency ...	592 12 7½		
		£607 7 2	*[65 4 8]*
		£607 7 2	*£65 4 8*

STATEMENT.

FOR YEAR ENDING 30TH SEPTEMBER, 1897.

FUND.

ORDINARY EXPENDITURE.

		1896-97.	*1895-96.*
I. *General Expenses—*			
Secretary's Salary, ...	£300 0 0		*£175 0 0*
Do. Commission for collection of Arrears of Subscriptions,	0 0 0		*3 2 3*
Institution's proportion of net cost of maintenance of Buildings,	198 8 11		*190 16 3*
Interest on Medal Funds invested in Buildings, ...	18 14 3		*16 19 1*
Library Books, ...	19 15 2		*18 15 8*
Binding Periodicals and Papers,	6 7 11		*6 5 8*
Stationery and Postages, etc.,	23 8 10		*15 0 3*
Travelling Expenses, ...	12 10 0		*0 0 0*
Office Expenses, ...	7 16 0		*0 0 0*
Advertising, Insurance, etc., ...	1 17 0		*1 10 6*
Law Expenses, £1 6s; Assistance at Meetings, £3 3s, ...	0 0 0		*4 9 0*
		588 18 1	*[431 18 8]*
II. "*Transactions*" *Expenses—*			
Printing and Binding,	£260 14 9		*209 1 0*
Lithography, ...	85 7 0		*75 14 3*
Postages, ...	36 17 10		*32 9 0*
Reporting, ...	14 19 0		*14 3 6*
Delivery of Annual Volume, ...	5 11 6		*9 18 5*
		403 10 1	*[341 6 2]*
III. *Awards—*			
Premiums for Papers, ...		15 0 0	*13 7 0*
IV. *Surplus* carried down, ...		12 8 8½	*61 7 0*
		£1019 16 10½	*£847 18 10*

EXTRAORDINARY EXPENDITURE.

Honorarium to late Secretary, ...	500 0 0		
Balance of late Secretary's Salary, ...	37 10 0		
Printing and Advertising *re* Secretaryship, ...	7 17 2		
Arrears of Subscriptions valued per last Accounts at £112 Do. valued per Bal. Sheet, at 50 Reduction in valuation written off,	62 0 0	607 7 2	*0 0 0*
Balance, being surplus, ...		0 0 0	*65 4 8*
		£607 7 2	*£65 4 8*

BALANCE SHEET, AS AT

LIABILITIES.			As at 30th Sept., 1897.	*As at 30th Sept., 1896.*
I. *Sundry Creditors*, ...			£481 3 4	*£397 12 4*
II. *Subscriptions* paid in advance, ...			4 0 0	*0 0 0*
III. *Medal Funds*—				
Marine Engineering—				
Balance as at 1st Oct., 1896,	£491 3 5			
Interest received during year, £13 18s; *less* cost of medal, £10,... ..	3 18 0			
		495 1 5		*491 3 5*
Railway Engineering—				
Balance as at 1st Oct., 1896,	£296 19 10			
Interest received during year,	7 18 0			
		304 17 10		*296 19 10*
Graduates'—				
Balance as at 1st Oct., 1896,	£27 6 9			
Cost of medal, £1 7s 6d; *less* interest received during year, 18s 7d,	0 8 11			
		26 17 10		*27 6 9*
			826 17 1	*[815 10 0]*
IV. *Capital Accounts*—				
General Fund—				
Balance as at 1st Oct., 1896,	£1591 10 2			
Deficiency, 1896-97,	592 12 7½			
		998 17 6½		*1591 10 2*
Building Fund—				
Balance as at 1st Oct., 1896,	£1667 15 5			
Life Members' Subscriptions, £165; Entry money, £64 15s; and Interest, £14 9s 8d; received during year,	244 4 8			
		1912 0 1		*1667 15 5*
			2910 17 7½	*[3259 5 7]*
			£4222 18 0½	*£4472 7 11*

30TH SEPTEMBER, 1897.

ASSETS.			As at 30th Sept., 1897.	*As at 30th Sept., 1896.*
I. *Heritable Property*—				
Total Cost,	£7094 16 3			
Of which one-half belongs to Institution, ...		£3547 8 1		*£3547 8 1*
Less Institution's proportion of Bond, ...		500 0 0		*1500 0 0*
			£3047 8 1	*2047 8 1*
II. *Investments*—				
Clyde Trust Mortgage, ...			300 0 0	*300 0 0*
Glasgow Corporation Mortgage, ...			0 0 0	*750 0 0*
III. *Books in Library*—				
Valued at, say			500 0 0	*500 0 0*
IV. *Furniture and Fittings*—				
Valued at, say		£50 0 0		
Walnut Desk, at cost, ...		15 10 0		
			65 10 0	*50 0 0*
V. *Rent due but unpaid*—			10 0 0	*0 0 0*
VI. *Arrears of Subscriptions*—				
Session 1896-97—				
33 Members at £1 10/, and Entry-money, £2		£51 10 0		
1 Associate at £1,		1 0 0		
40 Graduates at 10/,		20 0 0		
		£72 10 0		
Previous sessions—				
11 Members,	£27 0 0			
15 Graduates,	11 0 0			
		38 0 0		
Total,		£110 10 0		
Valued at, say			50 0 0	*112 0 0*
VII. *Cash*—				
In Bank, ...		£243 1 11		
In Secretary's hands, ...		6 18 0½		
			249 19 11½	*712 19 10*
			£4222 18 0½	*£4472 7 11*

ABSTRACT OF "HOUSE EXPENDITURE" ACCOUNT FOR SESSION 1896-97.

INCOME.	11 months, to 30th Sep., 1897.	*12 months, to 31st Oct., 1896.*	EXPENDITURE.	11 months, to 30th Sep., 1897.	*12 months, to 31st Oct., 1896.*
Rents for Letting Rooms, ...	£57 5 0	*£94 6 6*	Salary to Curator, ...	£125 16 8	*£135 0 0*
Balance, being excess Expenditure, ...	396 17 10	*381 12 6*	Salary to Attendant at Library, Cleaning, etc., ...	38 0 0	*36 5 1½*
Payable—One-half by Institution, ... £198 8 11			Feu-duty, Taxes, and Insurance,	40 15 8½	*35 0 8½*
,, ,, Philosophical Society, 198 8 11			Interest on Bond, ...	101 10 0	*116 0 0*
			Alterations, Repairs & Renewals,	110 9 10	*130 12 4*
			Coal, Gas, and Electric Light,	36 7 1	*20 1 9*
			Stationery, Postages, and Incidental Expenses, ...	1 3 6½	*2 19 1*
	£454 2 10	*£475 19 0*		£454 2 10	*£475 19 0*

Note.—The Account of the House Committee, of which the above is an abstract, is kept by Mr John Mann, C.A., Treasurer to the Committee, and is periodically audited by the Auditors appointed by the Institution and the Philosophical Society.

EDWARD H. PARKER, *Secretary to the House Committee.*

GLASGOW, 11*th November*, 1897.—We have examined the foregoing Financial Statement of the Treasurer, the Accounts of the Marine and Railway Engineering Medal Funds, the Graduates' Medal Fund, the Building Fund, the New Buildings Account, and the House Expenditure Account, and find the same duly vouched and correct, the Amounts in Bank being as stated.

(Signed) PETER STEWART,
W. A. CHARLTON, } AUDITORS.

REPORT OF THE LIBRARY COMMITTEE.

The additions to the Library during the year include 57 volumes by purchase; 5 volumes, 1 part, and 5 pamphlets by donation; while 66 volumes and 109 parts were received in exchange for the "Transactions" of the Institution. Of the periodical publications received in exchange, 23 are weekly, 16 monthly, and 3 quarterly. Thirty-one volumes were bound during the year.

The Library now comprises 2536 volumes.

As the proceedings of the most important engineering societies are to be found in the Library of the Institution, the Committee begs to draw the attention of Members to the existence of this particular section.

On behalf of the Institution, the Committee desires to tender its thanks to the donors for the presentations made, and to Mr Edward Thunderbolt for his donation of ten shillings to the Library Fund.

DONATIONS TO THE LIBRARY.

British Corporation for the Survey and Registry of Shipping. Rules, etc., for 1897. From the Corporation.

Calendar, Queen's College, Galway, 1897-98. From the College.

De Chasseloup-Laubat, M.L., Les Chaudières Marines. (From Memoires et Compte Rendu des Travaux de la Société des Ingénieurs Civilis de France, April, 1897); 8vo pamphlet, 1897.

Dunn, P. Livingston, St. Rollox Locomotive and Carriage Works of the Caledonian Railway. (From Minutes of Proceedings, Institution of Civil Engineers, Vol. 129); 8vo. London, 1897.

Ingham, Wm., Torquay Waterworks. (From Transactions of the British Association of Waterworks Engineers, 1897); 8vo. pamphlet. From the Author.

Jacobus, J. S., On Determining the Moisture in Steam; 8vo. pamphlet, 1887.

Journal of the Iron and Steel Institute. General Index, Vols. 1-50, 1869-96; 8vo. London, 1898. From the Institute.

Report of the Naval Court of Inquiry upon the Destruction of the U.S. Battle Ship "Maine" in Havana Harbour, February 15th, 1898. From U.S. Government.

Rowan, F. J., Boiler Incrustation and Corrosion; pamphlet, 8vo. London, 1876.

Rowan, F. J., Light Railway: A One-Rail or Trestle System of. (From Transactions of the Federated Institution of Mining Engineers); 8vo. pamphlet, 1898. From the Author.

Strata of Northumberland and Durham, as proved by Borings and Sinkings; U to Z. From North of England Inst. of Engineers.

BOOKS ADDED TO THE LIBRARY BY PURCHASE.

Barber, T. Walter, Repair and Maintenance of Machinery; 8vo. London, 1895.

Barker, A. H., Graphic Methods of Engine Design; 8vo. Manchester, 1897.

Benjamin, Park, The Intellectual Rise in Electricity: A History; 8vo. London, 1895.

Blaine, R. J., Hydraulic Machinery; 8vo. London, 1897.

Boller, A. P., Practical Treatise on the Construction of Iron Highway Bridges; 4th edition; 8vo. New York, 1893.

Borchers, W., Electric Smelting and Refining, being the 2nd edition of "Elektro-Metallurgie"; translated by G. M'Millan; 8vo. London, 1897.

Bright, Charles, Submarine Telegraphs; their History, Construction and Working; 8vo. London, 1898.

Burton, F. G., Engineering Estimates and Cost Accounts; 8vo. Manchester, 1896.

Campania and Lucania; "Engineering" Folio. London.

Carus-Wilson, C. A., Electro-Dynamics: The Direct Current Motor; 8vo. London, 1898.

Colyer, Fredk., Pumps and Pumping Machinery; 2nd edition, Vol. 1; 8vo. London, 1892.

Colyer, Fredk., Pumps and Pumping Machinery; Vol. 2; 8vo. London.

Cromwell, J. H., Treatise on Toothed Gearing; 4th edition; 8vo. New York, 1894.

Dibdin, W. J., Purification of Sewage and Water; 8vo. London, 1897.

Donkin, Bryan, Heat Efficiency of Steam Boilers: Land, Marine, and Locomotive; 4to. London, 1898.

Ewing, J. A., Mechanical Production of Cold, Howard Lectures on the. (Journal Society of Arts, Vol. 45, 1897); 8vo. London, 1897.

Farman, D., Auto-Cars, Cars, Tram Cars, and Small Cars; translated by L. Serravillier; 8vo. London, 1896.

Foley, N., Pocket-Book of Coal and Speed Tables for Engineers and Steam Users; 32mo. London, 1884.

Garbett, H., Naval Gunnery: A Description and History of the Fighting Equipment of a Man-of-War; 8vo. London, 1897.

Grover, F., Modern Gas and Oil Engines: A Practical Treatise on; 8vo. Manchester, 1897.

Halliday, George, Steam Boilers; 8vo. London, 1897.

Hay, Alfred, Alternate Current Working, The Principles of; 8vo. London, 1897.

Hiscox, G. D., Gas, Gasoline, and Oil Vapour Engines for Stationery, Marine, and Vehicle Motive Power; 8vo. London, 1897.

Hurst, Charles, Valves and Valve Gearing; 8vo. London, 1897.

Innes, C. H., The Centrifugal Pump, Turbines, and Water Motors, including the Theory and Practice of Hydraulics; 8vo. Manchester, 1893.

Jamieson, Prof. A., Text-Book of Applied Mechanics, Vol. 2; 8vo. London, 1897.

Kemp, Dixon, Yacht Architecture; 3rd edition; 2 vols. London, 1897.

Kent, W., Mechanical Engineers' Pocket-Book; 2nd edition; 8vo. New York, 1896.

Kneass, S. L., Practice and Theory of the Injector; 8vo. New York, 1894.

Ledoux, M., Ice-Making Machines; revised and transformed to English units by Deuton, Jacobus, and Riesenberger; 12vo. New York, 1893.

MacCord, C. W., Kinematics; 4th edition; 8vo. New York, 1893.

Mackrow, C., Naval Architects' and Shipbuilders' Pocket-Book of Formulae, Rules, and Tables; 8vo. London, 1896.

Oldknow, R. C., The Mechanism of Men-of-War; 8vo. London, 1897.

Parker, H. C., Systematic Treatise on Electrical Measurements; 8vo. London, 1897.

Peabody, C. H., and E. F. Miller, Steam Boilers; 1st edition; 8vo. New York, 1897.

Perry, John, Applied Mechanics; 8vo. London, 1897.

Phillips, J. A., and H. Louis, Treatise on Ore Deposits; 2nd edition; 8vo. London, 1896.

Popplewell, W. C., Heat and Heat Engines: An Elementary Treatise on; 8vo. Manchester, 1897.

Pullen, W. W. F., Application of Graphic Methods to Design of Structures; 8vo. Manchester, 1893.

Pupin, M. J., Thermodynamics of Reversible Cycles in Gases and Saturated Vapours; edited by Max Osterberg; 8vo. New York, 1894.

Reulaux, F., The Constructor: A Handbook of Machine Design; 4th edition; translated by H. H. Suplee; 4to. London, 1895.

Sennett, R., and H. J. Oram, Marine Steam Engine: A Treatise for Engineers and Officers of the Royal Navy and Mercantile Marine; 8vo. London, 1898.

Sennett, R., and H. J. Oram, Marine Steam Engine. (Duplicate Copy); 8vo. London, 1898.

Siebel, J. E., Compend of Mechanical Refrigeration; 2nd edition: 8vo. Chicago, 1896.

Sommerfeldt, H. A., Construction of Ships for Ocean and River

Service; new edition, with Folio Atlas of Plates; 8vo. London, 1861.

Tayler, A. J. W., Refrigerating and Ice-Making Machinery; 2nd edition; 8vo. London, 1897.

Templeton, W., Practical Mechanic's Workshop Companion; 17th edition; revised and enlarged by W. S. Hatton; 8vo. London, 1895.

Warren, W. H., Engineering Construction in Iron, Steel, and Timber; 8vo. London, 1894.

Watson, T. H., Naval Architecture: Manuel on Laying-off Iron, Steel, and Composite Vessels; 8vo. London, 1898.

Weisbach J., and G. Hermann, Mechanics of Pumping Machinery; 2nd edition; translated by K. P. Dahlstrom; 8vo. London, 1897.

Weisbach, J., and G. Hermann, Mechanics of Hoisting Machinery; translated from 2nd edition, by K. P. Dahlstrom; 8vo. London, 1893.

Wood, De Volson, Turbines, Theoretical and Practical; 2nd edition; 8vo. New York, 1896.

Wright, Lewis, Induction Coil in Practical Work, including Röntgen X Rays; 8vo. London, 1897.

Year-Book of the Scientific and Learned Societies of Great Britain and Ireland, 1898.

THE INSTITUTION EXCHANGES TRANSACTIONS WITH THE FOLLOWING SOCIETIES, &C.:—

American Institute of Electrical Engineers.

American Philosophical Society.

American Society of Civil Engineers, New York.

American Society of Mechanical Engineers, New York.

Association des Ingénieurs, Gand, Belgium.

Austrian Engineers' and Architects' Society, Vienna.

Bristol Naturalists' Society, Bristol.

Bureau of Steam Engineering, Navy Department, Washington.

Canadian Institute, Toronto.

Canadian Society of Civil Engineers, Montreal.
Edinburgh Architectural Association.
Engineering Association of New South Wales, Sydney.
Engineering Society of the School of Political Science, Toronto.
Engineers' and Architects' Society of Naples, Naples.
Franklin Institute, Philadelphia, U.S.A.
Geological Survey of Canada, Montreal.
Hull and District Institution of Engineers and Naval Architects, Hull.
Institute of Marine Engineers, London.
Institution of Civil Engineers, London.
Institution of Civil Engineers of Ireland, Dublin.
Institution of Junior Engineers, London.
Institution of Mechanical Engineers, London.
Institution of Naval Architects, London.
Iron and Steel Institute, London.
Liverpool Engineering Society, Liverpool.
Liverpool Polytechnic Society, Liverpool.
Literary and Philosophical Society of Manchester, Manchester.
Lloyd's Register of British and Foreign Shipping, London.
Manchester Association of Engineers, Manchester.
Master Car Builders' Association, Chicago, U.S.A.
Midland Institute of Mining, Civil, and Mechanical Engineers, Barnsley.
Mining Institute of Scotland, Hamilton.
North-East Coast Institution of Engineers and Shipbuilders, Newcastle-on-Tyne.
North of England Institute of Mining and Mechanical Engineers, Newcastle-on-Tyne.
Patent Office, London.
Philosophical Society of Glasgow.
Royal Academy of Sciences, Lisbon.
Royal Dublin Society, Dublin.
Royal Scottish Society of Arts, Edinburgh.
Royal Society of Tasmania, Hobart.
Sanitary Institute of Great Britain, London.

Scientific Library, U.S. Patent Office, Washington, U.S.A.
Shipmasters' Society, London.
Smithsonian Institution, Washington, U.S.A.
Société d'Encouragement pour l'Industrie Nationale, Paris.
Société des Ingénieurs Civils de France, Paris.
Société des Sciences Physiques et Naturelles de Bordeaux, Bordeaux.
Société Industrielle de Mulhouse, Mulhouse.
Society of Arts, London.
Society of Arts, Massachusetts Inst. of Technology, Boston.
Society of Engineers, London.
Society of Naval Architects and Marine Engineers, Washington, U.S.A.
South Wales Institute of Engineers, Swansea.
Technical Society of the Pacific Coast, San Francisco, U.S.A.
West of Scotland Iron and Steel Institute, Glasgow.

COPIES OF THE TRANSACTIONS ARE FORWARDED TO THE FOLLOWING COLLEGES, LIBRARIES, &C. :—

Advocates' Library, Edinburgh.
British Corporation for the Survey and Registry of Shipping, Glasgow.
Cornell University, Ithaca, U.S.A.
Dumbarton Free Public Library, Dumbarton.
Glasgow and West of Scotland Technical College, Glasgow.
Glasgow University, Glasgow.
Lloyd's Office, London.
Mercantile Marine Service Association, Liverpool.
M'Gill University, Montreal.
Mitchell Library, Glasgow.
Royal Naval College, Greenwich.
Stevens Institute of Technology, Hoboken, U.S.A.
Stirling's Library, Glasgow.
Trinity College, Dublin.
Underwriters' Rooms, Glasgow.
Do. Liverpool.
University College, London.
Yorkshire College, Leeds.

PUBLICATIONS RECEIVED PERIODICALLY IN EXCHANGE FOR INSTITUTION TRANSACTIONS:—

American Manufacturer and Iron World.
Cassier's Magazine.
Colliery Guardian.
Contract Journal.
Engineer.
Engineering.
Engineering Magazine.
Engineering and Mining Journal.
Engineers' Gazette.
Indian Engineer.
Indian and Eastern Engineer.
Industries and Iron.
Iron and Coal Trades' Review.
Iron and Steel Trades' Journal.
Journal de l'Ecole Polytechnic.
L'Industria.
Machinery.
Machinery Market.
Marine Engineer.
Mariner
Mechanical World.
Nature.
Portfeuille Economique des Machines.
Practical Engineer.
Revue Industrielle.
Shipping World.
Stahl und Eisen.
Steamship.
Syren and Shipping.
Transport.

ANDREW JAMIESON.
Hon. Librarian and Convener.

The Library of the Institution is open daily (except Saturdays) during the Winter Session from 9·30 A.M. till 8 P.M., and on Meeting Nights of the Institution and Philosophical Society till 10 P.M.; throughout the Summer months from 9·30 A.M. till 5 P.M., save during July, when it is closed for the Glasgow Fair Holidays, and open for the remainder of the month from 1 P.M. to 5 P.M.; and every Saturday from 9·30 A.M. till 2 P.M., during the winter session, and from 9-30 A.M. till 1 P.M. during the summer months.

Books will be lent on presentation of Membership Card to the Sub-Librarian.

Members have also the privilege of consulting the Books in the Library of the Philosophical Society.

The use of the Library and Reading Room is open to Members, Associates, and Graduates.

The Portrait Album lies in the Library for the reception of Members' Portraits. Members are requested when forwarding Portraits to attach their Signature to the bottom of Carte.

The Library Committee are desirous of calling the attention of Readers to the "Recommendation Book," where entries can be made of titles of books suggested as suitable for addition to the Library.

Copies of the Library Catalogue and Supplement, price 6d; or separately, 3d each, may be had at the Library, or from the Secretary.

A List of the Papers read and Authors' Names, from the First to the Thirty-Third Sessions, will be found in Vol. XXXIII. of the Transactions.

As arranged by the Council, a Register Book for Graduates now lies in the Library for the inspection of Members, the object being to assist Graduates of the Institution in finding suitable appointments.

Annual Subscriptions are due at the commencement of each Session; viz.:—

MEMBERS, £1 10s; ASSOCIATES, £1; GRADUATES, 10s.
LIFE MEMBERS, £20; LIFE ASSOCIATES, £15.

Membership Application Forms can be had from the Secretary or from the Librarian, at the Rooms, 207 Bath Street.

The Council, being desirous of rendering the Transactions of the Institution as complete as possible, earnestly request the co-operation of Members in the preparing of Papers for reading and discussion at the General Meetings.

Early notice of such Papers should be sent to the Secretary, so that the dates of reading may be arranged.

Copies of the reprint of Vol. VII., containing a paper on "The Loch Katrine Water Works," by Mr J. M. Gale, C.E., may be had from the Secretary; price to Members, 7s 6d.

Members of this Institution, who may be temporarily resident in Edinburgh, will, on application to the Secretary of the Royal Scottish Society of Arts, at his Office, 117 George Street, be furnished with Billets for attending the meetings of that Society.

The Meetings of the Royal Scottish Society of Arts are held on the 2nd and 4th Mondays of each month, from November till April with the exception of the 4th Monday of December.

OBITUARY.

Honorary Member.

Sir **Henry Bessemer** was elected an Honorary Member of the Institution in 1891.

As one of the foremost metallurgists, and one of the greatest benefactors of toiling humanity of this century, his name is of world-wide reputation.

He was born at Charlton, near Hitchin, on 19th January, 1813. He appears to have attended school in the neighbourhood, and when his education was finished he remained at home to assist in the type foundry which his father then owned. Concerning his early life little is generally known, but it is asserted that he first made a living by designing patterns for Paisley shawls. His first noteworthy discovery was the machine for "flaking" the metal to make bronze paint, and so jealously did he safe-guard his secret, that his wife and brother-in-law were his only fellow-workers, and his private house in St. Pancras the first factory for producing his bronze paint.

The subject of this notice first attracted general attention by his partial success in obtaining the rotation of cannon balls without rifling the guns. And although his device received encouragement from Napoleon III., it was abandoned because the inventor became convinced that the metal for making guns was inferior, and could be improved. This idea led to the Bessemer converters, which revolutionised the iron and steel trade of the world, and with which the inventor's name will be associated for many centuries.

He obtained the Telford Medal for a paper on his steel process read before the Institution of Civil Engineers in 1859. In 1871-73 he was President of the Iron and Steel Institute. In 1879 he received the honour of Knighthood, and was elected a Fellow of the Royal Society. He died at his residence, Denmark Hill, Surrey, on the 15th March, 1898.

Members.

Archibald Binnie Allan was born at Strathbungo, in the Parish of Govan, on the 19th December, 1850. He was a distinguished student at the Glasgow University, and took his certificate as a civil engineer in 1870. He received his early professional training under Mr Hugh Maclure, civil engineer, Glasgow, and in the office of the City Master of Works, under the late Mr Carrick.

In 1880 he was appointed burgh surveyor of Govan, and filled that position until the time of his death, which occurred suddenly on 23rd February, 1898.

Mr Allan became a Member of the Institution in 1872.

William Cowan was born at Edinburgh on the 15th October, 1823, and was educated at the High School there. He began his engineering career in 1839, and after completing his apprenticeship on the Arbroath and Forfar Railway, he filled positions on the "Edinburgh and Glasgow," "North British," and "Great Northern" Railways. In 1854 he received an appointment with the Great North of Scotland Railway Co., and went to reside in Aberdeen. Three years later he was promoted to locomotive and carriage superintendent with that Company, which post he held till his retirement in September, 1883.

He was the first in Great Britain to permanently adopt the bogie engine, and the first in Scotland to introduce cast-steel tyres, which at that time were made only by Krupp of Essen.

The health of Mr Cowan began to fail during the autumn of 1897 and on Christmas day of that year he was attacked with pneumonia. He rallied somewhat, but *diabetic coma* supervened, which caused his death on 10th March, 1898.

Mr Cowan became a Member of the Institution in 1861.

Frederick Colthurst Kelson was born in Bristol on 13th May, 1831, being a son of Mr Joseph Kelson, surgeon. He was educated at Bristol College, and served his apprenticeship with Messrs Muir & Pritchard, of Gravesend. After a varied and useful experience he entered the Royal Navy as an engineer, serving successively in H.M. ships "Caradoc," "Fisgard," "Antelope," and "Donegal," from 1860 to 1865. On leaving H.M. service he was engaged for some years with Messrs George Forrester & Co., Liverpool. In 1869 he was appointed superintendent engineer of the City of Cork Steam Packet Co., with the management of their yard and engine works at Cork. After some years this company sold the works at Cork, and Mr Kelson, returning to Liverpool, established himself as a consulting engineer. On the death of Mr Crichton in 1878, Mr Kelson succeeded him as superintendent engineer of the Cork Steamship Co., whose steamers sail out of Liverpool, and he held this appointment till his death.

Mr Kelson was a skilful engineer and naval architect, always abreast of the times, but exercising sound judgment in the adoption of improvements. From the large number of steamers built to his designs, he was widely known and highly esteemed amongst engineers and shipbuilders, for while zealously and honourably attending to the interests of his owners, he never made aught but friends of those with whom he came closely in contact.

His death, which arose from heart disease, and was very sudden, occurred at his residence, Angra Bank, Waterloo Park, Liverpool, on 10th July, 1897.

Mr Kelson joined the Institution as a member in 1883.

HUGH M'COLL was born in Glasgow in the year 1841. He served an apprenticeship in the works of Messrs Barclay, Curle & Co., Glasgow, and subsequently entered the drawing office of their ship department, in which he eventually became chief draughtsman. In 1861 he was appointed manager with Messrs Kay & Co., shipbuilders, Kinghorn, where he continued for a period of fourteen years. He left Kinghorn to become manager with Messrs S. P. Austin & Son, at the Wear Dockyard, Sunderland. That post Mr M'Coll held till February, 1897, when, owing to continued ill-health, he resigned. He was an able naval architect, and his kind and genial disposition gained for him universal respect and esteem. His death occurred in London on the 26th April, 1897, in the fifty-sixth year of his age.

Mr M'Coll was a Member of the Scottish Shipbuilders' Association at the time of its incorporation with the Institution in 1865.

DAVID M'CULLOCH was born at Kilmarnock on the 7th February, 1847, and was educated at the Academy there. He served his apprenticeship as a fitter and patternmaker in the Vulcan Works, Kilmarnock. Thereafter, he entered the drawing office of that establishment, and was subsequently induced to accept the appointment of manager of the engineering department. In 1893 he started business on his own account as a consulting engineer, and interested himself largely in the development of the Proell valve-gear. His death, which was due to apoplexy, took place suddenly at Kilmarnock on the 16th December, 1897.

Mr M'Culloch joined the Institution as a Member in 1871.

DAVID ROWAN was born at Ochiltree, Ayrshire, on the 4th December, 1822, where his father was a master slater, and with whom Mr Rowan served about three years as an apprentice slater.

In 1840 he commenced to serve an apprenticeship as an engineer with the late Mr John M'Andrew, St. Rollox Works, Glasgow. Seven years later he was appointed assistant to Mr Condy, of "steam hammer" fame, who was engineering manager of Messrs Dixon's Iron Works, and there he remained for about two years. For the next three years he was draughtsman with Messrs Neilson & Co., locomotive builders, whose works were then situated in Hydepark Street. Subsequently he was for two years manager with Messrs Smith & Rogers, marine engineers, and at the age of thirty-two was appointed manager in the engineering works of Messrs Caird & Co., Greenock. After remaining with Messrs Caird & Co. for about six years, he returned to Glasgow to become managing partner with Messrs James Aitken & Co., Cranstonhill, and while with that firm several important contracts were carried out under his superintendence, such as the Langloan blowing engines, and the pumping engines for supplying St. Petersburg with water. In 1866 he commenced business on his own account in Elliot Street as a manufacturer of marine engines.

Mr Rowan was one of the original members of the Institution, and held office in the Council more frequently than any other member of the Institution. For four sessions he acted as a vice-president and at the annual general meeting on 19th April, 1870, he was unanimously elected president for the two following sessions. It was during his term as president that the Institution was incorporated by Charter by the Board of Trade. In 1874 he was appointed convener of the committee elected by the Institution to report on safety-valves, and took a very active part in the work of that committee.

He devoted much energy to the promotion and welfare of the citizens of Glasgow. For many years he was a member of the Clyde Trust, and during the whole construction of the Queen's Dock, he watched its progress and development with great interest. He was also president of the Mechanics Institution for many years, and took part in the management of a number of the educational and benevolent institutions of the city.

Mr Rowan died at his residence, Woodside Place, Glasgow, on 30th July, 1898.

James Scott began his engineering career with Messrs James Aitken & Co., Cranstonhill, Glasgow, and on completion of his apprenticeship gained further experience in his profession with Messrs A. & W. M'Onie, Glasgow. After remaining with the latter firm some time, he went to Cuba, and subsequently to Trinidad, where he was engaged on various sugar plantations for about fifteen years. The last ten or twelve years of his career was spent in the Philippines, where he was concerned in the management of a foundry, and carried on an extensive business in sugar machinery.

He died on the 6th August, 1898, at Manila, in the 58th year of his age.

Mr Scott joined the Institution as a Member in 1893.

William Taylor was born in Glasgow in 1858, and served his apprenticeship with the late firm of Messrs Alexander Campbell & Co., engineers, Anderston Quay. In 1879 he entered the employment of Messrs David & William Henderson & Co., Finnieston, as a draughtsman, and was ultimately promoted to an important position with that firm.

He died at Partick on 22nd February, 1898, after a short illness.

Mr Taylor joined the Institution as a Graduate in 1882, and was elected a Member in 1897.

LIST OF HONORARY MEMBERS, MEMBERS, ASSOCIATES, AND GRADUATES

AT CLOSE OF SESSION 1897-98.

HONORARY MEMBERS.

	DATE OF ELECTION.
KELVIN, Lord, A.M., LL.D., D.C.L., F.R.SS.L. and E., Professor of Natural Philosophy in the University of Glasgow,	1859
ARMSTRONG, Lord, C.B., LL.D., D.C.L., F.R.S., Newcastle-on-Tyne,	1884
BRASSEY, Lord, K.C.B., D.C.L., 4 Great George street, Westminster, London, S.W.,	1891
BLYTHSWOOD, Lord, Blythswood, Renfrewshire,	1891
KENNEDY, Professor A. B. W., LL.D., F.R.S., 17 Victoria street, London, S.W.,	1891
MURRAY, Sir DIGBY, Bart., Hothfield, Parkstone, Dorset,	1891
WHITE, Sir WILLIAM HENRY, K.C.B., F.R.S., LL.D., Admiralty, London,	1894
DURSTON Sir A. J., K.C.B., Admiralty, London,	1896
FROUDE, R. E., F.R.S., Admiralty Experiment works, Gosport,	1897

MEMBERS.

	DATE OF ELECTION.
ADAM, J. MILLEN, Ibrox Iron works, Glasgow,	G. 25 Mar., 1890 M. 22 Jan., 1895
ADAMSON, JAMES, St. Quivox, Stopford road, Upton Manor, Essex,	23 Apr., 1869
AGNEW, GEORGE A., Woodland villa, Govan, Glasgow,	20 Mar., 1883
AILSA *(The most Honourable the Marquis of)*, Shipbuilder, Culzean castle, Maybole,	25 Jan., 1898
AITCHISON, WILLIAM, 49 Park road, Glasgow,	22 Oct., 1889
AITON, J. ARTHUR, 102 Fenchurch street, London, E.C.,	24 Nov., 1896
ALLAN, JOHN M., 3 Grantly street, Shawlands, Glasgow,	21 Jan., 1890

Names marked thus * were Members of Scottish Shipbuilders' Association at Incorporation with Institution, 1865.

Names marked thus † are Life Members.

ALLAN, J. R., Bintang, Dumbreck, Glasgow,	25 Jan., 1888
ALLAN, ROBERT, Demerara foundry, George Town, Demerara,	30 Apr., 1895
ALLAN, ROBERT, Engineer and Shipbuilder, Singapore, S. Settlements,	26 Apr., 1898
ALLAN, WILLIAM, M.P., Scotia Engine works, Sunderland,	20 Jan., 1869
ALLEY, STEPHEN E., Engineer, Langside house, Langside,	23 Nov., 1897
†ALLIOTT, JAMES B., The Park, Nottingham,	21 Dec., 1864
ALSTON, WILLIAM M., 24 Sardinia terrace, Hillhead, Glasgow,	G. 15 Feb., 1865 M. 18 Dec., 1877
†AMOS, ALEXANDER, Public Library of N.S.W., Sydney, New South Wales,	21 Dec., 1886
†AMOS, ALEXANDER, Jun.,	21 Dec., 1886
ANDERSON, JAMES, 100 Clyde street, Glasgow,	G. 24 Feb., 1874 M. 23 Nov., 1880
ANDERSON, JAMES H., Caledonian Railway, Glasgow,	20 Dec., 1892
ANDERSON, ROBERT, Clyde Street, Renfrew,	26 Jan., 1897
ANIS, Professor MOHAMED, Bey, Ministère des Travaux Publics, Cairo,	24 Apr., 1894
ANGUS, ROBERT, Lugar, Ayrshire,	28 Nov., 1860
ARCHER, W. DAVID, 47 Croham road, Croyden, Surrey,	20 Dec., 1887
ARNOT, WILLIAM, 70 West Regent street, Glasgow,	23 Jan., 1894
ARROL, THOMAS A., Germiston works, Glasgow,	21 Dec., 1875
ARROL, THOMAS, Jun., 5 Wilton mansions, Kelvinside, N., Glasgow,	20 Nov., 1894
†ARROL, Sir WILLIAM, LL.D., M.P., Dalmarnock Iron works, Glasgow,	27 Jan., 1885
†AULD, DAVID, 13 Broompark drive, Dennistoun, Glasgow,	Original
AULD, JOHN, Whitevale foundry, Glasgow,	28 Apr., 1885
AUSTIN, WM. R., 3 Caird drive, Partickhill, Glasgow,	23 Feb., 1897

BAIN, WILLIAM N., 40 St. Enoch square, Glasgow,	24 Feb., 1880
BAIN, WILLIAM P. C., Lochrin Iron works, Coatbridge,	26 Apr., 1891
BAIRD, ALLAN W., Eastwood villa, St. Andrew's drive, Pollokshields, Glasgow,	25 Oct., 1881
BALDERSTON, JAMES, Anchor mills, Paisley,	25 Jan., 1898
BALLINGALL, DAVID, 340 Maxwell road, Pollokshields, Glasgow,	27 Oct., 1896
BAMFORD, HARRY, M.Sc., The University, Glasgow,	24 Nov., 1896
BARCLAY, GEORGE, Vulcan works, Paisley,	25 Jan., 1898
BARNETT, J. R., Lilybank, Johnstone,	22 Dec., 1896

BARNETT, MICHAEL R., Ashfield, Pateley Bridge, Yorkshire,	22 Nov., 1887
BARR, JOHN, Glenfield Company, Kilmarnock,	A. 28 Oct., 1883 M. 25 Jan., 1898
BARR, Professor ARCHIBALD, D.Sc., Royston, Dowanhill, Glasgow,	21 Mar., 1882
BAXTER, GEORGE H., Clyde Navigation works, Dalmuir,	22 Mar., 1881
BAXTER, P., M'L., Copland works, Govan,	G. 22 Dec., 1885 M. 15 June, 1898
BEARDMORE, JOSEPH, Parkhead forge, Glasgow,	27 Oct., 1896
BEARDMORE, WILLIAM, Parkhead forge, Glasgow,	27 Oct., 1896
BEGBIE, WILLIAM, c/o Riddell, 55 Garnethill street, Glasgow,	15 June, 1898
BELL, CHARLES, The Birches, Stirling,	26 Jan., 1875
*†BELL, DAVID, 19 Eton place, Hillhead, Glasgow,	
BELL, IMRIE, 49 Dingwall road, Croyden, Surrey,	23 Mar., 1880
BELL, STUART, 65 Bath street, Glasgow,	26 Feb., 1895
BELL, THOMAS, 7 Clydeview, Partick,	G. 26 Apr., 1887 M. 27 Apr., 1897
BELL, W. REID, Box No. 2263, Post Office, Johannesburg, South African Republic,	22 Jan., 1889
BENNIE, H. OSBOURNE, Clyde Engine works, Polmadie, Glasgow,	25 Jan., 1898
BENNIE, JOHN, Auldhousfield, Eastwood, Pollokshaws,	22 Feb., 1898
BEVERIDGE, RICHARD JAMES, 342 Argyle street, Glasgow,	22 Feb., 1898
BIGGART, ANDREW S., 279 Nithsdale road, Pollokshields, Glasgow,	G. 20 Mar., 1883 M. 25 Nov., 1884
BILES, Professor JOHN HARVARD, Glasgow University, Glasgow,	25 Mar., 1884
BINNEY, WM. H., Marine Superintendent, Holyhead,	26 Jan., 1897
BIRD, JOHN R., 10 Morrison street, Glasgow,	25 Mar., 1890
BLACK, DAVID, 12 Huntly terrace, Shettleston,	22 Mar., 1898
BLAIR, DAVID A., Scotland street Copper works, Glasgow,	23 Mar., 1897
BLAIR, GEO., Jun., 38 Queen street, Glasgow,	G. 22 Jan., 1884 M. 23 Feb., 1897
BLAIR, GEORGE M'L., 129 Trongate, Glasgow,	17 Feb., 1869
BLAIR, H. MACLELLAN, Clutha Iron works, Vermont street, Glasgow,	G. 22 Jan., 1884 M. 22 Oct., 1889
BLAIR, JAMES M., Williamcraigs, Linlithgowshire,	27 Mar., 1867
BONE, WILLIAM L., Ant and Bee works, West Gorton, Manchester,	23 Oct., 1883
BORROWMAN, WILLIAM C., Engineer, Stobcross Engine works, Finnieston, Glasgow,	G. 27 Oct., 1885 M. 26 Oct., 1897

Bost, W. D. Ashton, Adelphi house, Paisley,	25 Jan., 1898
Bow, William, Thistle works, Paisley,	27 Jan., 1891
Bowser, Howard, 13 Royal crescent, West, Glasgow,	27 Jan., 1874
Brace, George R., 25 Water street, Liverpool,	25 Mar., 1890
Brier, Henry, 13 Ailsa drive, Langside, Glasgow,	22 Dec., 1891
Broadfoot, James, 55 Finnieston street, Glasgow,	G. 23 Dec., 1873 M. 22 Jan., 1884
Broadfoot, William R., Inchholm works, Whiteinch,	25 Jan., 1898
Brock, Henry W., Engine works, Dumbarton,	30 Apr., 1895
*Brock, Walter, Engine works, Dumbarton,	26 Apr., 1865
Brock, Walter, Jun., Levenford, Dumbarton,	27 Oct., 1896
Broom, Thomas M., Oakfield, East Greenock,	25 Apr., 1893
Brown, Alex. D., Dry Dock, St John's, Newfoundland,	22 Dec., 1896
Brown, Alexander T., 18 Glencairn drive, Pollokshields, Glasgow,	G. 25 Feb., 1879 M. 27 Oct., 1891
*Brown, Andrew, London works, Renfrew,	16 Feb., 1859
Brown, Andrew M'N., Strathclyde, Dalkeith avenue, Dumbreck, Glasgow,	G. 25 Jan., 1876 M. 24 Nov., 1885
Brown, Ebenezer Hall-, Helen street, Engine works, Govan, Glasgow,	G. 18 Dec., 1883 M. 26 Feb., 1895
Brown, George, Kirklee, Dumbarton,	23 Mar., 1886
Brown, James, Engine Department, Astilleros del Nervión, Bilbao, Spain,	G. 28 Oct., 1882 M. 26 Jan., 1896
Brown, James M'N., Glenfruin, Renfrew,	26 Jan., 1897
Brown, Matthew T., B.Sc., 194 St. Vincent street, Glasgow,	G. 25 Jan., 1881 M. 18 Dec., 1894
Brown, Walter, Castlehill, Renfrew,	28 Apr., 1885
Brown, William, Meadowflat, Renfrew,	G. 27 Jan., 1874 M. 22 Jan., 1884
Brown, William, Albion works, Woodville street, Govan, Glasgow,	21 Dec., 1880
Brown, William, Dubs & Co., Glasgow Locomotive works, Glasgow,	17 Dec., 1889
Brown, William, Old Hall, Kilmalcolm,	25 Mar., 1890
Brown, William S., Jr., 67 Washington street, Glasgow,	21 Dec., 1897
Bruce-Kingsmill, J., Newton house, Newton,	21 Dec., 1897
Bruhn, Johannes, 49 Sydenham park, Sydenham, London, S.E.,	G. 24 Oct., 1893 M. 22 Feb., 1898
Bryson, William Alexander, Burgh Electrical Engineer's Department, Town Hall, Leith,	27 Oct., 1896
Buckwell, George W., Board of Trade Office, Custom House arcade, Liverpool,	27 Apr., 1897

BURMEISTER, HARTVIG, Rahr & Raundrup, 1 Princess street, Manchester,	G. 24 Oct., 1872 M. 22 Nov., 1885
BURNS, JAMES W., 19 Clifford street, Glasgow,	21 Dec., 1880
BURT, THOMAS, 60 St. Vincent crescent, Glasgow,	22 Mar., 1881
CAIRD, ARTHUR, Messrs Caird & Co., Ltd., Greenock,	27 Oct., 1896
CAIRD, EDWARD B., 777 Commercial road, Limehouse, London,	29 Oct., 1878
†CAIRD, PATRICK T., Messrs Caird & Co., Ltd., Greenock,	27 Oct., 1896
CAIRD, ROBERT, Messrs Caird & Co., Ltd., Greenock,	20 Feb., 1894
CALDWELL, JAMES, 130 Elliot street, Glasgow,	17 Dec., 1878
CALDERWOOD, WILLIAM T., 88 Sinclair drive, Langside, Glasgow,	25 Jan., 1898
CAMERON, JOHN B., 111 Union street, Glasgow,	24 Mar., 1885
CAMERON, J. C., 24 Pollok street, Glasgow,	21 Dec., 1875
CAMERON, WILLIAM, 6 Gordon terrace, Shettleston,	25 Mar., 1890
CAMPBELL, GEORGE, Albany villa, Kilmailing terrace, Cathcart, Glasgow,	22 Mar., 1898
CAMPBELL, JOHN, Post Office, Vladivostock,	21 Jan., 1890
CAMPBELL, JOSEPH C., 1 University place, Partick, Glasgow,	27 Oct., 1896
CAMPBELL, W. S., 1 Thornwood terrace, Partick, Glasgow,	26 Mar., 1895
CAREY, EVELYN G., 4 Sunnyside avenue, Uddingston,	22 Oct., 1889
CARLAW, ALEX. L., 11 Finnieston street, Glasgow,	24 Dec., 1895
CARLAW, DAVID, Jun., 11 Finnieston street, Glasgow,	24 Dec., 1895
CARLAW, JAMES W., 11 Finnieston street, Glasgow,	24 Dec., 1895
CARRUTHERS, JOHN H., Ashton, Queen Mary avenue, Crosshill, Glasgow,	22 Nov., 1881
CARSWELL, THOS. P., 4 West George street, Glasgow,	27 Oct., 1896
CHAMEN, W. A., 75 Waterloo street, Glasgow,	22 Feb., 1898
CHALK, JAMES, 68 Bath street, Glasgow,	23 Feb., 1892
CHARLTON, W. A., 96 Hope street, Glasgow,	23 Jan., 1894
CHRISTIE, R. BARCLAY, 123 Hope street, Glasgow,	25 Apr., 1893
CHRISTISON, GEORGE, 68 Cambridge drive, Glasgow,	22 Feb., 1898
CLARK, JAMES LESTER, 102 Fenchurch street, London, E.C.,	24 Nov., 1896
CLARK, JOHN, British India Steam Navigation Co., 9 Throgmorton avenue, London, E.C.,	23 Jan., 1883
CLARK, WILLIAM, 208 St. Vincent street, Glasgow,	25 Apr., 1893
CLARK, WILLIAM, 88 Renfield street, Glasgow,	22 Dec., 1896
CLARK, WILLIAM GRAHAM, 27 Lawton road, Waterloo, Liverpool,	22 Feb., 1898

CLARKSON, CHARLES, Vine works, Philip street, Aston, Birmingham,	27 Oct., 1891
CLEGHORN, ALEXANDER, Datcha, Scotstounhill, Glasgow,	22 Nov., 1892
COATS, JAMES, Talara, Katharine drive, Govan,	21 Dec., 1897
COCHRAN, JAMES T., Messrs Cochran & Co., Shipbuilders, Birkenhead,	26 Feb., 1884
COCHRANE, JOHN, Grahamston foundry, Barrhead,	25 Mar., 1890
COCKBURN, GEORGE, 24 Sussex street, Glasgow,	25 Oct., 1881
COCKBURN, ROBERT, 14 Kelburn avenue, Dumbreck, Glasgow,	25 Jan., 1898
COLLIE, CHARLES, 19-21 Eaglesham street, Plantation, Glasgow,	26 Apr., 1898
COLVILLE, ARCHIBALD, Motherwell,	27 Oct., 1896
COLVILLE, DAVID, Jun., Jerviston house, Motherwell,	27 Oct., 1896
CONNELL, CHARLES, Whiteinch, Glasgow,	G. 19 Dec., 1876 M. 25 Mar., 1884
CONNER, BENJAMIN, 196 St. Vincent street, Glasgow,	G. 22 Dec., 1885 M. 26 Oct., 1897
CONNER, JAMES, Assistant Locomotive Engineer, Highland Railway, Inverness,	G 18 Dec., 1877 M. 24 Nov., 1885
COOPER, JAMES, Aberdeen Steam Navigation Company, Aberdeen,	19 Dec., 1893
COPELAND, JAMES, 24 George square, Glasgow,	17 Feb., 1864
†COPLAND, WILLIAM R., 146 W. Regent street, Glasgow,	20 Jan., 1864
COPESTAKE, S. G. G., Glasgow Locomotive works, Little Govan, Glasgow,	11 Mar., 1868
CORMACK, JOHN DEWAR, B.Sc., The University, Glasgow,	24 Nov., 1896
COULSON, W. ARTHUR, 47 King street, Mile-end, Glasgow,	15 June, 1898
COUPER, SINCLAIR, Moore Park Boiler works, Govan, Glasgow,	G. 21 Dec., 1880 M. 27 Oct., 1891
COURTIER-DUTTON, W. T., Shipbuilder and Engineer, 69 St. Vincent street, Glasgow,	22 Dec., 1896
COWAN, JOHN, Ingleholme, Greenock,	27 Apr., 1897
COWAN, M'TAGGART, 109 Bath street, Glasgow,	28 Nov., 1866
CRAIG, ARCHIBALD FULTON, Dykebar house, Paisley,	25 Jan., 1898
CRAIG, JAMES, 6 Edelweiss terrace, Partick,	G. 20 Dec., 1892 M. 21 Dec., 1897
CRAIG, JOHN, Rosevale, Port-Glasgow,	26 Mar., 1895
CRAWFORD, JAMES, 30 Ardgowan street, Greenock,	27 Oct., 1896
CRAWFORD, SAMUEL, Messrs John Scott & Company, Engineers and Shipbuilders, Kinghorn,	18 Dec., 1883
CRICHTON, JAMES L., 3 East Park terrace, Maryhill, Glasgow,	18 Dec., 1894

Crockatt, William, 179 Nithsdale road, Pollokshields, Glasgow,		22 Mar., 1881
Crow, John, Engineer, 236 Nithsdale road, Pollokshields, Glasgow,		25 Jan., 1898
Cunningham, Peter N., Easter house, Kennyhill, Cumbernauld road, Glasgow,		23 Dec., 1884
Currie, James, 16 Bernard street, Leith,		20 Jan., 1869
Cuthill, William, Beechwood, Uddingston,		24 Nov., 1896
Daniels, Thomas, Nasmyth, Wilson & Company, Ltd., Patricroft, near Manchester,		25 Apr., 1893
Davidson, David, 17 Regent Park square, Strathbungo, Glasgow,	G. M.	22 Mar., 1881 18 Dec., 1888
Davison, Thomas, 248 Bath street, Glasgow,		11 Dec., 1861
Deas, James, Engineer, Clyde Trust, Crown gardens, Glasgow,		17 Feb., 1869
Dempster, John, 49 Robertson street, Glasgow,		22 Feb., 1898
Denholm, James, 5 Derby terrace, Sandyford street, Glasgow,		21 Nov., 1883
Denholm, William, Meadowside Shipbuilding yard, Partick, Glasgow,	G. M.	18 Dec., 1883 21 Nov., 1893
Denny, Archibald, Braehead, Dumbarton,		21 Feb., 1888
Denny, James, Engine works, Dumbarton,		25 Oct., 1887
Denny, Col. John M., M.P., Garmoyle, Dumbarton,		27 Oct., 1893
Denny, Leslie, Leven Shipyard, Dumbarton,		30 Apr., 1895
Denny, Peter, Bellfield, Dumbarton,		21 Feb., 1888
Dick, Frank W., Palmer's Steel works, Jarrow-on Tyne,		19 Mar., 1878
Dickson, B. Gillespie, c/o J. T. Sellar, 8 Blackfriars street, Perth,		19 Nov., 1890
Dickson, William, Lanarkshire Steel Co., Motherwell,		15 June, 1898
Dimmock, John Wingrave, 2 Grantly gardens, Shawlands, Glasgow,		22 Mar., 1898
Dixon, James S., 97 Bath street, Glasgow,	G. M.	24 Dec., 1873 22 Jan., 1878
Dixon, Walter, 164 St. Vincent street, Glasgow,		26 Feb., 1895
Dobson, William, The Chesters, Jesmond, Newcastle-on-Tyne,		17 Jan., 1871
Donald, James, Abbey works, Paisley,		20 Jan., 1864
Donald, Robert Hanna, Abbey works, Paisley,		22 Nov., 1892
Donaldson, James, Almond villa, Renfrew,		25 Jan., 1876
Doyle, Patrick, F.R.S.E., 19 Lall Bazar st., Calcutta,		23 Nov., 1886
Drew, Alexander, 22 Rutland square, Edinburgh,		29 Apr., 1890
Drummond, Walter, The Glasgow Railway Engineering works, Govan, Glasgow,		26 Mar., 1895

DRYSDALE, JOHN W. W., 37 Westercraigs, Dennistoun, Glasgow,	23 Dec., 1884
DUBS, CHARLES R., Glasgow Locomotive works, Glasgow,	24 Oct., 1882
DUNCAN, GEORGE F., Ardenclutha, Port-Glasgow,	G. 23 Nov., 1886 M. 20 Mar., 1894
DUNCAN, HUGH, London road Iron works, Glasgow,	15 June, 1898
DUNCAN, JOHN, Ardenclutha, Port-Glasgow,	23 Nov., 1886
DUNCAN, ROBERT, Whitefield Engine works, Govan, Glasgow,	25 Jan., 1881
DUNLOP, DAVID JOHN, Inch works, Port-Glasgow,	23 Nov., 1869
DUNLOP, JOHN G., Clydebank, Dumbartonshire,	23 Jan., 1877
†DUNN, PETER L., 815 Battery street, San Francisco, U.S.A.,	26 Oct., 1886
DYER, HENRY, D. Sc., M. A., 8 Highburgh terrace, Dowanhill, Glasgow,	23 Oct., 1883
EASTON, WM. CECIL, B.Sc., City Engineer's Office, Glasgow,	22 Feb., 1898
EDWARDS, CHARLES, 5 Minard terrace, Partickhill, Glasgow,	26 Oct., 1897
ELGAR, FRANCIS, LL.D., F.R.S.S., L.& E., Fairfield Shipbuilding and Engineering Co., Limited, 113 Cannon street, London, E.C.,	24 Feb., 1885
ELLIOTT, ROBERT, B.Sc., Lloyd's Surveyor, Greenock,	G. 24 Mar., 1885 M. 21 Feb., 1898
ELSEE, THOMAS, Mensagerias Flaviales del Plala, Uruguay,	28 Jan., 1896
EVANS, MALCOLM T., 20 Kew gardens, Kelvinside, Glasgow,	23 Feb., 1897
FAIRWEATHER, WALLACE, 62 St. Vincent street, Glasgow,	24 Apr., 1894
FERGUSON, DANIEL, 27 Oswald street, Glasgow,	26 Apr., 1898
FERGUSON, JOHN, Shipbuilder, Leith,	G. 23 Nov., 1869 M. 19 Mar., 1878
FERGUSON, J. STRATHEARN, 19 Arundel drive, Langside, Glasgow,	23 Nov., 1897
FERGUSON, PETER, Phœnix works, Paisley,	22 Oct., 1889
FERGUSON, WILLIAM D., Albert villa, Ravenhill road, Belfast,	G. 27 Jan., 1885 M. 20 Mar., 1894
FERGUSON, WILLIAM R., Barclay Curle & Co., Ltd., Whiteinch, Glasgow,	G. 22 Feb., 1881 M. 22 Jan., 1895
FERRIER, JAMES, China Merchants Steam Nav. Co., Shanghai,	22 Dec., 1896
FIELDEN, IMMER, 2 Thornton villas, Holderness road, Hull,	24 Feb., 1874
FINDLAY, ALEXANDER, Parkneuk Iron works, Motherwell,	27 Jan., 1880
FINDLAY, E. WALTON, Ardeer, Stevenston,	G. 23 Dec., 1873 M. 25 Nov., 1884

Finlayson, Finlay, Clydesdale house, Mossend,	23 Dec., 1884
Fisher, Andrew, St. Mirren's Engine works, Paisley,	25 Jan., 1898
Fleming, Andrew E., Kandy, Ceylon,	23 Jan., 1894
Fleming, George E., 4 Doune quadrant, Kelvinside, Glasgow,	27 Oct., 1896
Fleming, William, 10 Heathfield terrace, Springburn, Glasgow,	25 Jan., 1898
Fletcher, James, 11 Ibrox Place, Whitefield road, Govan,	G. 28 Jan., 1896 M. 23 Nov., 1897
Flett, George L., 86 Sussex street, Paisley road, West, Glasgow,	22 Jan., 1895
Forsyth, Lawson, 10 Grafton square, Glasgow,	18 Dec., 1883
Foster, James, 11 St. Andrew's drive, Pollokshields, Glasgow,	26 Jan., 1897
Foulis, William, City Chambers, John Street, Glasgow,	18 Jan., 1870
Fox, Samson, Blairquhan Castle, Maybole,	2 Nov., 1880
Frame, James, 6 Kilmailing terrace, Cathcart, Glasgow,	23 Feb., 1897
Fraser, William, 121 North Montrose street, Glasgow,	19 Dec., 1893
Fullerton, Alex., Vulcan Works, Paisley,	22 Dec., 1896
Gale, Edmund William, 4 Rosebery place, Clydebank,	23 Nov., 1897
Gale, Jas. M., Corporation Water works, City Chambers, Glasgow,	24 Nov., 1858
Gale, William M., 18 Huntly gardens, Kelvinside, Glasgow,	24 Jan., 1893
Galloway, Charles S., Greenwood City, Vancouver, B.C.,	22 Jan., 1895
Gearing, Ernest, Fenshurst, Clarence drive, Harrogate,	20 Mar., 1888
Gemmell, E. W., Board of Trade Offices, 7 York street, Glasgow,	18 Dec., 1888
Gibb, Andrew, 30 South street, Greenwich, London, S.E.,	G. 23 Dec., 1873 M. 21 Mar., 1882
Gifford, Paterson, 101 St. Vincent street, Glasgow,	23 Nov., 1886
***Gilchrist, Archibald**, 5 Montgomerie cres., Glasgow,	23 Nov., 1859
Gilchrist, James, Stobcross Engine works, Finnieston quay, Glasgow,	G. 26 Dec., 1866 M. 29 Oct., 1878
Gillespie, Andrew, 34 St. Enoch square, Glasgow,	20 Nov., 1894
Gillespie, James, 21 Minerva street, Glasgow,	G. 24 Feb., 1874 M. 24 Mar., 1891
Glasgow, James, Fernlea, Paisley,	25 Jan., 1898

GLEN, D. C., Matheson & Company, 3 Lombard street, London, E.C.,	G. M.	23 Dec., 1884 21 Feb., 1893
†GOODWIN, GILBERT S., Alexandra buildings, James street, Liverpool,		28 Mar., 1866
GOODFELLOW, JOSEPH, 3 Towerhill terrace, Springburn, Glasgow,		11 Mar., 1868
GORDON, JOHN, 152 Craigpark street, Glasgow,		26 Mar., 1895
GOURLAY, H. GARRET, Dundee foundry, Dundee,		25 Apr., 1882
GOWAN, A. B., Messrs Vickers, Son & Maxim, Barrow-in-Furness,	G. M.	24 Jan., 1882 22 Jan., 1895
GRACIE, ALEX., Fairfield Shipbuilding and Engineering Company, Govan,	G. M.	26 Feb., 1884 24 Nov., 1896
GRAHAM, DAVID R., A. Stephen & Sons, Engine Department, Linthouse, Govan, Glasgow,		25 Apr., 1893
†GRAHAM, GEORGE, Engineer, Caledonian Railway, Glasgow,		12 Mar., 1858
GRAHAM, JOHN, 60 Cambridge drive, Kelvinside, Glasgow,		25 Jan., 1898
GRAHAM, WALTER, Kilblain Engine works, Greenock,	G. M.	28 Jan., 1896 15 June, 1898
GRANT, THOMAS M., 322 St. Vincent street, Glasgow,		25 Jan., 1876
GRAY, JAMES, Riverside, Old Cumnock, Ayrshire,		8 Jan , 1862
GRAY, WILLIAM, 2 Veir terrace, Dumbarton,		23 Feb., 1897
GRETCHIN, G. L., c/o The Clydebank Engineering and Shipbuilding Co., Clydebank,		25 Jan., 1893
GRIEVE, JOHN, Engineer, Motherwell,		25 Jan., 1898
GROVES, L. JOHN, Engineer, Crinan Canal, Ardrishaig,		20 Dec., 1881
GUTHRIE, JOHN, The Crown Iron works, Glasgow,		27 Oct., 1896
HAIGH, WILLIAM R., 15 Randolph gardens, Partick, Glasgow,		22 Dec., 1896
HALL, WILLIAM, Shipbuilder, Aberdeen,		25 Jan , 1881
HAMILTON, ARCHIBALD, New Dock works, Govan, Glasgow,	G. M.	24 Feb., 1874 24 Nov., 1885
HAMILTON CLAUD, 247 St. Vincent street, Glasgow,		15 June, 1898
HAMILTON, DAVID C., Clyde Shipping Company, 21 Carlton place, Glasgow,	G. M.	23 Dec., 1873 22 Nov., 1881
HAMILTON, JAMES, R. Napier & Sons, Govan, Glasgow,	G. M.	26 Dec., 1863 18 Mar., 1876
*HAMILTON, JOHN, 22 Athole gardens, Glasgow,		
HALLEY, WILLIAM LIZARS, Lennoxlea, Dumbarton,		21 Dec., 1897
HALKET, JAMES P., Glengall Iron works, Millwall, London, E.,		26 Oct., 1897
HARMAN, BRUCE, 35 Connaught road, Harlenden, London, N.W.,	G. M.	2 Nov., 1880 22 Jan., 1884

Harrison, J. E., 160 Hope street, Glasgow,	G. 26 Feb., 1889 M. 22 Feb., 1898
Hart, P. Campbell, John Finnie street, Kilmarnock,	24 Nov., 1896
Harvey, C. R., 15 Rosslyn terrace, Kelvinside, Glasgow,	G. 24 Feb., 1874 M. 23 Nov., 1880
Harvey, John H., Benclutha, Port-Glasgow,	22 Feb., 1887
Harvey, Robert, 224 West street, Glasgow,	24 Nov., 1896
Hastie, William, Kilblain Engine works, Greenock,	17 Jan., 1871
Hayward, Thomas Andrew, 18 Carrington street, Glasgow,	22 Mar., 1898
†Henderson, A. P., 30 Lancefield quay, Glasgow,	25 Nov., 1879
Henderson, Frederick N., Meadowside, Partick, Glasgow,	26 Mar., 1895
Henderson, J. Bailie, Government Hydraulic Engineer, Brisbane, Queensland,	18 Dec., 1888
†Henderson, John, Meadowside, Partick, Glasgow,	21 Jan., 1873
†Henderson, John L.,	25 Nov., 1879
Henderson, William Stewart, 6 Radnor st., Sandyford, Glasgow,	24 Nov., 1896
Henigan, Richard, Alma road, Avenue, Southampton,	31 May, 1870
Herriot, George, Board of Trade Offices, 7 York street, Glasgow,	20 Feb., 1877
Herriot, W. Scott, 11 Rosehill Street, Derby,	28 Oct., 1890
Hetherington, Edward P., 3 Westminster gardens, Hillhead, Glasgow,	22 Nov., 1892
Hide, William Seymour, Lydhurst avenue, Streatham Hill, London,	18 Dec., 1888
Hill, Thomas, 3 Whitevale, Dennistoun, Glasgow,	22 Jan., 1895
Hines, James, Dunedin lodge, Lenzie, Glasgow,	28 Jan., 1896
Hodgart, John, Lumsburn, Paisley,	22 Dec., 1896
Hogg, Charles P., 175 Hope street, Glasgow,	2 Nov., 1880
Hogg, John, Victoria Engine works, Airdrie,	20 Mar., 1883
Homan, William M'L., Orange Free State Railways, Kroonstad, Orange Free State, South Africa,	G. 26 Jan., 1892 M. 26 Oct., 1897
Holmes, F. G., Burgh Chambers, Govan,	23 Mar., 1880
Holmes, Matthew, Netherby, Lenzie,	20 Mar., 1883
Holms, A. Campbell, Lloyd's Register, 2 White Lion court, Cornhill, London,	24 Apr., 1894
Home, Henry, 11 St. Andrew's drive, Pollokshields, Glasgow,	23 Feb., 1897
Horne, John, Rokeby villa, Carlisle,	23 Nov., 1897
†Houston, Colin, Harbour Engine works, 60 Portman street, Glasgow,	25 Mar., 1890

HOUSTON, JAMES, Jr., Brisbane house, Bellahouston,	25 Jan., 1898
HOWAT, WILLIAM, 121 Raeberry street, Glasgow,	22 Feb., 1898
†HOWDEN, JAMES, 8 Scotland street, Glasgow,	Original
HUME, JAMES HOWDEN, 8 Scotland street, Glasgow,	22 Dec., 1891
*†HUNT, EDMUND, 121 West George street, Glasgow,	Original
HUNTER, GILBERT M., Government Railway, Sekondi, Gold Coast, West Africa,	G. 26 Oct., 1886 M. 19 Nov., 1889
HUNTER, JAMES, Aberdeen Iron works, Aberdeen,	25 Jan., 1881
HUNTER, JOSEPH GILBERT, Lloyd's Register, 12 Oriel chambers, Liverpool,	24 Feb., 1891
HUTCHESON, ARCH., Salterscroft Engine Works, Govan, Glasgow,	22 Dec., 1896
HUTCHESON, JOHN, 37 Mair street, Plantation, Glasgow,	22 Mar., 1898
HUTCHISON, JAMES H., Shipbuilder, Port-Glasgow,	26 Mar., 1895
HUTSON, GUYBON, Kelvinhaugh Engine works, Glasgow,	G. 23 Dec., 1873 M. 24 Nov., 1885
HUTSON, GUYBON, Jun., 47 Lilybank gardens, Glasgow,	21 Mar., 1893
†INGLIS, JOHN, LL.D., Point House Shipyard, Glasgow,	1 May, 1861
IRELAND, WILLIAM, 7 Ardgowan terrace, Glasgow,	25 Feb., 1890
JACK, ALEXANDER, 164 Windmillhill, Motherwell,	21 Nov., 1893
JACK, JAMES R., Mavisbank, Dumbarton,	27 Apr., 1897
JACKSON, PETER, 109 Hope street, Glasgow,	24 Mar., 1891
JACKSON, WILLIAM, Govan Engine works, Govan, Glasgow,	21 Dec., 1875
JAMIESON, Professor ANDREW, F.R.S.E., The Glasgow and West of Scotland Technical College, Bath st., Glasgow,	26 Mar., 1889
JARDINE, JOHN, Fairholm, Motherwell,	26 April, 1898
JONES, LLEWELLEN, Chesterfield house, 98 Great Tower street, London, E.C.,	25 Oct., 1892
JOHNSTON, DAVID, 9 Osborne terrace, Copland road, Glasgow,	25 Feb., 1879
JOHNSTON, ROBERT, Kirklee, Wallace street, Kilmarnock,	22 Mar., 1898
KELLY, ALEXANDER, 100 Hyde Park street, Glasgow,	23 Feb., 1897
KEMP, EBENEZER, D., 25 Grove road, Rockferry, Birkenhead,	G. 20 Feb., 1883 M. 25 Oct., 1892
KEMPT, IRVINE, Jun., Foresthill, Kelvinside, Glasgow,	G. 26 Feb., 1895 M. 27 Apr., 1897
KENNEDY, ALEXANDER M'A., Rosslea, Dumbarton,	30 Apr., 1895

Kennedy, John, R. M'Andrew & Co., Suffolk House, Laurence Pountney Hill, London, E.C.,	23 Jan., 1877
Kennedy, Robt., B.Sc., Glenfield Company, Kilmarnock,	23 Mar., 1897
Kennedy, Thomas, Glenfield Company, Kilmarnock,	22 Feb., 1876
Kennedy, William, 13 Victoria crescent, Dowanhill, Glasgow,	24 Apr., 1894
Kerr, Archibald, 2 Kelvinside gardens, Glasgow,	20 Nov., 1894
Kerr, James, 342 Argyle street, Glasgow,	22 Feb., 1898
Kidd, Alexander, Lloyd's Shipping Office, 74 Battery road, Singapore,	21 Jan., 1890
King, Donald, 1 Montgomerie cottages, Scotstoun, Glasgow,	G. 21 Dec., 1886 M. 20 Mar., 1894
King, J. Foster, The British Corporation, 69 St. Vincent street, Glasgow,	26 Mar., 1895
Kinghorn, John G., Tower Buildings, Water street, Liverpool,	23 Dec., 1879
Kincaid, John G., Oakfield, Greenock,	22 Feb., 1898
†Kirby, Frank E., Detroit, U.S.A.,	24 Nov., 1885
Knight, Charles A., 21 St Vincent place, Glasgow,	27 Jan., 1885
Knox, Robert, 10 Clayton terrace, Dennistoun, Glasgow,	24 Nov., 1896
Krebs, Frederick, 22 Amaliegade, Cophenhagen,	23 Mar., 1880
Lade, James A., Inch works, Port-Glasgow,	27 Jan., 1891
Laidlaw, John, 98 Dundas street, S.S., Glasgow,	25 Mar., 1884
Laidlaw, Robert, 147 East Milton street, Glasgow,	26 Nov., 1862
Laing, Andrew, The Wallsend Slipway Company, Newcastle-on-Tyne,	20 Mar., 1880
Laing, William, 17 M'Alpine street, Glasgow,	26 Oct., 1875
Lamberton, Andrew, Greenhill, Coatbridge,	27 Apr., 1897
Lang, James, c/o George Smith & Sons, City Line, 75 Bothwell street, Glasgow,	24 Feb., 1880
Lang, C. R., Holm Foundry, Cathcart, Glasgow,	G. 20 Nov., 188 M. 26 Nov., 1895
Lang, John, Jun., Lynnhurst, Johnstone,	26 Feb., 1884
Lang, Robert, Quarrypark, Johnstone,	25 Jan., 1898
Laurence, George B., Clutha Iron works, Paisley road, Glasgow,	21 Feb., 1888
Laws, Bernard Courtney, 2 Strone terrace, Dowanhill, Partick,	26 Oct., 1897
†Lee, Robert, 158 Milton street, Glasgow,	G. 21 Dec., 1886 M. 22 Mar., 1898
Lemkes, C. R. L., 194 Hope street, Glasgow,	A. 26 Feb., 1884 M. 22 Mar., 1898

LEITCH, ARCH., 40 St. Enoch square, Glasgow,	22 Dec., 1896
LESLIE, JAMES T. G., 148 Randolph terrace, Hill street, Garnethill, Glasgow,	25 Apr., 1893
LESLIE, WILLIAM,	24 Feb., 1891
†LINDSAY, CHARLES C., 217 W. George street, Glasgow,	G. 23 Dec., 1873 M. 24 Oct., 1876
LIST, JOHN, 3 St. John's park, Blackheath, London, S.E.,	26 Feb., 1884
LITHGOW, WILLIAM T., Port-Glasgow,	21 Feb., 1893
LIVESEY, ROBT. M., Mount Stuart, 10 Windsor esplanade, Cardiff,	26 Jan., 1897
†LOBNITZ, FRED., Clarence house, Renfrew,	G. 24 Mar., 1885 M. 20 Nov., 1896
LOCKIE, JOHN, Wh.Sc., 2 Custom House Chambers, Leith,	26 Jan., 1897
LONERGAN, ALFRED E., Whitefield Engine works, Govan, Glasgow,	17 Dec., 1889
†LORIMER, WILLIAM, Glasgow Locomotive works, Gushetfaulds, Glasgow,	27 Oct., 1896
†LOUDON, GEORGE FINDLAY, 10 Claremont Terrace, Glasgow,	25 Jan., 1898
LUSK, HUGH D., Rosebank, Greenock,	21 Feb., 1888
LYALL, JOHN, 69 St. Vincent crescent, Glasgow,	27 Oct., 1885
M'ARTHUR, JAMES D., 7 Westbank place, Hillhead, Glasgow,	26 Apr., 1898
†M'CALL, DAVID, 160 Hope street, Glasgow,	17 Feb., 1858
†MACCOLL, HECTOR, Bloomfield, Belfast,	24 Mar., 1874
MACOLL, HUGO, Wreath Quay Engineering works, Sunderland,	G. 20 Dec., 1881 M. 22 Oct., 1889
M'CREATH, JAMES, 208 St. Vincent street, Glasgow,	23 Oct., 1883
M'CULLOCH, FRANK, 5 Rutland crescent, Kinning Park, Glasgow,	27 Jan., 1891
MACDONALD, D. H., Brandon works, Motherwell,	24 Mar., 1896
MACDONALD, THOMAS, 180 Hope street, Glasgow,	25 Jan., 1898
M'EWAN, JAMES, Cyclops foundry, 50 Peel street, London road, Glasgow,	26 Feb., 1884
M'EWAN, JOSEPH, 35 Houldsworth street, Glasgow,	27 Jan., 1891
M'FARLANE, GEORGE, 121 West George street, Glasgow,	G. 24 Feb., 1874 M. 24 Nov., 1885
MACFARLANE, JAMES W., 12 Balmoral villas, Cathcart, Glasgow,	2 Nov., 1880
MACFARLANE, JAMES, Anniesle, Motherwell,	15 June, 1898
MACFARLANE, WALTER, 12 Lynedoch crescent, Glasgow,	26 Oct., 1886
M'GECHAN, ANDREW, 232 Paisley road, West, Glasgow,	26 Apr., 1898

M'GEE, DAVID, The Cottage, Clydebank,	22 Dec., 1896
†M'GEE, WALTER, Stoney brae, Paisley,	25 Jan., 1898
M'GEOCH, DAVID BOYD, Blackwood & Gordon, Port-Glasgow,	28 Jan., 1896
M'GREGOR, J. GRANT, Canadian Pacific Railway Engineering Department, Montreal,	G. 21 Dec., 1886 M. 28 Apr., 1891
M'GREGOR, JOHN B., 19 Bell street, Renfrew,	G. 18 Dec., 1883 M. 27 Apr., 1897
M'GREGOR, THOMAS, 10 Mosesfield terrace, Springburn, Glasgow,	26 Jan., 1886
M'INTOSH, DONALD, Dunglass, Bowling,	20 Feb., 1894
M'INTOSH, JOHN F., Caledonian Railway, St. Rollox, Glasgow,	28 Jan., 1896
M'INTYRE, HUGH, 68 Kent road, Glasgow,	22 Nov., 1887
MACKAY, EDWARD, 8 George square, Greenock,	6 Apr., 1887
M'KEAND, ALLAN, 42 Wilton gardens, Glasgow,	G. 19 Dec., 1882 M. 20 Mar., 1894
M'KECHNIE, JAMES, Messrs Vickers, Son, & Maxim, Barrow-in-Furness,	24 Apr., 1888
M'KENZIE, JOHN, Gardner & Son, 24 St. Vincent place, Glasgow,	25 Apr., 1893
M'KENZIE, JOHN, Speedwell Engineering works, Coatbridge,	25 Jan., 1898
MACKENZIE, THOMAS B., 342 Duke street, Glasgow,	G. 23 Jan., 1883 M. 26 Nov., 1895
M'KIE, J. A., Copland works, Govan,	25 Jan., 1898
MACKIE, WILLIAM A., Falkland bank, Partickhill, Glasgow,	22 Mar., 1881
†MACKINLAY, JAMES T. C., 110 Gt. Wellington street, Kinning park, Glasgow,	27 Oct., 1896
M'KINNEL, WILLIAM, 234 Nithsdale road, Pollokshields, Glasgow,	A. 21 Feb., 1893 M. 22 Feb., 1898
MACKINNON, James D., 93 Hope street, Glasgow,	24 Nov., 1896
M'LACHLAN, JOHN, Saucel Bank House, Paisley,	26 Oct., 1897
MACLAREN, JOHN F., B.Sc., Eglinton foundry Canal street, Glasgow,	23 Feb., 1892
MACLAREN, ROBERT, Eglinton foundry, Canal street, Glasgow,	G. 2 Nov., 1880 M. 22 Dec., 1885
MACLAY, Prof. ALEX., B.Sc., Clairinch, Milngavie,	28 Apr., 1891
*MACLEAN, Sir ANDREW, Viewfield house, Partick, Glasgow.	
MACLEAN, WILLIAM DICK, 173 Scotland street, Glasgow,	25 Jan., 1898
†MACLELLAN, WILLIAM T., Clutha Iron works, Glasgow,	21 Dec., 1886
M'MASTER, ROBERT, Linthouse, Glasgow,	25 Feb., 1890

*†MACMILLAN, WILLIAM, Holmwood, Whittinghame drive, Kelvinside, Glasgow,	
M'NAIR, JAMES, Norwood, Prestwick road, Ayr,	26 Nov., 1895
M'NEIL, JOHN, Helen street, Govan, Glasgow,	23 Dec., 1884
MACPHERSON, JOHN, 128 Hope street, Glasgow,	20 Nov., 1894
MACRAE, NORMAN, Northern Gold Fields Company, Salisbury, Mashonaland, South Africa,	26 Nov., 1895
M'WHIRTER, WILLIAM, 214 Holm street, Glasgow,	24 Mar., 1891
MARRIOTT, REUBEN, Plantation Boiler Works, Govan, Glasgow,	23 Feb., 1897
MARSHALL, DAVID, Glasgow Tube works, Glasgow,	22 Jan., 1895
MARR, JAMES BROWN, 53 Bradshaw street, Higher Broughton, Manchester,	21 Dec., 1897
MARTIN, ARCHIBALD, 100 Elderslie street, Glasgow,	24 Mar., 1896
MARTIN, E. L., 122 Leadenhall street, London, E.C.,	27 Oct., 1896
MATHEWSON, GEORGE, Bothwell works, Dunfermline,	21 Dec., 1875
MATHEWSON, ROBERT C., Glenburn Iron works, Greenock,	22 Jan., 1895
MATHIESON, DONALD A., 3 Germiston street, Glasgow,	26 Jan., 1897
MATTHEWMAN, F. A., 7 Gardenside terrace, Uddingston,	23 Nov., 1897
MATTHEY, C. A., Russell Rise, Reading,	26 Oct., 1897
MAVOR, HENRY A., 47 King street, Bridgeton, Glasgow,	22 Apr., 1884
MAVOR, SAM, 37 Burnbank gardens, Glasgow,	20 Nov., 1894
MAY, WILLIAM W., 5 Edelweiss terrace, Partickhill, Glasgow,	25 Jan., 1876
MAYER, WM., Morwell House, Dumbarton,	23 Feb., 1897
MECHAN, HENRY, 13 Montgomerie quadrant, Glasgow,	25 Jan., 1887
MECHAN, SAMUEL, 5 Kelvingrove terrace, Glasgow,	27 Oct., 1891
MELDRUM, JAMES, 3 Elmbank street, Glasgow,	G. 24 Oct., 1876 M. 28 Nov., 1882
MELVILLE, WILLIAM, Glasgow and South Western Railway, St. Enoch square, Glasgow,	23 Jan., 1883
MENZIES, WILLIAM, 7 Dean street, Newcastle-on-Tyne,	22 Mar., 1881
MIDDLETON, R. A., 4 Ashville Skeigoneil avenue, Belfast,	G. 24 Jan., 1882 M. 28 Oct., 1890
MILLAR, SIDNEY, 32 Annette street, Crosshill, Glasgow,	G. 26 Feb., 1889 M. 21 Dec., 1897
MILLER, JOHN F., Greenoakhill, Broomhouse,	G. 23 Dec., 1873 M. 22 Nov., 1881
†MIRRLEES, JAMES B., 45 Scotland street, Glasgow,	Original
MITCHELL, ALEXANDER, Hayfield house, Springburn,	26 Jan., 1886

MITCHELL, GEORGE A., F.R.S.E., 5 West Regent street, Glasgow,	25 Jan., 1898
MITCHELL, THOMAS, Gower street, Bellahouston, Glasgow,	20 Nov., 1888
MOIR, JOHN, 59 Park drive, Whiteinch, Glasgow,	23 Feb., 1897
MOLLISON, JAMES, 6 Hillside gardens, Partickhill	21 Mar., 1876
MOORE, JOSEPH, The Cottage, St. John's road, Richmond, London, S.W.,	21 Nov., 1883
MOORE, RALPH D., B.Sc., 13 Clairmont gardens, Glasgow,	27 Apr., 1897
MOORE, ROBERT T., B.Sc., 13 Clairmont gardens, Glasgow,	27 Jan., 1891
MORRICE, RICHARD WOOD, 39 Aytoun road, Pollokshields, Glasgow,	23 Feb., 1897
MORISON, WILLIAM, 41 St. Vincent crescent, Glasgow,	20 Mar., 1888
MORTON, ROBERT, 194 St. Vincent street, Glasgow,	G. 17 Dec., 1878 M. 23 Jan., 1883
MOTION, ROBERT, D. Stewart & Co., London road Iron works, Glasgow,	23 Feb., 1892
MOTT, EDMUND, Board of Trade Surveyor, 7 York street, Glasgow,	24 Mar., 1885
†MUIR, ALFRED, Machine Tool Maker, Sherbourne street, Manchester,	23 Feb., 1897
MUIR, HUGH, 7 Kelvingrove terrace, Glasgow,	17 Feb., 1864
MUIR, JAMES E., 45 West Nile street, Glasgow,	22 Dec., 1896
†MUIR, JOHN G.,	24 Jan., 1882
MUIR, ROBERT WHITE, 97 St. James road, Glasgow,	21 Dec., 1897
MUIRHEAD, WILLIAM, 37 West George street, Glasgow,	26 Oct., 1897
MUMME, CARL, 30 Newark street, Greenock,	22 Oct., 1895
MUNN, ROBERT A., 137 West George street, Glasgow,	22 Dec., 1896
MUNRO, ROBERT D., Scottish Boiler Insurance Company, 13 Dundas street, Glasgow,	19 Dec., 1882
MURDOCH, FREDERICK TEED, Atbara, 18 Emanuel avenue, Acton, London W.,	25 Feb., 1896
†MURDOCH, JAMES, 42 Newark street, Greenock,	Original
MURRAY, ANGUS, Strathroy, Dumbreck,	G. 14 May, 1878 M. 19 Nov., 1889
MURRAY, HENRY, Shipbuilder, Port-Glasgow,	22 Dec., 1896
MURRAY, JAMES, Westfield, Port-Glasgow,	22 Dec., 1896
MURRAY, JAMES, 94 Washington street, Glasgow,	26 Jan., 1886
MURRAY, RICHARD, 228 Central Chambers, Hope street, Glasgow,	26 Oct., 1897
MURRAY, THOMAS BLACKWOOD, B.Sc., 20 Balmoral crescent, Queen's park, Glasgow,	22 Dec., 1891
MURRAY, THOMAS R., The Crown Iron works, Glasgow,	25 Feb., 1896

NAPIER, HENRY M., Shipbuilder, Yoker, near Glasgow,	25 Jan., 1881
†*NAPIER, JOHN, C. Audley mansions, Grosvenor square, London,	23 Dec., 1857
†NAPIER, ROBERT T., 75 Bothwell street, Glasgow,	20 Dec., 1881
NEILSON, JAMES, Ironmaster, Mossend,	23 Mar., 1897
NELSON, ANDREW S., Snowdon, Sherbrooke avenue, Pollokshields, Glasgow,	27 Oct., 1896
NESS, GEORGE, 128A Queen Victoria street, London, E.C.,	23 Feb., 1897
NICOL, THOMAS, 2 Glenavon terrace, Partick, Glasgow,	18 Dec., 1883
NISH, WILLIAM, c/o W. L. C. Paterson, Finnieston-quay, Glasgow,	6 Apr., 1887
NORMAN, JOHN, 131a St. Vincent street, Glasgow,	11 Dec., 1861
O'BRIEN, WILLIAM, 21 Ibrox terrace, Govan, Glasgow,	27 Jan., 1891
O'NEILL, J. J., 3 Drumoyne place, Govan, Glasgow,	24 Nov., 1896
OLIPHANT, WM., Brittannia Engine works, Kilmarnock,	23 Feb., 1897
OLIVER, ROBERT S., Highland Railway Co., Inverness,	24 Jan., 1882
ORMISTON, JOHN W., Douglas gardens, Uddingston,	28 Nov., 1860
ORR, ALEXANDER T., Marine Department, London and North Western Railway, Holyhead,	24 Mar., 1885
PAASCH, HEINRICH, 27 Rue d'Amsterdam, Antwerp,	28 Oct., 1890
PATERSON, W. L. C., 5 Elmwood terrace, Jordanhill, Glasgow,	21 Nov., 1883
PATON, ALEXANDER R., Redthorn, Partick, Glasgow,	G. 25 Nov., 1879 M. 20 Nov., 1894
PATON, Professor GEORGE, Royal Agricultural College, Cirencester,	22 Nov., 1887
PATON, JOHN, 299 Shields road, Pollokshields, Glasgow,	26 Feb., 1889
PATRICK, ANDREW CRAWFORD, Johnstone,	25 Jan., 1898
PATTIE, ALEXANDER W., 24 Sutherland street, Hillhead, Glasgow,	22 Jan., 1895
PAUL, ANDREW, Levenford works, Dumbarton,	24 Apr., 1877
PAUL, FRED. W., Blochairn Steel works, Glasgow,	23 Nov., 1897
PAUL, MATTHEW, Levenford works, Dumbarton,	G. 26 Feb., 1884 M. 21 Dec., 1886
PEAT, JAMES D., Finnieston quay, Glasgow,	18 Dec., 1894
PECK, EDWARD C., Yarrow & Company, Poplar, London,	G. 23 Dec., 1873 M. 23 Oct., 1888
PECK, JAMES J., 9 Broomhill gardens, Partick, Glasgow,	22 Dec., 1896
PENMAN, ROBERT REID, 16 Annfield place, Glasgow,	25 Jan., 1898
PENMAN, WILLIAM, Springfield house, Dalmarnock, Glasgow,	25 Jan., 1898
PHILP, WILLIAM T., Workman Clark & Co., Ltd., Belfast,	G. 25 Oct., 1881 M. 27 Oct., 1891

Pickering, Robert Young, Braxfield, Lanark,	24 Nov., 1896
Pollock, David, 128 Hope street, Glasgow,	23 Feb., 1897
Pollok, Robt., Craiglea, Dumbarton,	22 Dec., 1896
Pope, Robert Band, Leven Shipyard, Dumbarton,	25 Oct., 1887
Pratten, William J., Harland & Wolff, Ltd., Belfast,	22 Dec., 1896
Purdon, Archibald, Inch works, Port-Glasgow,	27 Apr., 1897
Purvis, F. P., Don villa, Greenock,	20 Nov., 1877
Putnam, Thomas, Darlington Forge Co., Darlington,	15 June, 1898
Putt, Thomas H., 135 Kilmarnock road, Shawlands, Glasgow,	23 Mar., 1897
Pyle, James H., 88 Elliot street, Glasgow,	23 Feb., 1897
Rainey, Francis E., 109 Hope street, Glasgow,	27 Apr., 1897
Rait, Henry M., 155 Fenchurch street, London,	23 Dec., 1868
Ramage, Richard, Shipbuilder, Leith,	22 Apr., 1873
Ramsay, Charles, 14 Walmer terrace, Paisley road, W., Glasgow,	21 Dec., 1897
Rankin, John F., Eagle foundry, Greenock,	23 Mar., 1886
Rankin, Matthew, 3 Wilton crescent, Glasgow,	G. 2 Nov., 1880 M. 20 Mar., 1894
Rankine, David, 238 West George street, Glasgow,	22 Oct., 1872
Redfearn, Walter Maurice, c/o Hydraulic Engineering Co., Chester,	25 Jan., 1898
Reed-Cooper, T. L., 6 Spring gardens, Glasgow,	22 Dec., 1896
Reid, Andrew T., Hydepark Locomotive works, Glasgow,	G. 21 Dec., 1886 M. 18 Dec., 1894
Reid, Charles, Lilymount, Kilmarnock,	25 Jan., 1881
Reid, George W., Locomotive Department, Natal Government Railways, Durban, Natal, S. Africa,	21 Nov., 1883
Reid, James, Shipbuilder, Port-Glasgow,	17 Mar., 1896
†**Reid, James B.**, Chapelhill, Paisley,	24 Nov., 1891
Reid, James, 3 Cart street, Paisley,	25 Jan., 1898
Reid, J. Miller, 110 Lancefield street, Glasgow,	23 Mar., 1897
†**Reid, John**, Hydepark Locomotive works, Glasgow,	G. 21 Dec., 1886 M. 18 Dec., 1894
Rew, James H., Margaretta, Dumbreck, Glasgow,	27 Oct., 1896
Reynolds, Charles H., Sir W. G. Armstrong, Mitchell & Co., Walker Shipyard, Newcastle on-Tyne,	G. 23 Dec., 1873 M. 22 Nov., 1881
Richmond, The Hon. David *(Lord Provost of Glasgow)*, North British Tube works, Govan,	21 Dec., 1897
Richmond, John R., Holm foundry, Cathcart, Glasgow,	28 Jan., 1896
Riley, James, Glasgow Iron and Steel Company, Ltd., 36 St. Vincent place, Glasgow,	27 Apr., 1886
Risk, Robert, Halidon Villa, Cambuslang,	23 Mar., 1897

Ritchie, George, Parkhead Forge, Glasgow,	15 June, 1898
Robb, James W., 15 Huntly terrace, Shettleston,	25 Mar., 1890
Robertson, Alex., Jun., Forgemaster, Kilmarnock,	22 Dec., 1896
Robertson, Andrew R., 8 Park Circus place, Glasgow,	G. 12 Nov., 1892 M. 23 Feb., 1897
Robertson, Duncan, Baldroma, Ibrox, Glasgow,	24 Oct., 1876
Robertson, R. A., 8 Park Circus place, Glasgow,	22 Apr., 1884
Robertson, William, 123 St. Vincent street, Glasgow,	25 Nov., 1863
Robinson, J. F., Atlas works, Springburn, Glasgow,	24 Apr., 1888
Robin, Matthew, 15 Clifford street, Glasgow,	G. 20 Dec., 1887 M. 25 Jan., 1898
*†Robson, Hazelton R., 14 Royal crescent, Glasgow,	Original
Rodger, Anderson, Glenpark, Port-Glasgow,	21 Mar., 1893
Ronaldson, J. M., 44 Athole gardens, Glasgow,	24 Dec., 1895
Rosenthal, James H., 147 Queen Victoria street, London, E.C.,	24 Nov., 1896
Ross, James R., Parkhead forge, Glasgow,	24 Nov., 1896
Ross, J. MacEwan, Ardenlea, Lenzie,	G. 28 Nov., 1882 M. 27 Oct., 1891
Ross, Richard G., 21 Greenhead street, Glasgow,	11 Dec., 1861
Rowan, Frederick John, 121 West Regent street, Glasgow,	26 Jan., 1892
Rowan, James, 231 Elliot street, Glasgow,	G. 21 Dec., 1875 M. 27 Jan., 1885
Rowley, Thomas, Board of Trade Offices, Virginia street, Greenock,	18 Dec., 1888
Rudd, John A., 30 Hope street, Glasgow,	G. 24 Jan., 1883 M. 15 June, 1898
Russell, Frederick Alexander, 132 West Regent street, Glasgow,	25 Jan., 1888
†Russell, George, Alpha Works, Motherwell,	G. 22 Dec., 1858 M. 4 Mar., 1863
†Russell, James, 15 Kyle park, Uddingston,	G. 24 Nov., 1891 M. 25 Jan., 1898
Russell, Joseph, Shipbuilder, Port-Glasgow,	22 Feb., 1881
Russell, Joseph William, 158 Milton street, Glasgow,	G. 6 Apr., 1887 M. 25 Jan., 1898
Russell, Thomas W., New Dock works, Govan, Glasgow,	27 Apr., 1897
Rutherford, George, Mercantile Pontoon Company, Cardiff,	23 Mar., 1897

Salmon, Edward Mowbray, 2 White Lion court, Cornhill, London, E.C.,	21 Jan., 1890

SAMBRIDGE, JAMES R., c/o J. H. Holmes & Co., Portland road, Newcastle-on-Tyne,	22 Dec., 1896
SAMPSON, ALEX. W., Barns place, Clydebank,	22 Dec., 1896
SAMSON, PETER, Board of Trade Offices, Bedford street, Covent garden, London, W.C.,	24 Oct., 1876
SAMUEL, JAMES, Jun., 185 Kent road, Glasgow,	24 Feb., 1885
SANDERSON, JOHN, Lloyd's Register, Royal Exchange, Middlesbro'-on-Tees,	20 Feb., 1883
SAYERS, WILLIAM BROOKS, Glenwood, Bearsden,	25 Oct., 1892
†SCOBIE, JOHN, Box No. 93, Sierra Leone Railway, Freetown, West Coast of Africa,	G. 25 Mar., 1879 M. 23 Oct., 1888
SCOTT, CHARLES CUNNINGHAM, Greenock Foundry, Greenock,	27 Oct., 1896
SCOTT, CHARLES WOOD, Dunarbuck, Bowling,	15 June, 1898
SCOTT, JAMES, Engineer, Tayport,	22 Dec., 1896
SCOTT, JAMES E., 52 Coal Exchange, London,	30 Jan., 1872
SCOTT, JAMES, Jun., Strathclyde, Bowling,	15 June, 1898
SCOTT, JOHN, Abden works, Kinghorn,	25 Jan., 1881
SCOTT, JOHN, D., New Zealand Refrigeration Company, Oamaru, N.Z.,	21 Nov., 1893
*SEATH, THOMAS B., 42 Broomielaw, Glasgow,	28 Nov., 1860
SEXTON, Professor HUMBOLDT, Glasgow and West of Scotland Technical College, 204 George st., Glasgow,	25 Feb., 1896
SHANKS, ALEXANDER, Belgrade, Aytoun road, Pollokshields, Glasgow,	26 Jan., 1875
SHANKS, ALEXANDER, Jun., Eastwood Engine works, Pollokshaws, Glasgow,	26 Apr., 1892
SHANKS, WILLIAM, Tubal works, Barrhead,	15 June, 1898
SHARER, EDMUND, 8 Belhaven crescent, Glasgow,	30 Apr., 1895
SHEPHERD, JOHN W., Carrickarden, Bearsden,	26 Mar., 1889
SHERIFF, THOMAS, 4 Wolseley villas, Whiteinch, Glasgow,	22 Dec., 1896
SHUTE, ARTHUR E., 12 Clydeview, Partick, Glasgow,	27 Oct., 1896
SHUTE, CHARLES W., 4 Thornwood ter., Partick, Glasgow,	27 Oct., 1896
SHUTE, T. S., Heath house, King's road, N. Ormesby, Middlesbrough,	G. 19 Dec., 1893 M. 22 Feb., 1898
SIME, JOHN, 96 Buchanan street, Glasgow,	26 Jan., 1897
SIMONS, WILLIAM, Tighnabruaich, Argyleshire,	24 Nov., 1858
SIMPSON, ALEXANDER, 175 Hope street, Glasgow,	22 Jan., 1862
SIMPSON, ROBERT, B.Sc., 175 Hope street, Glasgow,	25 Jan., 1887
SINCLAIR, NISBET, 11 Randolph Gardens, Crow road, Partick, Glasgow,	G. 20 Mar., 1877 M. 20 Dec., 1887

SINCLAIR, RUSSELL, Consulting Engineer, 97 Pitt street, Sydney, N.S.W.	G. 25 Mar., 1884 M. 24 Mar., 1891
SLIGHT, GEORGE H., Jun., c/o James Slight, 131 West Regent street, Glasgow,	G. 28 Nov., 1882 M. 22 Oct., 1889
SMALL, WILLIAM O., 47 Clarendon street, Glasgow,	23 Feb., 1897
SMART, LEWIS A., Leven Ship-yard, Dumbarton,	22 Mar., 1898
SMILLIE, SAMUEL, 71 Lancefield street, Glasgow,	A. 24 Jan., 1888 M. 22 Feb., 1898
SMITH, ALEXANDER D., 5 Belmar terrace, Shields road, Pollokshields, Glasgow,	2 Nov., 1880
SMITH, HUGH WILSON, 2 Knowe terrace, Pollokshields, Glasgow,	25 Jan., 1898
SMITH, JAMES, 24 Melrose gardens, Glasgow,	25 Jan., 1898
SMITH, JAMES, Orange Grove Estate, Tacarigua, Trinidad, B.W.I.,	23 Oct., 1888
SMITH, OSBOURNE, Possil Engine works, Glasgow,	24 Dec., 1895
SMITH, WILLIAM, 50 Hotspur street, Tynemouth,	22 Nov., 1892
SNOWBALL, EDWARD, Hydepark Locomotive works, Springburn, Glasgow,	22 Feb., 1870
SOMERVAIL, PETER A., Dalmuir Ironworks, Dalmuir,	25 Jan., 1887
SOMERVILLE, THOMAS A., 264 Maxwell road, Pollokshields, Glasgow,	22 Feb., 1898
STARK, JAMES, 13 Princes gardens, Dowanhill, Glasgow,	27 Oct., 1896
†STEPHEN, ALEXANDER E., 9 Princes gardens, Dowanhill, Glasgow,	18 Dec., 1883
†STEPHEN, FREDERICK J., Linthouse, Govan, Glasgow,	30 Apr., 1895
*†STEPHEN, JOHN, Linthouse, Govan, Glasgow,	
STEVEN, JOHN, 32 Elliot street, Glasgow,	26 Oct., 1897
STEVEN, WILLIAM, 18 Sandyford place, Glasgow,	23 Jan., 1894
STEVENS, JOHN, 55 Ferry road, Renfrew,	23 Mar., 1897
STEWART, ALEXANDER W., Crescent, Dalmuir,	23 Jan., 1894
STEWART, ANDREW, 41 Oswald street, Glasgow,	25 Feb., 1890
STEWART, DUNCAN, 47 Summer street, Glasgow,	30 Jan., 1867
STUART, JAMES, B.Sc., Stanley villa, Langside, Glasgow,	23 Nov., 1897
†STEWART, JAMES, Harbour Engine works, 60 Portman street, Glasgow,	25 Mar., 1890
STEWART, JOHN GRAHAM, B.Sc., Bredisholm, Baillieston,	22 Mar., 1892
STEWART, PETER, 53 Renfield street, Glasgow,	27 Oct., 1874
STEWART, W. B., 10 Buckingham terrace, Hillhead, Glasgow,	G. 23 Dec., 1873 M. 24 Oct., 1882
STROMEYER, C. E., 9 Mount street, Manchester,	25 Apr., 1893

STUART, JAMES, 115 Wellington street, Glasgow,	22 Oct., 1889
SUTHERLAND, SINCLAIR, North British Tube works, Govan,	21 Dec., 1897
SYME, JAMES, 8 Glenavon terrace, Partick,	23 Jan., 1877

TAIT, JAMES, County Buildings, Wishaw,	28 Oct., 1879
TANNETT, JOHN CROYSDALE, Vulcan works, Paisley,	25 Jan., 1898
TATHAM, STANLEY, Montana, Burton road, Branksome park, Bournemouth, W.,	G. 21 Dec., 1880 M. 15 June, 1898
TAVERNER, H. LACY, 48 West Regent street, Glasgow,	22 Dec., 1896
TAYLOR, PETER, c/o Messrs Taylor & Mitchell, Garvel Shipyard, Greenock,	28 Apr., 1885
TAYLOR, ROBERT, 39 Kelly street, Greenock,	27 Oct., 1896
TAYLOR, STAVELEY, Messrs Russell & Company, Shipbuilders, Port-Glasgow,	25 Mar., 1879
THEARLE, SAMUEL J. P., Bickleigh, Uddingston,	22 Dec., 1896
THODE, GEORGE W., 21 St Vincent place, Glasgow,	27 Jan., 1885
THOM, JOHN, 5 Westbank quadrant, Hillhead,	26 Feb., 1889
THOMSON, Prof. ARTHUR W., D.Sc., College of Science, Poona, India,	26 Apr., 1887
THOMSON, G. CALDWELL, 23 Elisabeth street, Riga, Russia,	24 Oct., 1893
THOMSON, GEORGE, 14 Caird drive, Partickhill, Glasgow,	18 Dec., 1883
THOMSON, GEORGE, 35 Marchmont crescent, Edinburgh,	G. 23 Nov., 1880 M. 20 Nov., 1894
THOMSON, GEORGE C., 4 The Green, Bromborough Pool, near Birkenhead,	G. 24 Feb., 1874 M. 22 Oct., 1889
THOMSON, GEORGE P., Clydebank, Dumbartonshire,	25 Apr., 1882
THOMSON, JAMES, M.A., 22 Wentworth place, Newcastle-on-Tyne,	23 Mar., 1886
THOMSON, JAMES M., Glentower, Kelvinside, Glasgow,	12 Feb., 1868
THOMSON, JAMES R., Clydebank, Dumbartonshire,	21 Mar., 1882
THOMSON, JOHN, 3 Crown terrace, Dowanhill, Glasgow,	20 May, 1868
THOMSON, R. H. B., Govan Shipbuilding yard, Govan, Glasgow,	26 Feb., 1895
THOMSON, ROBERT, c/o Barr, Thomson & Co., Ltd., Engineers, Kilmarnock,	25 Jan , 1898
THOMSON, WALTER M., Hayfield, Motherwell,	G. 20 Nov., 1894 M. 24 Dec., 1895
THOMSON, W. B., Ellengowan, Dundee,	14 May, 1878
THOMSON, WILLIAM, 71 University gardens terrace, Glasgow,	G. 23 Dec., 1884 M. 27 Oct., 1896

Thunderbolt, Edward, Argus House, Portland place, Hillhead, Glasgow,	23 Feb., 1897
Tidd, George E., 25 Gordon street, Glasgow,	22 Oct., 1895
Todd, David R., Babcock & Willcox, Ltd., Renfrew,	G. 25 Jan., 1887 M. 25 Oct., 1892
Tullis, David K., Kilbowie Iron works, Kilbowie,	23 Nov., 1897
Tullis, James, Kilbowie Iron works, Kilbowie,	23 Nov., 1897
Turnbull, Alexander Pott, 264 Maxwell road, Pollokshields, Glasgow,	25 Jan., 1898
Turnbull, Alexander, St. Mungo's works, Bishopbriggs, Glasgow,	21 Nov., 1876
†Turnbull, John, Jun., 18 Blythswood square, Glasgow,	23 Nov., 1875
Turnbull, Wm. George, Hallside Steel works, Newton,	21 Dec., 1897
Waddell, James, 15 Moray place, Glasgow,	23 Mar., 1897
Wallace, Duncan M., 23 Ardgowan street, Greenock,	27 Oct., 1896
Wallace, John, 12 Kelvingrove street, Glasgow,	26 Jan., 1892
Wallace, Peter, Ailsa Shipbuilding Co., Troon,	23 Jan., 1883
Wallace, W. Carlile, Atlas Steel and Iron works, Sheffield,	24 Mar., 1885
Ward, John, Leven Shipyard, Dumbarton,	26 Jan., 1886
Warde, Henry W., 71 Waterloo street, Glasgow,	15 June, 1898
Warden, Willoughby C., 25 Gordon street, Glasgow,	24 Mar., 1896
Watkinson, Prof. W. H., The Pines, Crookston,	19 Dec., 1893
Watson, G. L., 108 West Regent street, Glasgow,	23 Mar., 1875
Watson, William, Superintendent Engineer, Clyde Shipping Company, Greenock,	24 Nov., 1896
Watson, Sir W. Renny, 16 Woodlands terrace, Glasgow,	16 Mar., 1864
Watt, Alexander, Inchcape, Paisley,	25 Jan., 1898
Webb, R. G., Richardson & Cruddas, Byculla, Bombay,	G. 21 Dec., 1875 M. 26 Oct., 1886
Weddell, Jas., Park villa, Uddingston,	22 Dec., 1896
Wedgwood, Arthur D., Forgemaster, Dumbarton,	26 Jan., 1897
Weighton, Prof. R. L., M.A., Durham College of Science, Newcastle-on-Tyne,	G. 17 Dec., 1878 M. 22 Nov., 1887
†Weir, George, 18 Millbrae crescent, Langside, Glasgow,	22 Dec., 1874
†Weir, James, Holmwood, 72 St. Andrew's drive, Pollokshields,	22 Dec., 1874
Weir, John, John Scott & Co., Engineers and Shipbuilders, Kinghorn,	G. 22 Apr., 1884 M. 26 Nov., 1895
†Weir, Thomas, China Merchants' Steam Navigation Co., Marine Superintendent's Office, Shanghai, China,	23 Apr., 1889

Weir, Thomas D., c/o Brown, Mair, Gemmill & Hyslop, 162 St. Vincent street, Glasgow,	G. 19 Dec., 1876 M. 26 Feb., 1884
Welsh, James, 3 Princes gardens, Dowanhill, Glasgow,	G. 24 Nov., 1885 M. 26 Oct., 1897
Welsh, Thomas M., 3 Princes gardens, Dowanhill, Glasgow,	17 Feb., 1869
West, Henry H., 5 Castle street, Liverpool,	23 Dec., 1868
White, Richard S., Shirley, Jesmond, Newcastle-on-Tyne,	20 Feb., 1883
Whitehead, James, 6 Buchanan terrace, Paisley,	6 Apr., 1887
Wildridge, John, Consulting Engineer, Sydney, N.S.W., Australia,	25 Nov., 1884
Williams, Llewellyn Wynn, B.Sc., Cathcart, Glasgow,	22 Feb., 1898
Williamson, James, Director H.M. Dockyards, Whitehall, London,	23 Dec., 1884
Williamson, James, Marine Superintendent, Gourock,	24 Mar., 1896
Williamson, Robert, Brithdir works, Alexandra docks, Newport, Mon.,	20 Feb., 1883
Wilson, Alexander, Dawsholm Gasworks, Maryhill, Glasgow,	28 Jan., 1896
Wilson, Alexander, Hyde Park Foundry, Finnieston street, Glasgow,	23 Feb., 1897
*Wilson, Alex. H., Aberdeen Iron works, Aberdeen,	
Wilson, David, Arecibo, Porto Rico, West Indies,	25 Oct., 1887
Wilson, Gavin, 107 Pollok street, S.S., Glasgow,	22 Oct., 1889
Wilson, James, Engineer, Corporation Water Works, Edinburgh,	23 Dec., 1868
†Wilson, John, 165 Onslow drive, Dennistoun, Glasgow,	22 Feb., 1870
Wilson, John, 29 Waterloo street, Glasgow,	G. 29 Jan., 1883 M. 24 Feb., 1891
Wilson, John, 154 West George street, Glasgow,	24 Dec., 1895
Wilson, Matthew G., 43 Oxford street, Glasgow,	25 Jan., 1898
Wilson, W. H., 45 Scotland street, Glasgow,	22 Feb., 1898
Wilson, William, Lilybank Boiler works, Glasgow,	30 Apr., 1895
*†Wingate, Thomas, Viewfield, Partick, Glasgow,	20 Jan., 1858
Wood, Robert C., 26 Brisbane street, Greenock,	23 Mar., 1897
Workman, Harold, B.Sc., Dunluce, Dullatur,	21 Dec., 1897
Wrench, William G., 27 Oswald street, Glasgow,	25 Mar., 1890
Wright, Robert, 172 Kilmarnock Road, Shawlands,	22 Dec., 1896
Wylie, Alexander, Kirkfield, Johnstone,	26 Oct., 1897
Wyllie, James Brown, 134 St. Vincent street, Glasgow,	G. 25 Oct., 1887 M. 26 Jan., 1897
Wylie, William, 3 Maxwell drive, Pollokshields, Glasgow,	26 Apr., 1898

Young, John, Galbraith street, Stobcross, Glasgow,	27 Nov., 1867
Young, J. Denholm, 2a Tower Chambers, Liverpool,	G. 24 Jan., 1888 M. 23 Jan., 1894
Young, Thomas, 4 West Regent street, Glasgow,	20 Mar., 1894
Young, William Andrew, Millburn House, Renfrew,	26 Mar., 1895
Younger, A. Scott, 4 Abercrombie terrace, Paisley road, Glasgow,	24 Nov., 1896

ASSOCIATES.

*Aitken, Thomas, 8 Commercial street, Leith.	
Andrews, Henry W., 128 Hope Street, Glasgow,	21 Dec., 1897
Allan, Alexander B., Clyde Wire Ropery, Rutherglen,	27 Apr., 1897
Armour, William Nicol, 175 West George street, Glasgow,	24 Nov., 1896

Bain, Andrew, 17 Athole gardens, Glasgow,	26 Oct., 1897
Baillie, Archibald, 2 Balmoral terrace, Glasgow,	25 Jan., 1898
Begg, William, 34 Belmont gardens, Glasgow,	19 Dec., 1886
Blair, Herbert J., 80 Gordon street, Glasgow,	23 Feb., 1897
Brown, Capt. A. R., 24 George square, Glasgow,	21 Dec., 1897
†Brown, John, B.Sc., 11 Somerset place, Glasgow,	25 Jan., 1876
Bryce, John, Sweethope cottage, North Milton road, Dunoon,	18 Jan., 1865

Cassells, John, Hazel bank, 62 Glencairn drive, Pollokshields, Glasgow,	21 Dec., 1880
Cassels, William, Cairndhu, 12 Newark drive, Pollokshields, Glasgow,	21 Feb., 1893
Claussen, A. L., 118 Broomielaw, Glasgow,	22 Jan., 1892

Dewar, James, 11 Regent Moray street, Glasgow,	22 Dec., 1897

Names marked thus * were Associates of Scottish Shipbuilders' Association at incorporation with Institution, 1865.

Names marked thus † are Life Associates.

DIXON, WILLIAM, H., 164 St. Vincent street, Glasgow,	15 June, 1898
DODDRELL, EDWARD E., 11 Bothwell street, Glasgow,	26 Oct., 1897
DONALD, ROBERT K., 42 Cadogan street, Glasgow,	23 Mar., 1897

FERGUSON, PETER, 19 Exchange square, Glasgow,	27 Apr., 1897
FISHER, WALTER L., Glenburn Iron works, Greenock,	26 Mar., 1895

GALLOWAY, JAMES, Jun., Whitefield works, Govan, Glasgow,	27 Oct., 1891
GARDNER, JAMES S., 138 George street, Glasgow,	23 Mar., 1897
GARDNER, ROBERT, 235 West Regent street, Glasgow,	18 Mar., 1863
GOODRICH, WALTER FRANCIS, 101 St. Vincent street, Glasgow,	21 Dec., 1897
GUTHRIE, ALLAN, 2 Whittinghame drive, Kelvinside, Glasgow,	25 Jan., 1898

HALLIDAY, GEORGE, 23 Alfred place, Bedford, square, London, W.C.,	21 Dec., 1897
HOLLIS, H. E., 40 Union street, Glasgow,	23 Nov., 1897
HOLLIS, JOHN, 40 Union street, Glasgow,	23 Nov., 1897
HUNTER, JOHN, 2 Broomhill terrace West, Partick, Glasgow,	22 Jan., 1895

KINGHORN, WILLIAM A., 81 St. Vincent street, Glasgow,	24 Oct., 1882
KYLE, JOHN, Cathay, Forres, N.B.,	23 Feb., 1897

M'ARA, ALEXANDER, 65 Morrison street, Glasgow,	22 Nov., 1892
MACBRAYNE, LAWRENCE, 11 Park Circus place, Glasgow,	26 Mar., 1895
MACDOUGALL, DUGALD, 1 Crosshore street, Greenock,	26 Jan., 1897
M'GECHAN, ROBT. K., 17 Oswald street, Glasgow,	26 Apr., 1898
M'INTYRE, JOHN, 33 Oswald street, Glasgow,	23 Feb., 1897
M'INTYRE, T. W., 123 Hope street, Glasgow,	24 Jan., 1893
M'MILLAN, ARCHIBALD, Rosebery place, Clydebank,	25 Jan., 1898
M'PHERSON, Captain DUNCAN, 3 Cecil street, Paisley road, West, Glasgow,	26 Jan., 1886
MERCER, JAMES B., Broughton Copper works, Manchester,	24 Mar., 1874
MILLAR, THOMAS, Hazelwood, Langside, Glasgow,	22 Mar., 1898

Mowbray, Archibald H., c/o Messrs Smith & M'Lean, Mavisbank, Glasgow,	22 Feb., 1898
Morton, Alfred, 8 Prince's square, Glasgow,	22 Feb., 1898
*Napier, James S., 33 Oswald street, Glasgow.	
Prentice, Thomas, 175 West George street, Glasgow,	24 Nov., 1896
Reid, John, 30 Gordon street, Glasgow,	22 Dec., 1896
Rigg, William, 3 Grantly place, Shawlands, Glasgow,	22 Jan., 1889
Riddle, John C., 8 Gordon street, Glasgow,	15 June, 1898
Ritchie, James, 40 St. Enoch square, Glasgow,	22 Mar., 1898
Roberts, William Ibbotson, 6 Ancaster drive, Glasgow,	15 June, 1898
Robertson, William, Oakpark, Mount Vernon,	27 Apr., 1897
Ross, Thomas A., Glenwood, Bridge-of-Weir,	20 Mar., 1894
Service, George William, 175 West George street, Glasgow,	24 Nov., 1896
Smith, George, 75 Bothwell street, Glasgow,	25 Jan., 1876
Smith, John, 13 Gt. George street, Hillhead, Glasgow,	22 Feb., 1898
Strachan, G., Fairfield works, Govan,	26 Oct., 1897
Taylor, John, Stanley house, South avenue, Govan,	25 Jan., 1898
Wallace, H., 544 St. Vincent street, Glasgow,	27 Apr., 1897
Warren, Robert G., 115 Wellington street, Glasgow,	28 Jan., 1896
Watson, H. J., 5 Oswald street, Glasgow,	
Webster, J. A., Clydesdale works, Sheffield,	23 Nov., 1897
Weir, Andrew, 102 Hope street, Glasgow,	25 Jan., 1898
Wild, Charles William, Broughton Copper Company, Limited, 16 St. Enoch square, Glasgow,	24 Mar., 1896
Wrede, Frederick Lear, 25 Bentinck street, Greenock,	25 Jan., 1898
Young, John D., Scottish Boiler Insurance Company, 13 Dundas street, Glasgow,	19 Dec., 1882
Young, William, Galbraith street, Stobcross, Glasgow.	

GRADUATES.

Adam, Matthew A., 12a Hydepark mansions, London, N.W.	28 Apr., 1896
Agnew, William H., Laird Brothers, Birkenhead,	28 Nov., 1882
Aitken, H. Wallace, Netherlea, Pollokshields, Glasgow,	24 Jan., 1888
Albrecht, J. August, Hawarden, Bothwell,	23 Nov., 1897
Allan, James, 144 Buccleuch street, Glasgow,	24 Jan., 1888
Anderson, Adam R., Croftvale, Renfrew,	23 Mar., 1897
Anderson, George C., Mavisbank, Partickhill, Glasgow,	24 Dec., 1895
Arbuthnott, Donald S., c/o Charles Brand & Son, 172 Buchanan street, Glasgow,	23 Oct., 1888
Arnott, Hugh Steele, Ravenswood, Annfield road, Partick, Glasgow,	26 Oct., 1897
Arundel, Arthur S. D., Penn street works, Hoxton, London, N.,	23 Dec., 1890

Baker, Frederick, W., 149a Tremont street, Boston, U.S.A.,	20 Mar., 1894
Barba, Alfonso G.,	22 Dec., 1896
Barman, Harry D. D., 27 University avenue, Glasgow,	24 Apr., 1888
Baxter, Edmund G.,	22 Nov., 1892
Bell, Norman, 217 St. Andrew's road, Pollokshields, Glasgow,	27 Oct., 1896
Bell, Richard, Castle O'er, Langholm,	20 Mar., 1894
Bennett, Duncan, c/o Mills, 91 Kent road, Glasgow,	26 Oct., 1897
Bishop, Alexander, 3 Germiston street, Glasgow,	24 Mar., 1885
Black, John, 49 Kingswood road, Moseley, Birmingham,	25 Oct., 1892
Blair, Archibald, 15 Craigmore terrace, Partick,	27 Oct., 1885
Blair, Archibald, Jun., 7 Corunna street, Glasgow,	27 Oct., 1891
Blair, Frank R., Ashbank, Maryfield, Dundee,	22 Mar., 1892
Bowie, Robert, 180 Hope street, Glasgow,	20 Nov., 1894
Bowman, W. D.,	22 Dec., 1891
Boyd, Guy W., 3 Queen Margaret crescent, Glasgow,	26 Oct., 1897
Boyle, Edward S. S., 9 Arlington street, Glasgow,	25 Jan., 1898
Brand, Mark, B.Sc., Barrhill cottage, Twechar, Kilsyth,	24 Jan., 1888

Brown, Alexander Taylor, 2 Parkgrove terrace, Sandyford, Glasgow,	26 Oct., 1897
Brown, David A., 57 St. Vincent crescent, Glasgow,	23 Feb., 1897
Brown, James,	20 Mar., 1888
Brown, J. Pollock, 2 Park Grove terrace, Glasgow,	18 Dec., 1894
Bryce, John, 10 Wilton drive, Glasgow,	22 Dec., 1896
Buchanan, Walter G., 17 Sandyford place, Glasgow,	27 Jan., 1891
Burnside, Bertram W., c/o Mrs Stewart, 16 Flemington street, Springburn, Glasgow,	24 Feb., 1891

Caird, William, 57 Tierney road, Streatham hill, London, S.W.,	21 Jan., 1890
Calder, John, 37 Forest road, Aberdeen,	24 Feb., 1891
Caldwell, Hugh, Oak house, Blackwood, Newport, Mon.,	27 Jan., 1891
Cameron, Hugh, 40 Gardner street, Partick, Glasgow,	25 Oct., 1892
Campbell, Angus, 25 Stafford road, Southampton,	24 Jan., 1888
Carslaw, William H., Jun., Parkhead Boiler works, Parkhead, Glasgow,	23 Dec., 1890
Cassells, Robert D., B.Sc., 62 Glencairn drive, Pollokshields, Glasgow,	28 Oct., 1890
Chalmers, Alex. D., Electricity Supply Station, Coatbridge,	27 Oct., 1896
Cleland, John, B.Sc., Mansion house, Easterhouse,	26 Feb., 1884
Cleland, W. A., Yloilo, Philippine Islands,	25 Apr., 1893
Cochrane, James, Resident Engineer's Office, Harbour works, Table Bay, Capetown,	27 Oct., 1891
Conner, Alexander, 9 Scott street, Glasgow,	26 Feb., 1884
Coutts, Francis, 25 Roslin terrace, Aberdeen,	27 Oct., 1885
Craig, Alexander, Netherlea, Partick, Glasgow,	26 Nov., 1895
Craig, James, Netherlea, Partick,	22 Feb., 1898
Crichton, J., 117 Ardgowan street, Glasgow,	23 Nov., 1897

Davies, Harry L., 14 Barton street, Westminster, London, S.W.,	18 Dec., 1888
Dekke, Kristian S., Bergen, Norway,	22 Dec., 1891
Deveria, Lewis M. T., c/o P. M'Intosh & Son, 129 Stockwell street, Glasgow,	10 Feb., 1883
Diack, James A., 10 Caird drive, Partickhill, Glasgow,	22 Jan., 1895
Dick, Thomas B., Post office, Vallejo, California, U.S.A.,	23 Nov., 1886
Dobson, James, c/o Steele, 5 Grafton square, Glasgow,	22 Dec., 1896
Donald, B. B., 275 Onslow drive, Dennistoun, Glasgow,	20 Mar., 1888
Donald, Patrick D., B.Sc.,	24 Feb., 1891
Donaldson, A. Falconer, Beechwood, Partick, Glasgow,	27 Oct., 1896
Dunlop, Alex., 14 Derby terrace, Sandyford, Glasgow,	21 Dec., 1897

Dunlop, William, c/o Stabilimento Odero, Sestri Ponento, Italy,	22 Jan., 1884
Dunn, Turner, 20 Park circus, Glasgow,	21 Feb., 1893
Edmiston, Alexander A., Ibrox house, Govan,	22 Feb., 1898
Feist, John Arnold, Taradale cottage, East Peckham, Kent,	24 Mar., 1896
Fergus, Alexander, 7 Ibrox place, Glasgow,	22 Dec., 1891
Ferguson, James M.,	25 Oct., 1892
Ferguson, Lewis, Fergus villa, Paisley,	22 Jan., 1895
Ferguson, Peter, Jun., Fergus villa, Paisley,	22 Jan., 1895
Fergusson, W. L., Hawcoat lane, Abbey road, Barrow-in-Furness,	22 Dec., 1891
Findlay, Louis, c/o Mrs Ferguson, 29 Bentinck street, Glasgow,	21 Feb., 1893
France, James, 8 Hanover terrace, Kelvinside, Glasgow,	26 Oct., 1897
Fraser, J. Imbrie, 13 Sandyford place, Glasgow,	27 Apr., 1886
Fryer, Tom J., Totley Brook, near Sheffield,	18 Dec., 1894
Fulton, Norman O., Haughbank house, Mauchline,	23 Feb., 1892
Fyfe, Charles F. A., 48 Rosebank terrace, Glasgow,	18 Dec., 1894

Galloway, Andrew, 11 Camphill avenue, Langside, Glasgow,	24 Oct., 1893
Gardner, Hugh, Minas Schwager, Coronel, Chili,	23 Apr., 1889
Gibson, Robert E., Engineer's Office, St. Enoch station, Glasgow,	25 Jan., 1898
Goudie, William J., B.Sc., 92 Albert drive, Crosshill, Glasgow,	21 Dec., 1897
Gourlay, James, 11 Crown gardens, Dowanhill, Glasgow,	27 Oct., 1891
Gourlay, R. Cleland, 11 Crown gardens, Glasgow,	24 Dec., 1895
Govan, William A., c/o Mrs Kane, corner 52nd street and Keystone Street, Pittsburg Pa., U.S.A.,	18 Dec., 1894
Graham, Walter, Westwood, Bearsden,	28 Jan., 1896

Harvey, Ernest Rivers, c/o Mrs Haywood, 63 Great Western road, Glasgow,	22 Mar., 1898
Hay, William, 60 Breadalbane street, Glasgow,	20 Dec., 1892
Henderson, David Cardross Bank villa, Cardross,	20 Feb., 1883
Hepting, F. W. L., 2 Albert mansions, Crosshill, Glasgow,	20 Nov., 1894
Horn, Peter Allan, 201 Kent road, Glasgow,	26 Oct., 1897
Houston, William C., 4 Abbotsford place, Glasgow,	26 Oct., 1897
Howson, George, 8 Park terrace, Govan, Glasgow,	22 Dec., 1891
Hudson, Gerard, 24 Willowbank street, Glasgow,	22 Jan., 1895

Inglis, John F., Pointhouse Shipyard, Partick,	26 Oct., 1897
Innes, W., 11 Walmer terrace, Glasgow,	22 Feb., 1898
Irving, Archibald B., 3 Newton terrace, Glasgow,	20 Nov., 1894
Jackson, Harold D., 10 Hillend gardens, Hyndland road, Glasgow,	24 Mar., 1891
Johnstone, Alexander C., 7 Blackburn street, Paisley road, West, Glasgow,	25 Jan., 1898
Johnstone, Robt., 10 Hayburn crescent, Partick,	26 Apr., 1898
Jones, T. C., Rose Cottage, Langlands road, Govan,	23 Nov., 1897
Kay, Alexander J., 38 Hill street, Garnethill, Glasgow,	24 Oct., 1893
Kemp, Daniel, 69 Prince Edward street, Crosshill, Glasgow,	23 Nov., 1886
Kemp, John, 1 Thornwood terrace, Partick, Glasgow,	28 Oct., 1890
Kemp, Robert G., 2 Ravenscroft avenue, Connswater, Belfast,	28 Oct., 1890
King, Charles A., B.Sc., Welbeck street, Sutton-in-Ashfield, Notts,	25 Apr., 1893
King, John, 16 Lefroy street, Newcastle-on-Tyne,	26 Jan., 1886
Kinmont, David W., Princes street station, Edinburgh,	20 Feb., 1894
Kirk, John, 4 Minard terrace, Partickhill, Glasgow,	20 Nov., 1894
Kirkwood, William D., 30 Queen Mary avenue, Glasgow,	26 Oct., 1897
Knox, Alex., 12 Westbank terrace, Hillhead, Glasgow,	23 Nov., 1897
Laing, Robert, Northbank, Partickhill, Glasgow,	21 Feb., 1893
Lamont, Thomas W., Hawkhead works, Paisley,	22 Nov., 1892
Lauder, Thomas H., Parkhead forge, Glasgow,	19 Dec., 1893
Law, Alexander, 44 Dowanhill street, Partick,	26 Apr., 1898
Le Clair, Louis J., 5 Petershill road, St. Rollox, Glasgow,	24 Nov., 1896
Lee, John, 15 St. John street, Mansfield,	26 Jan., 1886
Lee, Robert, 13 Hamilton ter., West Partick, Glasgow,	21 Dec., 1886
Leitch, William Orr, Jun., Engineer's Department, Imperial Railway, Tientsin, North China,	22 Dec., 1891
Lennox, Alexander, 34 Glasgow street, Hillhead, Glasgow,	23 Jan., 1894
Lennox, George K.,	28 Apr., 1896
Leslie, John, 29 Elder Park street, Govan, Glasgow,	20 Dec., 1892

Lester, William R., 4 Strathmore gardens, West, Glasgow,	21 Nov., 1883
Lloyd, Herbert J., c/o Wessenberg, 4 Cromwell street, Glasgow,	21 Dec., 1897
M'Arthur, Archibald, 19, Ainslie gardens, Partickhill, Glasgow,	24 Jan., 1893
Maccallum, Patrick F., Milton House works, Abbey hill, Edinburgh,	2 Nov., 1880
M'Coll, Peter, Stewartville place, Partick,	18 Dec., 1883
Macdonald, John F., 36 Willowbank street, Glasgow,	21 Dec., 1897
MacEwan, Henry, 5 Cathkin terrace, Mount Florida, Glasgow,	27 Oct., 1891
M'Ewan, John, 211 Dumbarton road, Glasgow,	26 Oct., 1887
Macfarlane, Duncan, Jun., 25 St. Andrew's drive, Pollokshields, Glasgow,	26 Oct., 1897
M'Gann, M. R., 4 Dunkeld place, Hillhead, Glasgow,	23 Mar., 1897
M'Gillivray, John A., 167 Broomloan road, Govan,	26 Oct., 1897
M'Gregor, John L., Coatbridge Engine works, Coatbridge,	28 Jan., 1896
M'Intosh, George, Dunglass cottage, Bowling,	22 Jan., 1895
M'Intosh, John, Oak bank, Bowling,	22 Jan., 1895
Macintosh, John, 7 Park quadrant, Glasgow,	18 Dec., 1894
Mack, James, Princes street station, Edinburgh,	21 Dec., 1886
Mackay, Harry J. S., 1 West Bank place, Hillhead, Glasgow,	22 Feb., 1898
Mackay, Lewis C., Jun , Lyttle park, East Kilbride,	22 Dec., 1896
Mackenzie, James, Fulton Engine works, Blackston street, Liverpool,	25 Oct., 1881
Mackie, James, 478 St. Vincent street, Glasgow,	23 Mar., 1897
Mackie, Thomas P., 27 Alexander street, Glasgow,	23 Feb., 1897
Mackie, William, 29 Thomson street, Govan,	21 Dec., 1897
M'Kinnell, Robert, 56 Dundas street, S S , Glasgow,	26 Feb., 1883
Mackintosh, Robert D., Bellevue place, Garngad hill, Glasgow,	20 Nov., 1894
M'Lean, Joseph M., 1 Bloomfield terrace, Govan,	26 Apr., 1898
Macleod, T. Torq. M., 3 Park terrace, Govan,	27 Oct., 1896
Macmillan, Campbell, B.Sc., 16 Dalhousie street, Glasgow,	24 Nov., 1896
M'Millan, John, 26 Ashton terrace, Glasgow,	27 Jan., 1885
M'Vitae, Andrew, 4 Clutha street, Paisley road, West, Glasgow,	21 Dec., 1886

M'Whirter, Anthony C., 214 Holm street, Glasgow,	21 Dec., 1897
Maitland, Cree, Manager, Sunger Ujong Railway, Port Dickson, Malay Peninsula,	22 Feb., 1887
Maitland, John, 53 Bentinck street, Glasgow,	26 Nov., 1894
Mather, John Boyd, Kirkhill, Mearns,	20 Mar., 1894
Menzies, George, 20 St. Vincent crescent, Glasgow,	22 Jan., 1889
Menzies, Robert,	22 Jan., 1889
Mercer, John, c/o Miss Berry, 2 Glenavon terrace, Crow road, Partick,	22 Oct., 1895
Millar, John S., 22 Rothesay gardens, Partick,	20 Nov., 1894
Millar, Thomas, Sir W. G. Armstrong, Whitworth & Co., Ltd., Walker Shipyard, Newcastle on-Tyne,	25 Nov., 1884
Miller, John, 811 Govan road, Govan, Glasgow,	23 Apr., 1889
Miller, Robert F., 10 Windsor terrace, West, Glasgow,	25 Feb., 1890
Mitchell, Charles, 1 Cambridge terrace, Pollokshields, Glasgow,	25 Jan., 1898
Mitchell, R. M., 24 Howard street, Bridgeton, Glasgow,	23 Nov., 1897
Moir, Ernest W., c/o S. Pearson & Son, 10 Victoria street, Westminster, London,	25 Jan., 1881
Mollison, Hector A., B.Sc., 6 Hillside gardens, Partickhill, Glasgow,	22 Nov., 1892
Morrison, Arthur M, 15 Albion crescent, Dowanhill, Glasgow,	17 Dec., 1889
Morrison, A., Alt-na-craig, Greenock,	23 Nov., 1897
Mort, Arthur, c/o Mrs French, 71 Church lane, Old Charlton, Kent,	26 Jan., 1897
Morton, Charles C., Ingleside, The Park, Waterloo, Liverpool,	25 Jan., 1898
Morton, W. Reid, 8 Ardgowan terrace, Glasgow,	26 Oct., 1897
Mowat, Magnus, 12 Talbot lane, Leicester,	26 Oct., 1897
Muir, James H., 140 Bath street, Glasgow,	26 Jan., 1892
Muirhead, William, Cloberhill, Knightswood, Maryhill, Glasgow,	28 Apr., 1891
Mumme, Ernest C., c/o Agent and Chief Engineer, Bengal and North-Western Railway, Gorakpur, North-West Provinces, India,	22 Nov., 1892
Murdoch, John A., 7 Park Circus place, Glasgow,	25 Oct., 1892
Murphy, B. Stewart, c/o H. Hogarth, 72 Great Clyde street, Glasgow,	24 Oct., 1893
Myles, David, Northumberland Engine works, Wallsend-on-Tyne,	20 Dec., 1887
Mylne, Alfred, 116 Woodlands road, Glasgow,	26 Jan., 1897

Napier, John S., Herbertshire, Denny,	26 Jan., 1892
Newton, Charles A., c/o Miss Davison, 51 Grant street, Glasgow,	25 Jan., 1898
Nicholson, Thomas,	26 Jan., 1886
Nowery, William, 37 Derby street, Glasgow,	21 Dec., 1897

Orr, J., 53 Bentinck street, Glasgow,	22 Oct., 1895
Orr, John, B.Sc., South African College, Cape Town,	26 Mar., 1895
Osborne, Hugh, 30 Rose street, Garnethill, Glasgow,	22 Dec., 1891
Osborne, Marshall, 13 Westbourne terrace, Stockton-on-Tees,	22 Dec., 1891

Paterson, James V., 307 Walnut street, Philadelphia, U.S.A.,	24 Jan., 1888
Paterson, Joseph Barr, 15 Eldon street, Glasgow,	22 Mar., 1898
Paton, Thomas, 1 Fairley street, Govan, Glasgow,	20 Dec., 1892
Peacock, James, 2 Wilton mansions, Glasgow,	22 Nov., 1881
Pirret, Corsar, 9 Roslyn terrace, Kelvinside, Glasgow,	24 Dec., 1896
Pollock, Gilbert F., 10 Beechwood drive, Tollcross, Glasgow,	27 Jan., 1891
Pollok, John, Portland park, Hamilton,	22 Feb., 1898
Portch, Ernest C., 2 Park view, Langside, Glasgow,	26 Oct., 1897
Preston, John C., Assistant Engineer, Brisbane Board of Water works, Brisbane, Queensland,	6 Apr., 1887
Prentice, Hugh, Millbank, Yoker,	26 Apr., 1898
Pringle, William S., 97 Desswood place, Aberdeen,	24 Oct., 1893

Ralston, Shirley B., 34 Gray street, Glasgow,	23 Feb., 1897
Raphael, Robert A., 150 Renfrew street, Glasgow,	24 Dec., 1895
Reid, David H., Attiquin, Maybole,	25 Oct., 1887
Reid, James, 128 Dumbarton road, Glasgow,	22 Oct., 1895
Reid, James G., Renfield house, Renfrew,	23 Dec., 1884
Reid, Walter,	26 Feb., 1884
Richmond, James, 24 Sutherland terrace, Hillhead, Glasgow,	23 Jan., 1894
Richmond, John H., 99 Grant street, Glasgow,	23 Jan., 1894
Ritchie, James, 1 Westbank place, Hillhead, Glasgow,	26 Oct., 1897
Robertson, Alexander, 272 Darnley street, Pollokshields, Glasgow,	26 Oct., 1886
Robertson, Edward F.,	28 Oct., 1890

Rodger, Anderson, Jun., Glenpark, Port-Glasgow,	15 June, 1898
Roger, George William, Irvine Shipbuilding and Engineering Coy., Ltd., Irvine,	24 Nov., 1896
Roy, William, 14 Wilton drive, Kelvinside, Glasgow,	25 Jan., 1898
Russell, James, 119 Grange road, East, Middlesbrough,	22 Dec., 1891

Sadler, Herbert C., B Sc., 2 Minard terrace, Partickhill, Glasgow,	19 Dec., 1893
Scobie, Alexander, Culdees, Partickhill, Glasgow,	27 Oct., 1885
Scott, Harry, 76 Kenmure st., Pollokshields, Glasgow,	22 Dec., 1896
Scott, John R., 51 Love street, Paisley,	21 Dec., 1897
Scott, Thomas R., 101 Mayfield road, Edinburgh,	22 Dec., 1896
Seath, Thomas R., Sunny Oaks, Langbank,	23 Mar., 1886
Seath, William Y., Sunny Oaks, Langbank,	23 Mar., 1886
Sexton, George A., 2 Hillhead gardens, Partickhill, Glasgow,	24 Nov., 1896
Sharp, John, 147 East Milton street, Glasgow,	24 Oct., 1882
Sharpe, William, Engineer-in-Chief's office, Natal Government Railway, Maritzburg, Natal,	24 Dec., 1895
Shaw, John J., 12 Lynedoch place, Glasgow,	24 Apr., 1894
Sibbald, Thomas Knight, 162 Queen's drive, Glasgow,	26 Oct., 1897
Simpson, David C., 1 Fairlie Park drive, Crow road, Partick,	20 Dec., 1892
Sloan, John Alexander, 11 Rose street, Garnethill, Glasgow,	25 Jan., 1898
Smith, Alexander, 5 Doune quadrant, Kelvinside, Glasgow,	24 Nov., 1891
Smith, George F., 11 Woodside terrace, Glasgow,	26 Oct., 1897
Smith, James, 20 Dumbarton road, Glasgow,	20 Dec., 1892
Smith, James A., Union Bank house, Virginia place, Glasgow,	18 Dec., 1894
Smith, Charles, 8 Muirpark gardens, Partick,	24 Apr., 1894
Spalding, William, 532 St. Vincent street, Glasgow,	25 Oct., 1892
Sperry, Austin, 2100 Pacific avenue, San Francisco, U.S.A.,	23 Mar., 1897
Stark, James, Messrs Swan and MacLaren, Penang, Straits Settlements,	22 Dec., 1891
Stearns, William B., P.O. Box 702, Marblehead Yacht yard, Marblehead, Mass., U.S.A.,	20 Mar., 1894
Steel, James, 34 Old Broad street, London, E.C.,	26 Jan., 1892
Steven, David M., 18 Sandyford place, Glasgow,	15 June, 1898

STEVEN, J. M., 2 Hampton Court terrace, Glasgow,	20 Dec., 1892
STEVEN, JOHN A., 12 Royal crescent, Glasgow,	22 Nov., 1881
STEVENS, CLEMENT H., c/o Blandy Bros. & Co., Las Palmas, Grand Canary,	22 Dec., 1891
STEVENSON, ARCHIBALD, Yloilo, Philippine Islands,	25 Apr., 1893
STEVENSON, WILLIAM, 24 Heaton grove, Heaton, Newcastle-on-Tyne,	25 Jan., 1881
STEWART, HENRY, 26 Evelyn avenue, Bloomfield, Belfast,	26 Oct., 1897
STIRLING, ANDREW, Denny & Co., Engine works, Dumbarton,	21 Dec., 1875
STOVE, THOMAS R ,	26 Feb., 1895
SWAN, JAMES, Arcadia street, Dorchester, Mass., U.S.A.,	23 Mar., 1897
SYMINGTON, JAMES R., Dardene, Kilmalcolm,	21 Dec., 1886
TAYLOR, J. F., c/o Young, 300 Duke street, Glasgow,	23 Nov., 1897
THOMSON, AMBROSE H , Surveyors' Department, Court house, Marylebone lane, London, W.,	24 Mar., 1891
THOMSON, GRAHAM H., Jun., 2 Marlborough terrace, Glasgow,	22 Feb., 1898
THOMSON, JAMES, Hayfield, Motherwell,	20 Nov., 1894
THOMSON, FREDERICK, 18 Westbank terrace, Hillhead, Glasgow,	26 Jan., 1892
TOD, PETER, C. & H. Crichton & Company, Engineers, Victoria road, Liverpool,	27 Oct., 1885
TOD, WILLIAM, c/o Miss Granger, 24 St. Vincent crescent, Glasgow,	22 Feb., 1898
TURNBULL CAMPBELL, 39 Victoria street, Westminster, London,	27 Oct., 1891
TURNBULL, JAMES, South Overdale, Langside, Glasgow,	22 Mar., 1892
TURNBULL, W. L., 18 Blythswood square, Glasgow,	27 Oct., 1891
TURPIN, C., 874 Govan road, Govan,	23 Nov., 1897
WALKER, JOHN, 1 Church road, Ibrox, Glasgow,	20 Nov., 1894
WALKER, G. UNDERWOOD, 56 Woodhead street, Dunfermline,	21 Mar., 1893
WALLACE, JOHN, Jun., 12 Kelvingrove street, Glasgow,	26 Jan., 1892
WANNOP, CHARLES H., Barclay, Curle & Co., Limited, Finnieston quay, Glasgow,	24 Feb., 1885
WATSON, ROBERT, 2 Glencairn drive, Pollokshields, Glasgow,	22 Mar., 1881
WATT, HARRY, 2 Cambridge terrace, Pollokshields, Glasgow,	20 Dec., 1892
WATT, ROBERT D., Butterfield & Swire, French Bund, Shanghai, China,	27 Apr., 1880

WEDDELL, ALEXANDER H., Park villa, Uddingston,	22 Dec., 1896
WEIR, WILLIAM, Holm foundry, Cathcart, Glasgow,	28 Jan., 1896
WELSH, GEORGE MUIR, 3 Princes gardens, Dowanhill, Glasgow,	21 Dec., 1897
WEMYSS, GEORGE B., 175 Comelypark street, Dennistoun, Glasgow,	28 Nov., 1882
WEST, ERNEST WM., The Fairfield Co., 113 Cannon street, London, E.C.,	20 Dec., 1892
WHARTON, FRED., 17 Moorfield road, W. Didsbury, Manchester,	26 Oct., 1897
WHITEHEAD, JOHN, Eccleston, Wallace st., Kilmarnock,	18 Dec., 1883
WHITTELSEY, HENRY N., 83 Substation, New York,	23 Mar., 1897
WILSON, JOHN H., 4 Underwood, Paisley,	27 Oct., 1896
WOODS, JOSEPH, 4 Rosenthal road, Catford, London,	25 Feb., 1896
WOTHERSPOON, WILLIAM, c/o Mrs Masterton, 12 Sylvan place, Edinburgh,	19 Dec., 1893
WRIGHT, ROBERT, c/o Mrs Arnott, 552 St. Vincent street, Glasgow,	26 Oct., 1897
YOUNG, JOHN, Jr., 9 Dover street, Glasgow,	23 Nov., 1897

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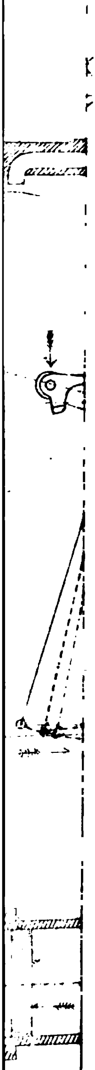
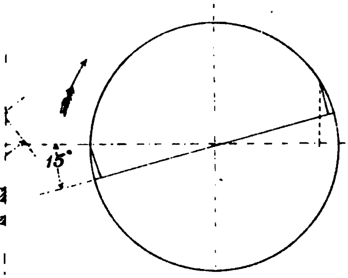
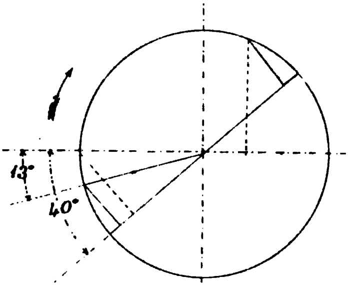


Fig. 17.



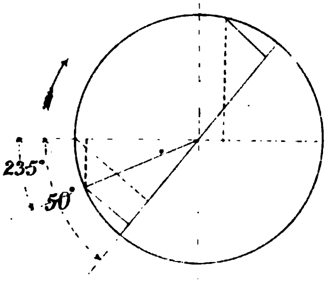
CUT OFF ·94

Fig. 18.



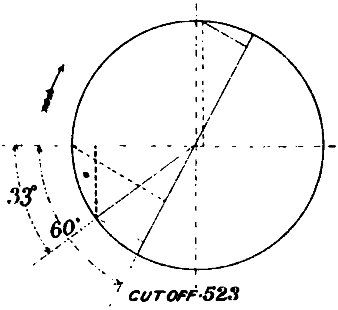
CUT OFF ·695

Fig. 20.



CUT OFF ·615

Fig. 21.



CUT OFF ·523

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Fig. 11.

DURR

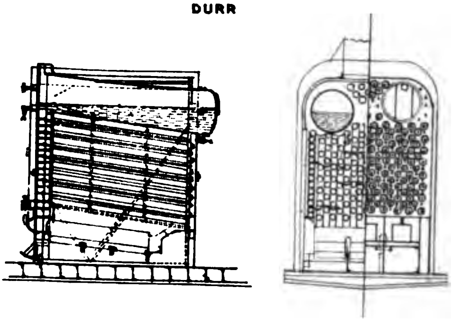

Fig. 10.

PERKINS

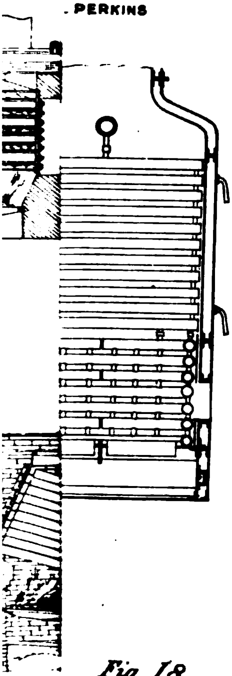

Fig. 12.

BUCKLING

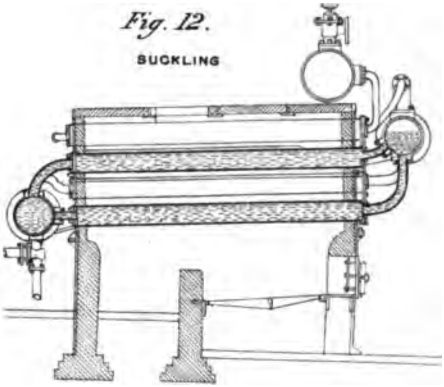

Fig. 19.

C. WARD

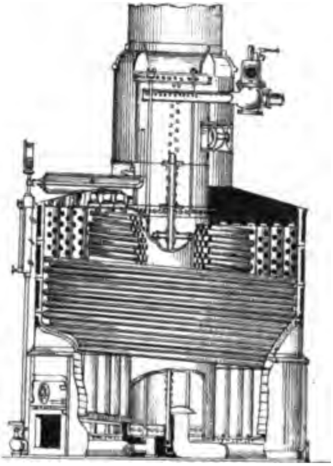

Fig. 18.

HERRESHOFF

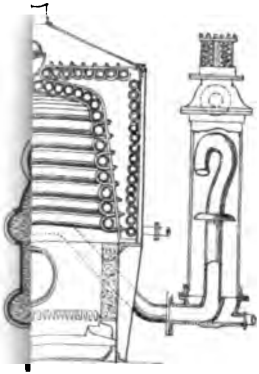

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Fig. 27.

CRADDOCK

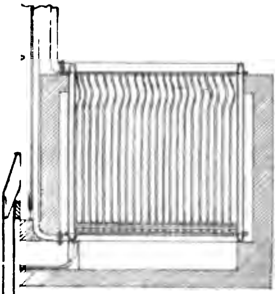

Fig. 28.

CRADDOCK

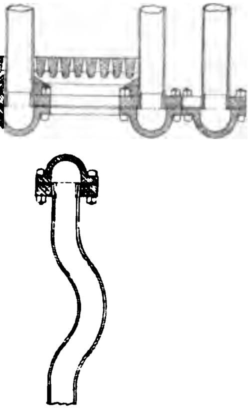

Fig. 49.

PETERSON

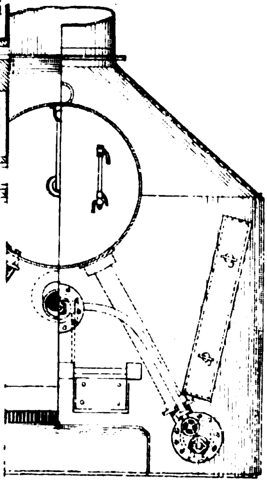

Fig. 29.

ROWAN & HORTON (1869)

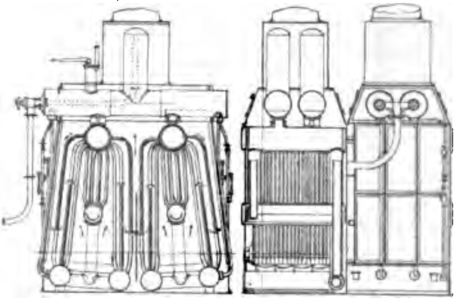

Fig. 30.

JORDAN

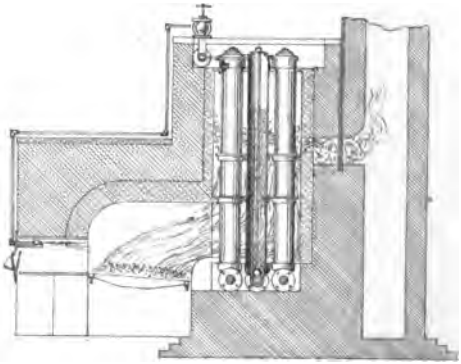

Fig. 50.

CHURCH

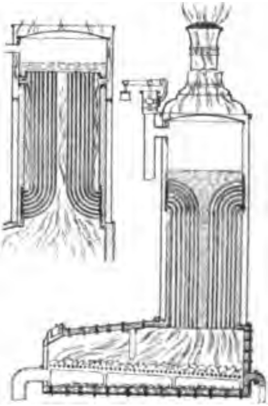

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PLATE V.

Fig. 38.

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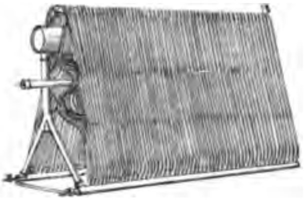

Fig. 39.

FLEMING & FERGUSON

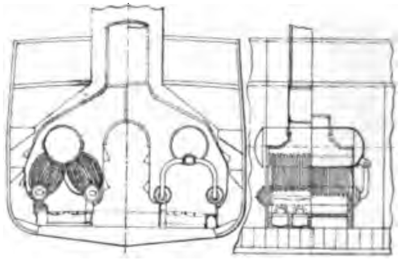

Fig. 46.

HARRISON

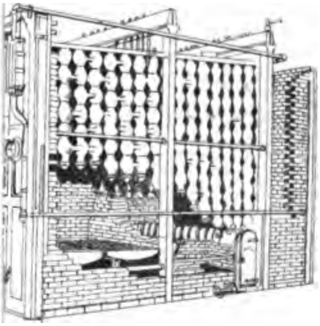

Fig. 47.

ROBERTS

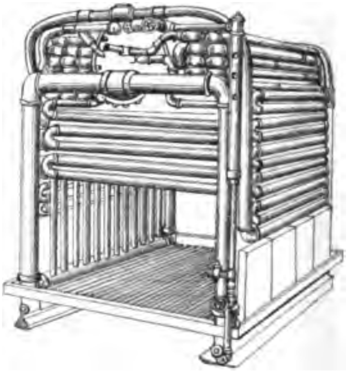

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PLATE VI.

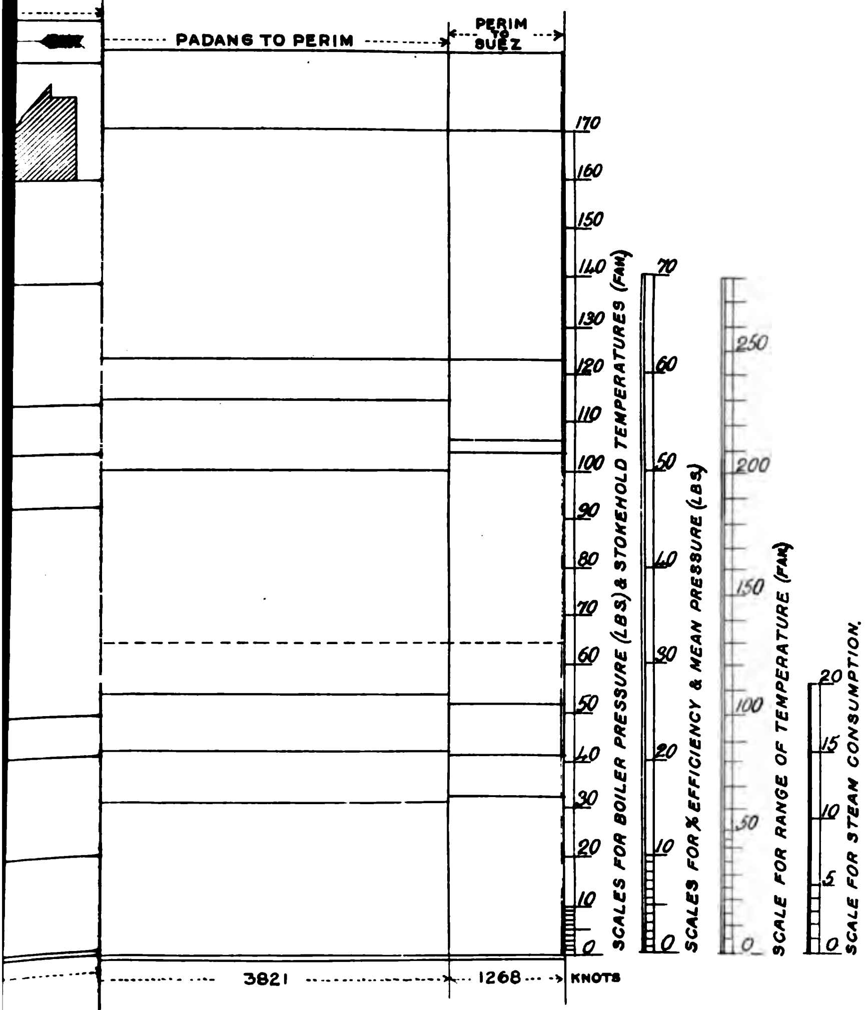

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PLATE VI.

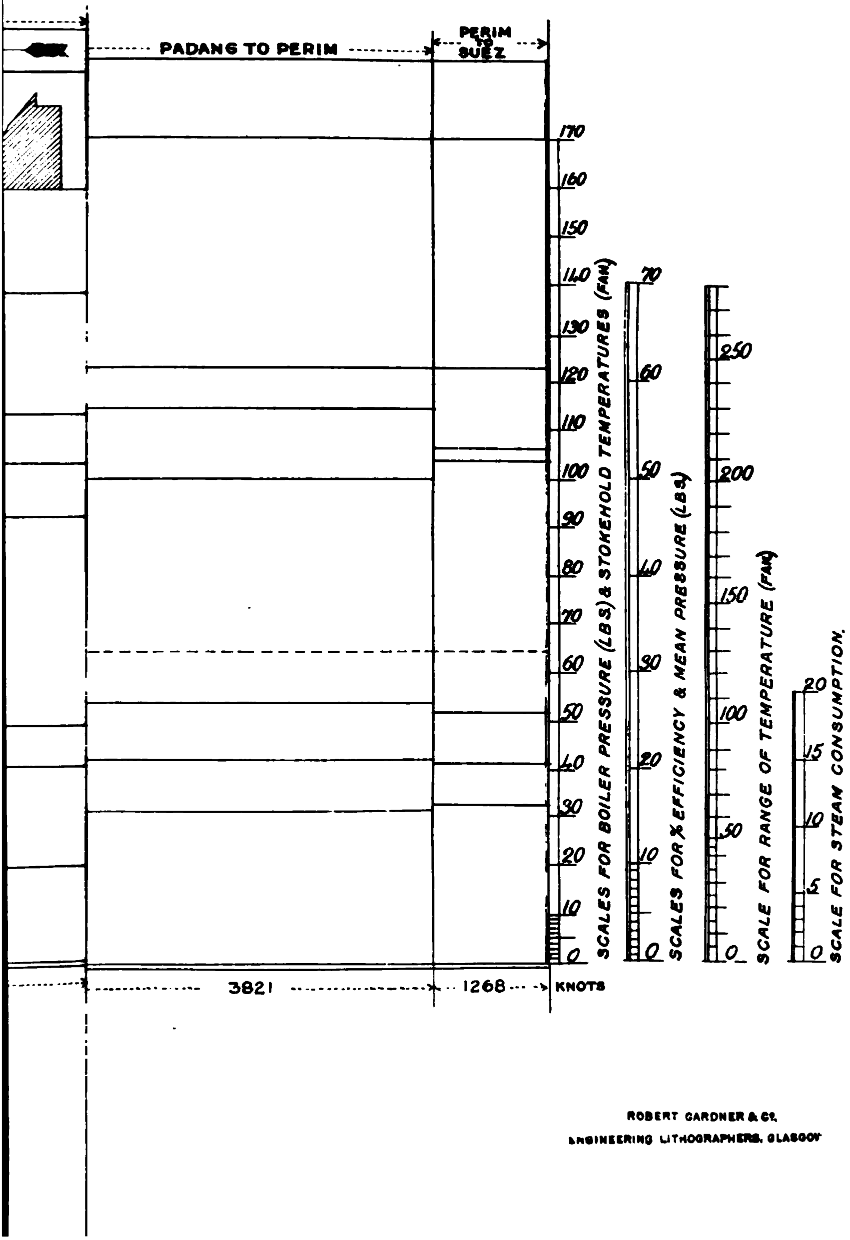

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PLATE VIII.

Fig.

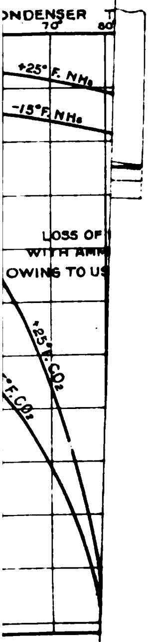

Fig. 15.

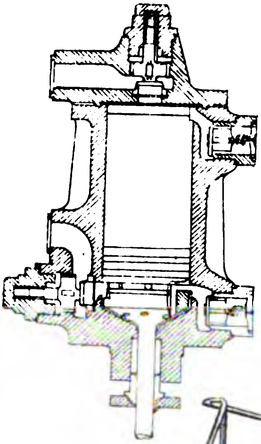

Fig. 17.ª

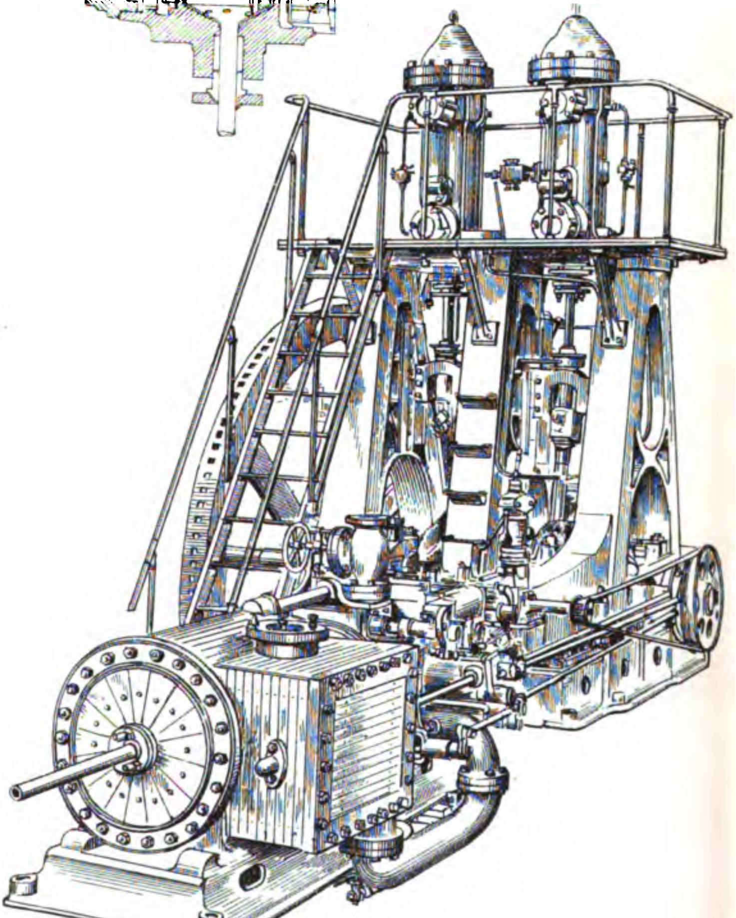

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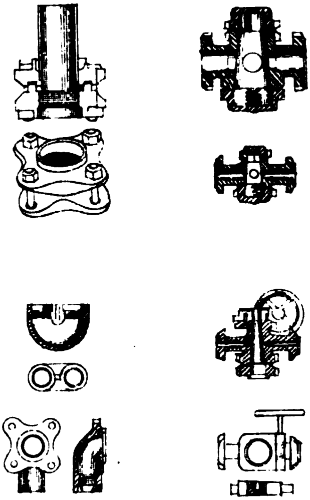
Fig. 21.



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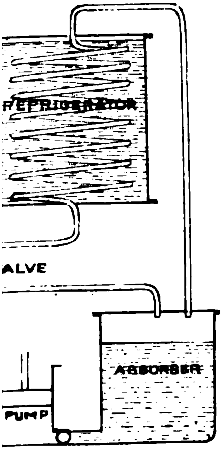
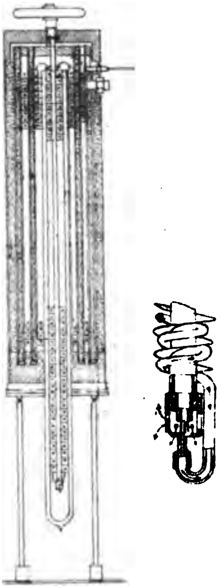


Fig. 27.



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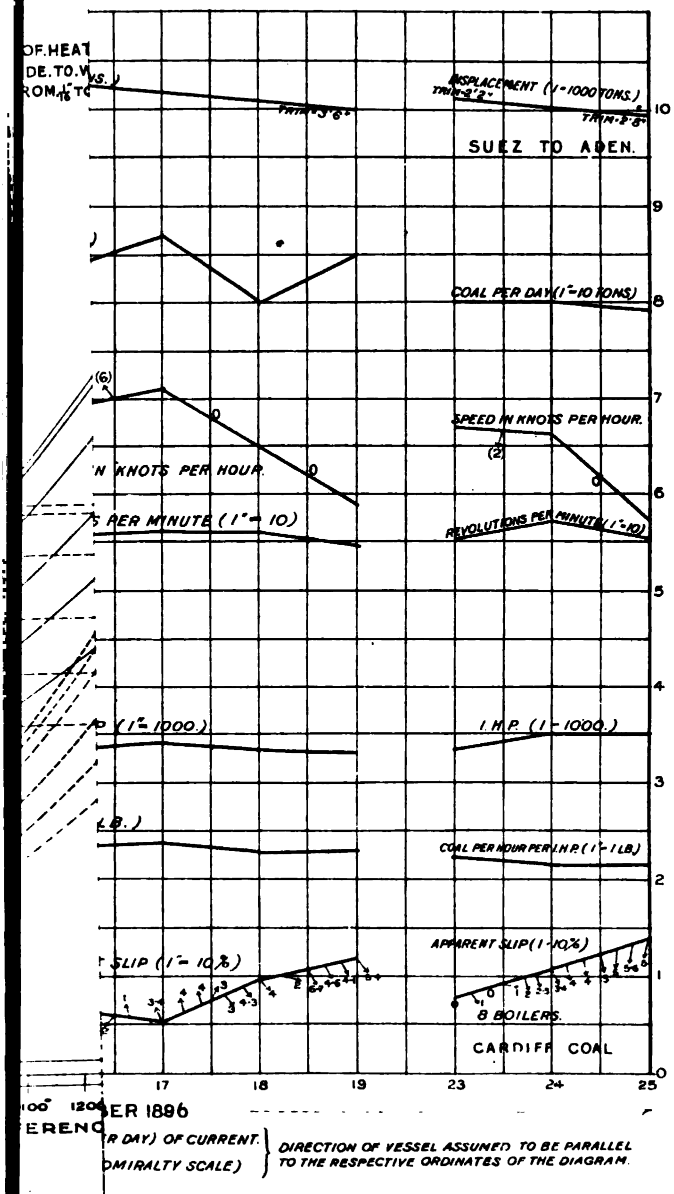
REMAR REMARKS ON "A GRAPHIC LOG." *PLATE. X.*

KHERSON."

9. g 1.



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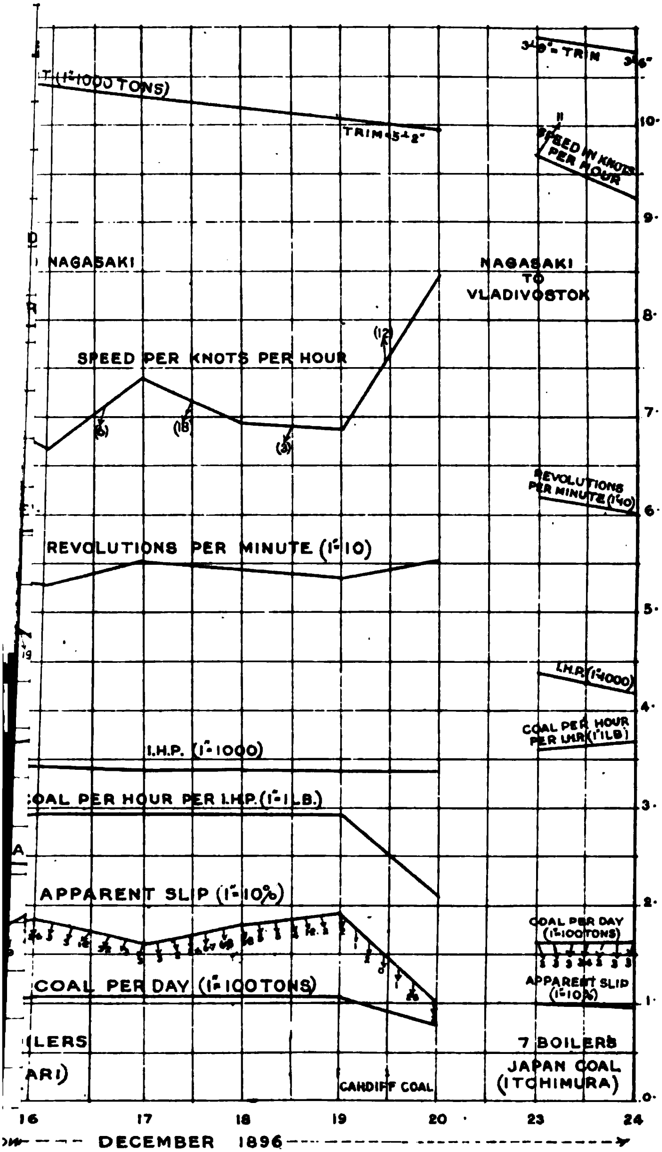
Log 3.



D (IN MILES PER DAY) OF CURRENT.
E OF WIND (ADMIRALTY SCALE)

DIRECTION OF VESSEL ASSUMED TO BE PARALLEL TO THE RESPECTIVE ORDINATES OF THE DIAGRAM.

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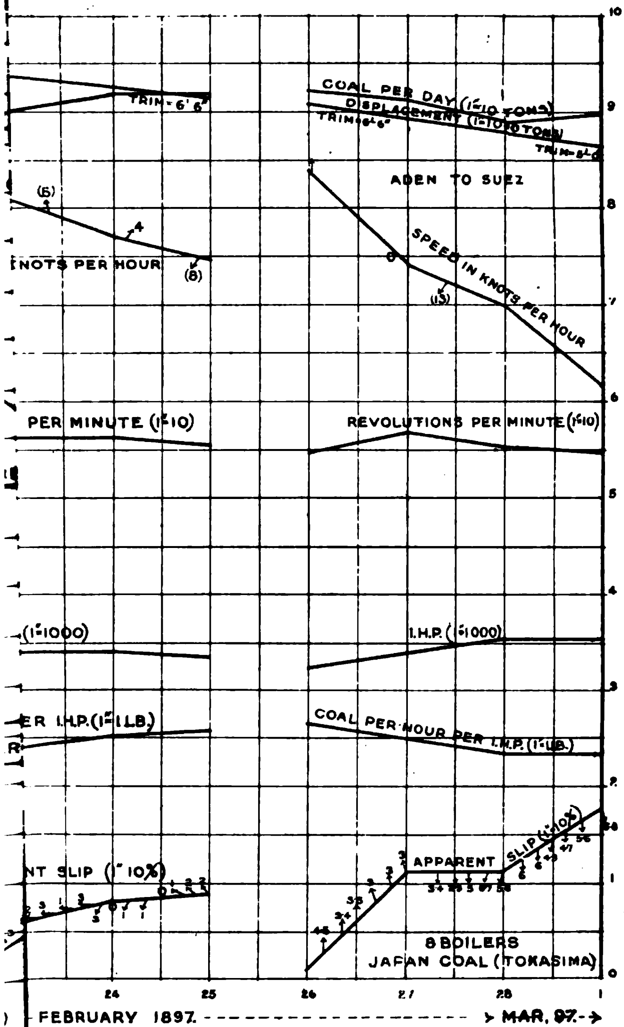
PLATE XII.

Log 5.



MILES PER DAY) OF CURRENT. }
TIO WIND (ADMIRALTY SCALE) } DIRECTION OF VESSEL ASSUMED TO BE PARALLEL TO THE RESPECTIVE ORDINATES OF THE DIAGRAM.

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NE BOILER FURNACES, BY MR W. R. AUSTIN.

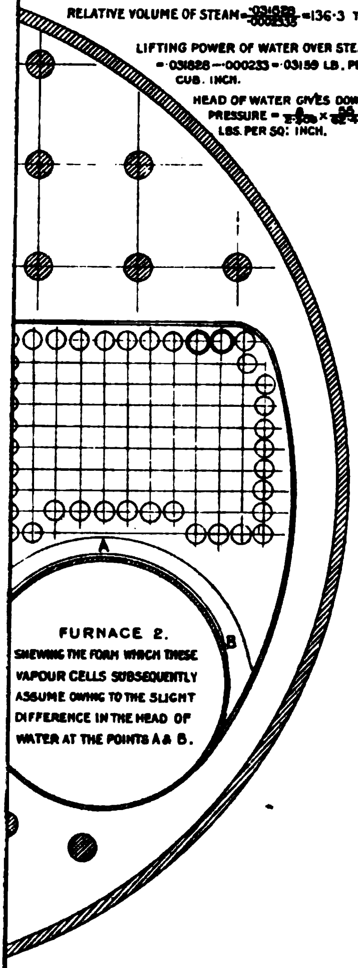
KEEP "STEAM ARRESTED IN GENERATION"
ER A HEAD OF WATER = 8 FEET, AT A

FOOT OF STEAM = ·4035 LBS.
INCH $= \frac{\cdot 4035}{1728} = \cdot 0002335$ LBS
ER AT ABOVE PRESSURE $= \frac{2 \times 62\cdot 425}{\frac{373+461}{360} + \frac{500}{373+461}} = 55$ LBS PER CUB. FT
EIGHT OF CUBIC INCH OF WATER $= \frac{55}{1728} = \cdot 031828$ LBS.

RELATIVE VOLUME OF STEAM $= \frac{\cdot 031828}{\cdot 0002335} = 136\cdot 3$ TO 1 OF WATER

LIFTING POWER OF WATER OVER STEAM
$= \cdot 031828 - \cdot 000233 = \cdot 03159$ LB. PER
CUB. INCH.

HEAD OF WATER GIVES DOWNWARD
PRESSURE $= \frac{8}{2\cdot 308} \times \frac{55}{62\cdot 4} = 3\cdot 05$
LBS. PER SQ: INCH.



FURNACE 2.
SHEWING THE FORM WHICH THESE VAPOUR CELLS SUBSEQUENTLY ASSUME OWING TO THE SLIGHT DIFFERENCE IN THE HEAD OF WATER AT THE POINTS A & B.

& Shipbuilders
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PLATE XIV

Fig. 6.

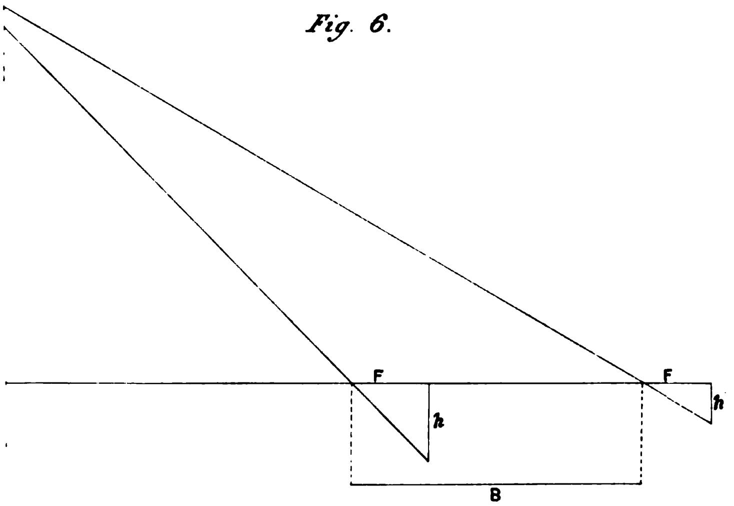

Fig. 7.

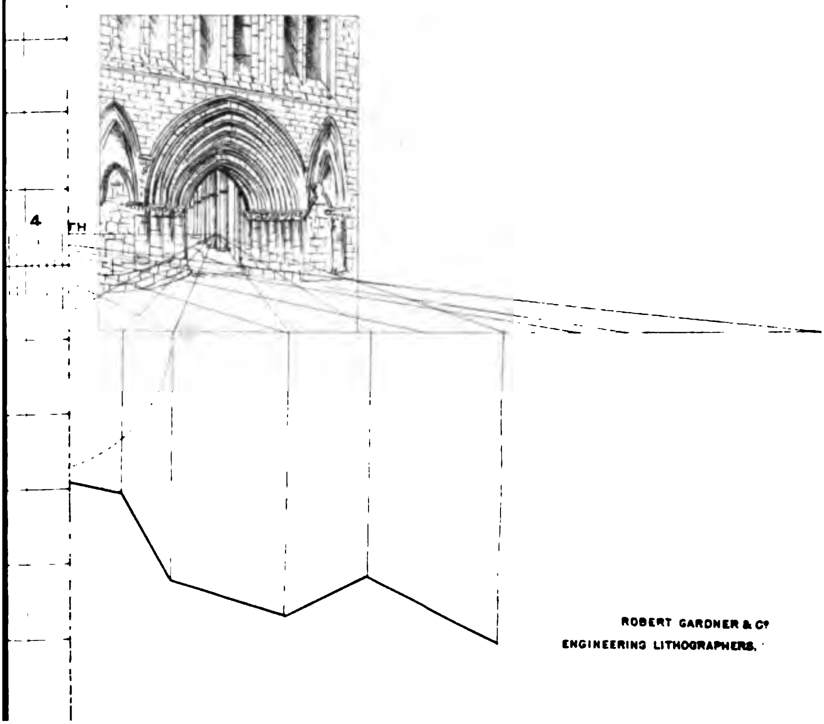

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PLATE XV

Fig. 12.

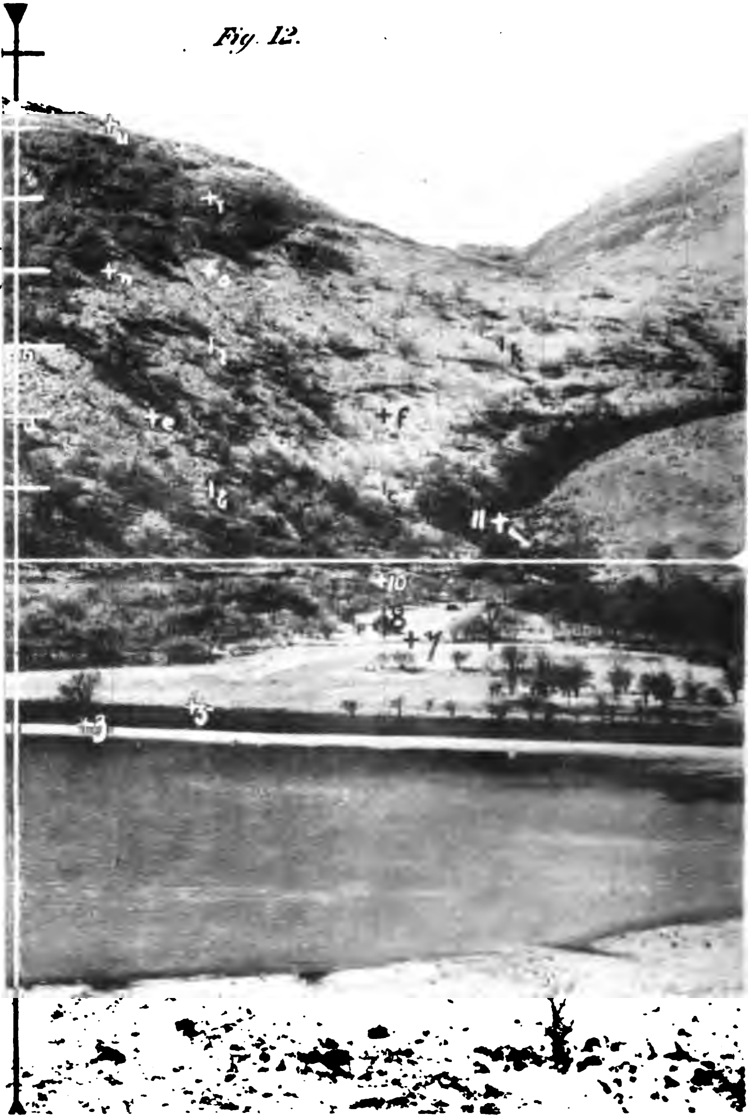

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Fig. 15.

Fig. 16.

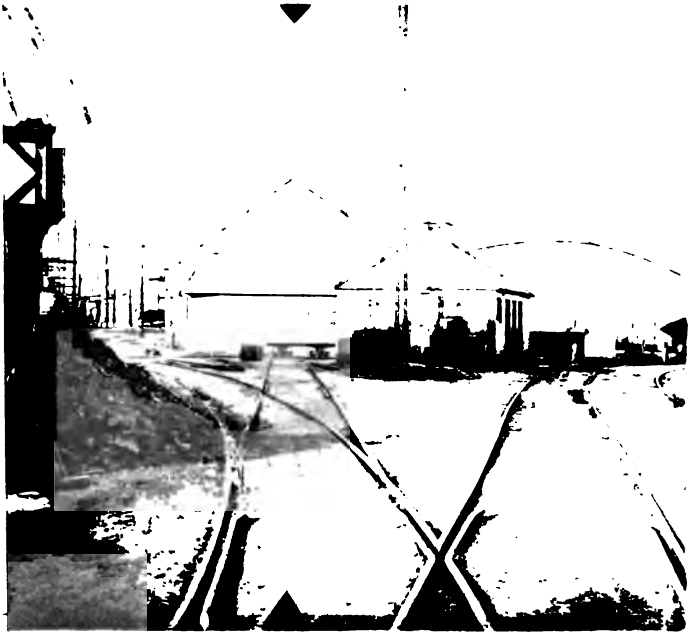

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PLATE XVII.

Fig. 1

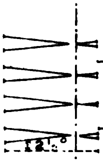


Fig.

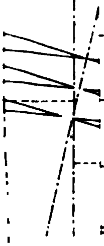
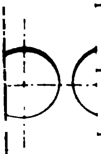


Fig. 3



VI	VII	VIII	
1/8	1/8 3/16	3/16 5/16	PORT SIDE
1/2	0 7/16	0 3/16	
1/16	1/8 1/8	1/8 1/8	
3/16	0 3/8	0 1/4	
1/4	0 3/16	0 1/16	
9/16	1/8 3/8	0 3/8	
1/4	1/16 0	0 1/4	
3/4	0 3/8	0 1/16	
0	1/8 3/8	1/8 3/8	STARBOARD SIDE
0	1/4 0	3/16 ↑ 1/32	
3/8	1/16 1/4	1/8 5/16	
↑ 1/8	1/16 0	1/16 0	
7/16	1/8 9/16	3/16 1/2	
3/8	1/16 1/2	1/16 3/8	
9/16	0 1/4	1/8 3/8	
1/2	1/8 1/4	1/8 5/16	

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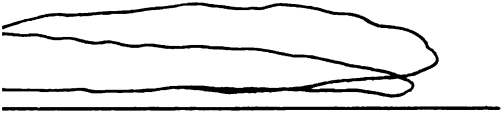
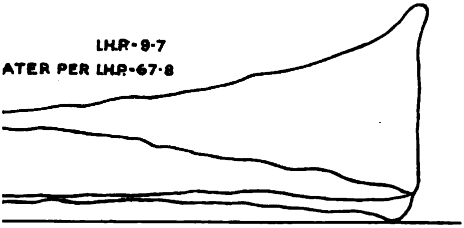
PLATE XVIII.

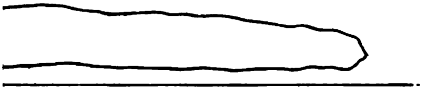
I.H.P.-4.4
ER PER I.H.P.-87



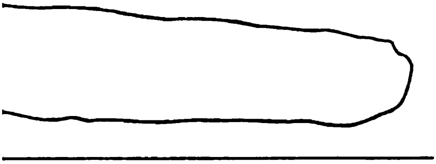
I.H.P.-9.7
ATER PER I.H.P.-67.8



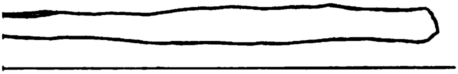
I.H.P.-9
S. WATER PER I.H.P.-95.8



I.H.P.-10.28
VATER PER I.H.P.-60



IHP-1.38
I. WATER PER I.H.P.-180.7



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