# TRANSACTIONS

OF THE

# INSTITUTION OF ENGINEERS

# IN SCOTLAND.

VOLUME IV.

FOURTH SESSION, 1860-61.

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GLASGOW:
WILLIAM MACKENZIE, 45 & 47 HOWARD STREET.
1861.

GLASGOW: PRINTED BY WILLIAM MACKENZIE, HOWARD STREET.

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*Elected 11th April*, 1860.

## FOURTH SESSION, 1860-61.

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# CONTENTS.

## FOURTH SESSION, 1860-61.

# PLATES.

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.

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*Note.*—The issue of the present volume has been delayed with the expectation of including in it a paper (with extensive tables) *On Experiments on the Comparative Strength, &c., of Steel and Wrought Iron, by Messrs. Robert Napier & Sons*—supplementary to the paper published in Volume II. As, however, more time than was anticipated is required to complete the paper, it will be issued separately as soon as ready.

GLASGOW, 30*th September*, 1861.

# INSTITUTION

OF

# ENGINEERS IN SCOTLAND.

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## SESSION 1860-61.

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The First Meeting of the Session was held in the Philosophical Society's Hall, Andersonian Buildings, George Street, Glasgow, on Wednesday, 31st October, 1860—Walter M. Neilson, Esq., President, in the chair.

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The President delivered the following Introductory Address:—

Gentlemen,—In commencing the business of this our Fourth Session, it will be my duty first to notice briefly what has been done by us during the meetings of the preceding session; and I regret to be obliged to state, that, although at our first meetings of last year there appeared a prospect of an interesting and successful session, from the number of papers there was reason to believe would have been brought before your notice, your council were nevertheless much disappointed in finding that many of our members, from other engagements, were unable to overtake the preparation of the various subjects intended to have been submitted to you for your consideration and discussion. I trust, however, that we will, during the meetings of this session, not only have those papers we looked for last year, but that our members will show an increasing interest in the progress of our Institution, by devoting a portion of their time to bringing before us such subjects as they may have had their attention more particularly directed to during the recess.

I think I may state plainly that we, as an Institution yet in our infancy, do not arrogate to ourselves the position of being teachers or lights to the world, but rather the more humble place of followers in the footsteps of those parent institutions of a similar kind in England, of an older growth, from whom we are too distantly situated to participate in their active existence. And whilst we feel it a privilege and an honour to be able to advance in any way those great and useful objects which form the study and the pursuit of members of such an institution as we profess to support, still we consider it one of the most valuable results we can attain, to excite the production of such information, knowledge, and experience as will, by intercommunication, teach one another, and assist us to occupy the positions in which we are placed, with greater satisfaction to ourselves, greater success in our onward efforts, and greater honour to our country.

In noticing the most important subjects which occupied our attention at the meetings of last year, I would mention first the straightening of the great chimney of the Crawford Street chemical works. The very successful application of the scientific skill of those engineers who advised the remedy for the injury the chimney had received from being too rapidly built, as came out in discussion, must have been very gratifying to all the parties interested in the operation. This chimney, notwithstanding its having swayed considerably from the vertical when nearly finished, by being cut with the saws and implements exhibited to you, at various places on the high or windward side, or that on which the gale acted, was made perfectly erect, and afterwards completed to its present total height of 468 feet from the foundation—now the highest chimney in the world.

The valuable paper by Mr. Milne, on the new works executed by him at the improvements on the Grangemouth harbour in connection with the Forth and Clyde navigation, deserves particular notice, as an example of a class of work we have not now often the opportunity of witnessing. The difficulties which were required to be overcome from the nature of the ground, and the peculiarities of the locality, were ably grappled with; and the novel manner in which Mr. Milne obtained the requisite depth of water, without cutting through the only safe and reliable foundation he had to build upon, exhibits a beautiful adaptation of cast-iron to such structures, producing not only a much stronger, but also, what is of great importance, a cheaper work.*

The improvements alluded to are still being carried on, and farther important works are now in execution. We hope Mr. Milne will favour us with the particulars of the whole operations; and we are satisfied that any member who takes an interest in such undertakings will be well repaid by a visit to Grangemouth harbour, which is now in direct communication with Glasgow by rail.

* By a typographical error at page 34, Vol. III., the cost is made £1800. It should have been £18,000.

The subject, *Improvements in Iron Ship-building*, for both mercantile and war use, brought before us by Mr. Simons in his excellent communications, is one in which we would expect many of the members of this Institution to take a lively interest. To the public generally — the strength of iron ships is a highly important question. The many disasters of the past year have called the attention of almost every one to the safety of iron vessels, and the press has plainly stated that, in public opinion, many iron ships have not been built as they ought to have been; and our own Clyde has been pointed at as not guiltless in this direction. We are indebted to Mr. Simons, as a shipbuilder of known reputation and energy, for bringing the question of improvements in iron ship-building thus frankly before us, and challenging the discussion of the whole matter by our members. I hope, however, that the non-attendance of those whom we would expect to take most interest in this important subject, at the different times when it has been under consideration, will not be taken as any indication of their indifference to a matter which the public expect to demand from them as ship-builders their most earnest consideration. There can, I think, be no doubt, at all events, that it must be both gratifying and assuring to the public, to see that ship-builders do use all their skill and energy to make the iron ships they build of the very strongest and safest description they can obtain from their own experience or that of others.

The account of the application and construction of hydraulic presses, communicated by Mr. D. More, could not fail to be interesting, showing to what a great extent, and for how many different purposes, hydraulic power is now used in the operations connected with manufactures and commerce at home and abroad. If the communication had not been of so general a character, but had entered more into the details of construction, the recorded results of the long experience of a firm of such reputation as Messrs. A. More & Son deservedly possess for the construction of hydraulic presses, would have formed a very valuable addition to the volume of our Transactions.

I will only further mention—Mr. Tait's carefully-conducted experiments on his engine and steam-boiler, noticing the great value for reference of all carefully-conducted and reliable experiments;—Mr. Lawrie's papers on the form of ships, and on the treatment of steam for the development of power—two subjects of the very greatest importance, forming, as they do, the element of the success of steam navigation, subjects which have been much discussed, and in which there is still great room for more discussion. These, and communications from Professor C. Piazzi Smyth, Dr. Rankine, Mr. Napier, Mr. Moffat, and others I cannot overtake in detail, formed the business of our Institution during the last session.

The past year does not seem to have left us any great strides in engineering progress to record; but, although no marked leaps may be conspicuous, still the steady onward progress of improvement is not stayed —silently, but perseveringly, the useful work moves on. We are apt to be dazzled by the sudden outburst of some new effort of inventive genius, and lose sight of the great value of the perfecting of details, and the applying to useful practice the suggestions of those who may, with minds unfettered by the pressing cares of ordinary business, wander over the movements in life's busy affairs, discover some want to be supplied, some error to be corrected, or some new path onwards to which they point, but, unable to do more, leave the accomplishment to others.

The success of many useful inventions, mainly if not altogether, has often depended upon the labour and perseverance of the practised hand, who works out, and gives existence to, what is presented to him as mere visions of the mind; and perhaps the greater merit is due rather to the successful applier—than to the mere originator of ideas.

It is remarkable how much of late the public mind has been directed to the construction of implements of warfare. Science seems, in the past few years, to have somewhat left its usual course—the pursuit of the arts of peace—and turned to the prosecution of the more exciting arts of war. This has been strikingly exemplified in the many schemes brought forward for the better construction of everything required in the conduct of war, defensive or offensive.

The great perfection to which rifled arms and ordnance has been brought, beautifully illustrates the value of the directing spirit of science, and forcibly presses upon us the conviction—that our future successes before our enemies will depend upon the great intelligence and scientific skill displayed both in the construction and use of our weapons, as much as upon the strong arm and indomitable courage of our people.

The great power given to heavy ordnance naturally demands farther efforts to obtain some efficient means of defence from this new-created destruction; and now that, on the ocean, the natural element of our nation, the wooden walls of old England are no longer able to defend us, we may only trust in walls of iron, and bulwarks of steel. This necessity calls for ships of an entirely novel construction and new combinations of material; and we may reasonably consider that we have not yet arrived at the proper kind of vessel to be defended, or the proper kind of defence to be used. The shipbuilder, the engineer, and the iron manufacturer, have an opportunity of conferring great benefit upon the government and the country by giving their assistance in this matter—not only to produce vessels suitable for the purposes required, but to devise machinery and other means—by which the material and the construction may be obtained at as small a cost to the nation as possible.

Our country's defence may be a subject which, strictly considered, does not come within the range of the objects of our Institution; but when we find the engineer called upon to take such an important part—in devising the means and constructing the instruments by which our safety from our country's enemies is to be maintained, I think it cannot be considered out of place, even here, to notice briefly something of the constructions and machinery of the modern art of war.

As stated by Mr. Simons in his paper on battle-ships, the time has evidently arrived when iron should be substituted for wood in their construction, for the very obvious reasons which he gave; and that speed will form a very essential element in the efficiency of such vessels cannot be doubted, more particularly if it should be attempted to use them, as has been proposed, for running down an enemy. Such rams, heavily loaded with their iron cases, powerful and necessarily heavy machinery, guns, ammunition, and stores, will require great skill in their construction to obtain all the qualities demanded of them. The danger of such vessels suddenly going down, in the event of any misfortune, naturally presents itself, and the means of preventing such a catastrophe should be, as far as possible, provided for.

It may be considered desirable to have another class of vessels, of a limited speed, to act as floating batteries, in fixed positions, where any portion of our coast should unexpectedly require to be defended. These vessels would be of an entirely different form from the others, and might have convenient accommodation for the naval reserves and stores of all descriptions.

Swift despatch boats will always form an important branch of our naval service, but there is little difficulty in providing vessels of this class—with sufficient speed to keep them out of harm's way.

A connected system of railways upon our exposed coasts has been suggested as a great assistance to our means of defence. It is obvious, with keen-eyed swift steamers, and well-worked telegraphs, our artillery and volunteers, with such communications, would be rendered doubly valuable by being ever ready where a foe might plant his foot upon our shores.

Harbours of refuge and fortifications open a large field to the civil engineer. The construction of fortifications is happily something new to us in this country, and we also trust the time is far distant when they will be otherwise than something new to the soldier on the soil of Great Britain. One cannot but feel alarmed at the prospect of the execution of such great works being undertaken by our government. We have some experience of how works of immense magnitude have been completed by private enterprise, and trust some means may be adopted through which the patience of the nation will escape a trial which, in comparison with such works as the building the houses of parliament, with the misfortunes of Big Ben into the bargain, will be but a phantom.

I will venture to say it will be unfortunate for the people of this country, and much to be regretted, if that localized concentration of the directing powers of the nation in our great metropolis, should deliver up the construction of those great works—perhaps the greatest the government of this country has ever undertaken—into the hands of those only who are directly connected with the government, or others fortunate by the influence which proximity to the seat of power has given them—to the exclusion of all others less favourably situated, but who, nevertheless, have equal claims for participating in the opportunities which the expenditure of so vast an amount of the nation's wealth gives for the exercise of their profession; and I would say more—it seems hardly fair to Scotland, with her fame for ship-building and steam-engine making, and with her great powers of production in all works of iron, that there should not be one single royal dockyard or arsenal within her bounds; and that the benefits, which the constant disbursements of the large amount of public money confer upon the districts in which these establishments are located, should be altogether denied to this northern portion of the kingdom.

In taking a cursory view of what, at present, more particularly occupies the attention of those who, like ourselves, are engaged in the pursuits of such objects as properly come under the consideration of our Institution, I can only notice, within the limits of this short address, a few of those which come most prominently before us, and in which we are more immediately interested. Steam-ship building very naturally presents itself—one of the most important practical subjects we can turn our attention to—and economy of fuel in marine engines, a department of this subject which, at the present time, occupies considerable attention. I have already, on former occasions, remarked that the consumption of fuel in our marine engines demands the immediate and earnest attention of our engineers; and it is gratifying to observe the successful efforts now being made in that direction. I also pointed out what appeared to me the means to be used to obtain the desired end; and ventured to predict that surface condensation and higher pressure of steam would be universally adopted in all marine engines. Surface-condensation is no new thing to the engineers on the Clyde. Very many years ago considerable efforts were made by one of our then eminent engineers, and not without some success, to introduce surface condensers into our Clyde steamers; but the difficulties of constructing and maintaining the apparatus in an efficient state were so great that the idea was abandoned; and engineers have gone on from year to year, turning out annually thousands of horses power, without almost giving the matter of economy in fuel a consideration. It is an established fact that a most perfect vacuum can be obtained by the system of condensation we allude to; and we cannot for a moment doubt that the practical skill and perseverance of the present day, aided by the perfection to which the production of constructive material has attained, will overcome all the difficulties—which have hitherto prevented one of the greatest improvements in the marine steam-engine from taking its proper place in the grand economy of steam navigation.

The pure water obtained for evaporation from the new condenser will for ever banish from existence that vexatious annoyance of salting in the boilers, and allow of no excuse for priming; thus giving a far greater freedom to boiler construction, opening up an extended field for the skill of the boilermaker—which leads us to hope that ere long a cheap, compact, and safe marine boiler for pressures above 100 lbs. will become an article of common manufacture. Then nothing will be wanting but to perfect the details, and compete for the best results from the whole system.

It is generally admitted that in iron ship-building there are many improvements yet to be made, and we have of late seen various proposals for increasing the strength of vessels—by using different forms of material, as well as by differently arranging its position in the structure of the vessel. But the form and proportions of the hull itself as a whole, and the figure and disposition of the weight of the part above the water line, in relation to the portion immersed appears to be an important matter for consideration, in order to obtain a structure in which the severe strains caused by labouring in a heavy sea will not concentrate their destructive forces on some weak point, which would have been otherwise able to bear its own proportion of (fatigue) stress, but gives way—in consequence of the unequal duty it is called upon to perform, by the malconstruction of the other parts of the vessel. No doubt vessels ought to be differently built to meet the requirements of the different trades for which they are intended, both as to cargoes to be carried, and the seas to be sailed in. It may seem to some curious that iron steam vessels should be specially built for particular service, whilst the old wood-built ships were considered fit to sail in any sea; but the necessarily weaker form, from the great length required to obtain the speed, must not be forgotten, and the fatigue a sailing vessel suffers at sea cannot be compared to what any screw trader has to submit to. The steamer takes its course in whatever direction the wind may blow or the sea roll, and by being forced against the waves in every possible direction, is strained, twisted, and shaken in a manner no sailing vessel can be.

Many of our members who are familiar with the practice of ship-building must admit the fact that, in their experience, the forms and proportions of both the submerged and emerged portions of vessels are not governed by any distinct rules, deduced from any known laws, which would undoubtedly be discovered by a thorough investigation into those forces which act upon the vessel, under all the circumstances to which it may be exposed, and the resistances to those forces, which the vessel, in the performance of its duty, must be able successfully to give.

I would venture to suggest—a better quality of iron, and a more secure system of rivetting would do much to increase the strength of iron vessels. I have repeatedly had striking examples of the very great differences in the strength and durability of constructions composed of plates of iron—particularly when above three-eighths of an inch in thickness—rivetted together in the ordinary manner, when compared with similar examples, where the corresponding rivet holes were carefully made parallel, and the rivets fitted tightly in their places. It is, of course, impracticable to obtain perfect accuracy in the rivet holes of a ship's plates, but any means or system which could improve the practice would, in my opinion, be of great value.

If the improvements which have lately been made in the economy of the production of steel, be still farther carried out, it is not unreasonable to presume that that material may yet enter largely into those constructive parts where very great strength is required, at the same time, not increasing the weight of the whole vessel, whilst adding very greatly to its strength.

I will here only farther repeat—what I stated in my address at the commencement of last session—how much it is to be regretted that the members of our Institution, more particularly interested in this matter, do not bring forward the results of their experience in iron ship-building, in order that the opportunity which this Institution gives might be taken advantage of—to compare different results, by which much valuable data might be obtained, and laws discovered as already referred to, and the various questions be discussed, upon which there is so great variety of opinions, such as—the form and dimensions to produce given desired results; the amount of power that can be most effectively applied to different kinds of vessels; how to obtain the greatest amount of power with the least quantity of fuel; form, diameter, pitch, and speed of propellers; arrangement of masting and rigging to give the best combined result of propeller and canvas; steering; rolling in a sea way; the unpleasant vibration produced by some propellers, and the great lateral oscillation observed in some vessels, both obviously tending greatly to aggravate the evil of insufficient rivetting; peculiarities in setting compasses of different vessels; deviations of compass in the same vessel;—and many other inquiries which will suggest themselves to those more practically acquainted with the subject than I can be.

In the landward department, of the great business of locomotion, the increasing demand for greater facilities, in accommodating the locomotion of the ever accumulating crowds of the people, urges forward the engineer to yet greater efforts. And now we have the extraordinary work going on of forming an underground railway through London—burrowing among a labyrinth of sewers, gas mains and water mains. This railway pushes on to connect all the termini of the railways in the metropolis.

The propriety of connecting the different termini in large cities is becoming every day more apparent. The transit of passengers, goods, and minerals, from one depot to another, is a source of great inconvenience to the traveller, expense to the trader, and nuisance to the citizen; thoroughfares are crowded, streets are worn and destroyed,—by a traffic which the business of our cities has no right to be encumbered with. Even in our own city, should it continue to enjoy the prosperity with which it has been favoured in past years, ere long some of the streets, wide as they are compared with those of sister cities, will become unmanageable, and their deficiencies a great hindrance to the active energy of our merchants and traders. If our railway termini were connected,—with a branch to the harbour, and rails upon our quays to the ships' sides—bringing the shipping in direct communication with the rising manufacturing and coal-producing districts around Glasgow, an immense boon would be conferred on the trading public, on our citizens, and on our shipping interest.

The time seems to have arrived when the ordinary facilities for conveyances, even in our cities, in their crowded thoroughfares, are not considered sufficient for the demands of the age. In America, and in France, we have had for many years street horse railways; and if we consider for a moment the number of horses, carts, waggons, omnibuses, &c., in Glasgow, and calculate the power necessary to draw the loads over the streets, and estimate how much less power would do the same work on a railroad, the saving of horses power which could be effected would be enormous; and, be it remembered, not steam horse power, but real flesh and blood horses power, the cost of which very few are well aware of. Of course, the cost of transit would be proportionally reduced; and the saving in "rolling stock," and tear and wear of street paving, would form a large item in the common economy. Our public authorities and the conservators of our roads are, perhaps, scarcely yet prepared to give way to the rail; but there seems no reason to doubt that the public convenience, and even the public safety, would be greatly increased by adopting properly constructed street railways; and the difficulties to be overcome in their construction and management are not such as, in the present state of engineering intelligence, ought to be considered insurmountable.

It would appear now to be considered as a matter not to be questioned, that, in the present state of locomotive progress and experience, an engine can be made to run and do work satisfactorily on common roads. Several engines at work in England have given considerable promise of success, but there appears still to be some difficulties yet to be overcome in producing a good serviceable and durable road engine. That such a thing is at present required, there is no doubt, and the mechanical engineer has a new field to open up, in this direction, for his skill and industry.

Upon our railways we observe a continued tendency of traffic to flow in certain great streams. This is naturally to be expected. Our great cities, with their busy suburbs, form centres to which railroads converge, ministering to the wants of the immense populations, and carrying away the produce of their industry. These great carrying lines are well named trunk lines, and the feeders branches; or, they might as appropriately be compared to great rivers, with their tributary streams running into them. We consequently find the increasing demand for transport on these trunk lines requiring more powerful means of transit and greater speed, larger trains and larger engines. The locomotive engine has now been increased in power and in size, almost we should think, to the extreme limits the narrow gauge will admit of. As examples of, perhaps, the most successful of this class of engine, I may mention those recently built for the Caledonian railway by Mr. Connor, the locomotive superintendent of that line. The cylinders are 17½ inches in diameter, and the stroke 24 inches, with driving wheels 8 feet in diameter, weighing each engine about 27½ tons. The first of these engines has been at work now for about a year, and its performance has been in every way satisfactory. I remember well the engines made for this same railway in 1831 (then the Glasgow and Garnkirk) by Messrs. Stephenson of Newcastle. The cylinders were 10 inches diameter, stroke 14 inches, with four wheels 4½ feet diameter, and weighed 5 tons. Certainly a striking contrast to the engine of the present day, and affording a forcible example of the progress of the power of locomotion. On trunk lines the necessity for, and the economy in, such powerful plant and high speeds, has been well established; but in the branch lines, where the trains are smaller, and there is no necessity for any such high speed, I think a greater effort should be made, in an opposite direction, to accommodate the rolling plant, and also the permanent way, more to the limited amount of traffic carried on these lines.

The economy to be arrived at—by low speeds, and locomotive plant particularly adapted for such a system, does not appear to be sufficiently appreciated. The saving in the cost of bridges, permanent way, and its maintenance, would be very great; and if railways were made strictly on this principle, many of our thinly-scattered populations might yet participate in the benefit of railway communication—now the great high road on which the commercial intercourse of the country is conducted—and without which, those unfavoured districts of our country must remain deprived of one of the greatest stimulants to progress and improvement.

Situated as Glasgow is, in the midst of an immense coal and iron district, where the production of the one, and the manufacture of the other, is carried on to so large an extent, we have reason to feel disappointed that we have had, I may say, almost no communications on the engineering works connected with this great and important department of our industry.

The mining engineer—has no where more scope for the exercise of his profession than in the West of Scotland, and there is much that comes within the range of his experience that would form most valuable subject for the notice of our Institution. I need only mention the various methods of surveying and the instruments used;—testing mineral fields by boring; the different ways of conducting coal and ironstone workings, especially in peculiar or difficult mineral fields; the difficulties encountered, and how they are overcome; sinking of pits where they ought to be sunk; draining, pumping, ventilation, and such like. The mechanical engineer engaged in making mining machinery might also perhaps profitably to himself, as well as instructively to others, submit for discussion blowing engines, pumping and winding engines, rolling-mill engines, with their boilers, and numerous machineries to which they are attached —all no doubt brought to great perfection, but we must not assume that there is not yet room for farther improvement.

We have much to look for from the civil engineer—in the construction of docks, harbours, quays, and jetties—our Clyde furnishes excellent examples of certain descriptions of such works. And the numerous harbours around our coasts, although they may not be of large extent, would still give opportunities of showing that, within the scope of the profession under which such works properly fall, there is not wanting among us that experience and skill, sufficient without foreign aid, to undertake such new works as the increasing trade and commerce of our own part of the country must periodically demand.

I cannot at this time farther particularize the numerous subjects which present themselves to us within that great field upon which the engineer is called to operate—railway works, water works, gas works, telegraph works, sanitary works of every description—all offer ample opportunity for investigation, and tempt the enterprising spirit into an arena within which many have found honour, and have reached the highest pinnacle of fame.

I have now called your attention, although, I fear, in a very imperfect manner, to a few of those topics which appeared to me most conspicuous in the great engineering progress of our country. I doubt not, however, but the views I have taken, and the opinions I have not avoided giving expression to, may not meet with your unaninamous approval, and be subject to much just criticism. This I expect, neither could I desire it to be otherwise, but would rather court the utmost freedom in the expression of opinions, which set one against the other, stand or fall, by the facts with which they are supported, and lead to truth—the great aim and end of all well-directed inquiries. This leads me to notice, before I close, what I daresay has not escaped the notice of you all—the desire shown at the present day,—by men engaged in the various pursuits connected with those arts which constitute the business of our lives,—to associate themselves together for the purpose of better acquiring a knowledge, and assisting the progress and development, of those objects to which their every-day labours are directed. The existence of scientific societies we have been long accustomed to, but it must be a matter of satisfaction and encouragement to us to observe so many of those engaged in the noble art to which we have the honour to belong, associated as we are, for the purpose of collecting and investigating facts, deducing from them truths, and the laws and rules by which the successful accomplishment of these great works have been attained, works which stand out as monuments of the genius, the industry, and wealth of our nation.

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On the motion of Professor Macquorn Rankine, seconded by Mr. William Johnstone, a unanimous vote of thanks was passed to the President for his able and interesting address.

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The PRESIDENT then drew attention to a small

*American Air Engine,*

which was exhibited at work. Diagrams were also shown, with the assistance of which its construction and action were explained by Messrs. J. R. Napier, and J. Brownlee.

The engine, which is the invention of Captain Ericsson, is represented in Plate I.; fig. 1 being a vertical section, and fig. 2, a plan. The cylinder consists of two parts, the working part, or cylinder proper, A, and the heating chamber, B; the latter being partly sunk into, and encompassed by, the furnace chamber, C. Within the cylinder there are the working piston, D, and a second piston, E, with a plunger, F, attached. This plunger is made of a light material, a bad conductor of heat, and serves to prevent too great a radiation of heat from the heating chamber, B, to the working cylinder, A; and, at the same time, in consequence of its nearly filling the chamber, to spread the air in a thin sheet over the heating surface, and thus induce it the more rapidly to take up heat. The plunger piston, E, is formed with a circle of small passages, which are closed by a loose ring when the plunger piston moves inwards towards the furnace, but which are open when the plunger piston moves outwards. With the parts in the positions represented in fig. 1, the air in the space between the pistons, D, E, is in a comparatively cold, but somewhat compressed state. The plunger, F, and piston, E, are about to move outwards, which will have the effect of transferring this air to the back of the plunger, F, and the air becoming heated in consequence, will expand and force out the piston, D; the pistons, D and E, moving nearly together at this part of the stroke. The movement of the piston, D, is communicated by the levers, $d$, $d^1$, and connecting-rod, $d^2$, to the crank of the shaft, G, giving the latter half a turn, the piston, D, reaching its outmost position at the mouth of the cylinder, A. The rod of the plunger piston, E, passes through the piston, D, and is connected to a lever, $e$, the latter being fixed to a lever, $e^1$, connected by a rod, $e^2$, to the crank of the shaft, G. The plunger piston, E, having followed the piston, D, to near the end of its stroke, is, by the continued rotation of the shaft, G, due to the action of its flywheel, $g$, caused to move rapidly backwards, whilst a cam on the shaft, G, by means of a lever, $h$, opens an outlet valve, H, and the used air behind the plunger is expelled. At the same time the recession of the plunger piston, E, causes a fresh supply of cold air to enter between the pistons through a valve, I, provided in the piston, D, for that purpose; this air afterwards becoming somewhat compressed by the recession of the piston, D, into the position in which it is represented in fig. 1.

The PRESIDENT was sorry he could not give the Institution any information respecting the engine. He had written to America and endeavoured to get some particulars about its power and relative consumption of fuel; but he was answered to the effect that they would send him an engine, but declined to give him any information about it. He hoped, however, that some gentlemen present might be able to throw light upon it.

Professor MACQUORN RANKINE said he saw a resemblance in some parts of it to parts of the first air-engine, that of Dr. Stirling, patented in 1816; The first point of resemblance was the manner in which the air was driven by the plunger from the cold to the hot end of the cylinder. Another point was the combination of connecting-rods and levers in Ericsson's engine, which were like certain levers and connecting-rods introduced for the same purpose by Dr. Stirling. But an important difference between this engine and Dr. Stirling's was, that this engine took in a fresh supply of air at each stroke, so that it must work at very low pressure; whereas, Dr. Stirling's engine by permanently confining a quantity of air, could work at very high pressure. With regard to the economy of fuel as compared with power, he said that there was a possibility of economising fuel, by giving a greater heating surface. But he did not think, from the appearance of this engine, that it could be intended to economise fuel to any great extent, because such a large proportion of the heat must evidently go up the chimney without being communicated to the air inside of the cylinder. It was likely that the engine was intended for use as a convenient mode of getting small power where there were objections to the erection of a boiler. It was very desirable that some experiments should be made, in order to get precise data as to the consumption of fuel compared with the power of the engine. He had seen many pamphlets written about these engines, but it was disappointing to find that they contained no information as to the proportion of fuel consumed to the work performed, although there were many vague praises of the engine, and accounts of its driving various machines. He hoped that some definite experiments would be made with this engine. He heard a gentleman in the room say before the commencement of the business, that some experiments had been made with one of these engines, which had given a consumption of 30 lbs. of charcoal per horse-power per hour. If the engine was really so wasteful, the cause must be the small heating surface; and he had no doubt that if it could be arranged so that the fire should communicate as much heat as it did in steam boilers, the engine would be a more economical one.

However, supposing it not to be economical, it might be useful as a convenient and simple engine.

The PRESIDENT said that this engine which they had heard so much about, was evidently a very ingenious machine, and he believed could be made at a very small cost. He believed that it was not intended to be an economical engine, but rather to be used for convenience. He thought it was both interesting and amusing to look into this matter. It was very desirable that correct results of the performance of the engine should be obtained; and therefore, he suggested that Professor Rankine and Mr. J. R. Napier, if they could spare the time, might make some experiments, and he would be very glad to provide the oil, coals, and indicator.

Mr. J. FERGUSON said he had seen one driving a thrashing mill at Berlin about a fortnight ago, and it was going tolerably quickly.

Mr. DAVID ROWAN remarked, that in Hamburg a short time ago, he had seen one going very slowly. He had asked about the consumption of fuel for the power, and he was told that it had been wrought at about a horse-power, and burnt 30 lbs. of charcoal per hour.

A unanimous vote of thanks was passed to the President, for bringing the engine before them.

THE SECOND MEETING of the Session was held in the Philosophical Society's Hall, on Wednesday, 28th November, 1860, the PRESIDENT in the chair.

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The following paper was read:—

## *On the Application of Transversals to Engineering Field-work.*

By PROFESSOR W. J. MACQUORN RANKINE.

The illustrious Carnot, eminent at once in war, politics, literature, and science, published about the year 1806 a short essay on what he called the "Theory of Transversals;" a branch of geometry at once simple in its principles, and useful in its applications, but little known or studied in Britain.

A *transversal*, as defined by Carnot, is a line, either straight or curved, which cuts another system of straight or curved lines; and the theory of transversals relates chiefly to the proportions amongst the parts into which the lines belonging to that system are cut by the transversal. He confines his attention in his essay to straight and circular transversals.

The object of the present paper is to describe a few of the simplest applications of the theory of transversals to engineering field-work, by which the operations of ranging and measuring the inaccessible parts of straight lines and circular curves may be facilitated.

### SECTION I.—*Ranging and Measurement, with the Chain and Poles alone, of inaccessible portions of a straight line.*

A long station-line in a chained survey, or a straight part of the centre-line of an intended railway, may have one or more places in its course through which, owing to the intervention of buildings, woods, precipices, water, swamps, or other obstacles, it may be difficult or impossible to chain along the line with accuracy; and some cases also, it may be impossible to range the line directly across the obstacle. Those difficulties are most readily met by the use of angular instruments; but, in the absence of such instruments, the chain and poles alone may be used; and that is the case supposed in the present paper.

Three kinds of cases may be distinguished:—First, those in which the obstacle can be seen over from side to side, and chained round, but not chained across. Secondly, those in which it can neither be seen over nor chained across, but can be chained round; and, thirdly, those in which the obstacle can be seen over, but neither chained across nor chained round.

In the simplest of these three cases, when it is possible to see over the obstacle and to chain round it, it is unnecessary to have recourse to the theory of transversals. The present paper, therefore, considers the two more difficult cases only.

In those two cases, also, there are well-known methods by ranging and measuring a straight line parallel and equal to the inaccessible line, by setting out triangles of certain figures, and in certain positions, and the like; but, in all these methods, the surveyor is tied down to particular positions for the auxiliary points and lines, which he ranges and chains. The advantage of the method of transversals is, that it leaves the surveyor at liberty to lay out his auxiliary points and lines in such positions as he may judge to be most convenient, upon consideration of the figure and nature of the ground.

Problem First.—To range and measure a straight line across an obstacle which can be chained round, but neither chained across nor seen over.

In figs. 1 and 2, Plate II., let $a$ and $b$ be two points in the chained straight line at the near side of the obstacle, about as far apart as the inaccessible distance, $b\,c$, is judged to be. Mark a station, C, so as to form a well-conditioned triangle with $a$ and $b$; prolong the lines, $b$ C and $a$ C, until two points, A and B, are reached, through which a straight line can be ranged and chained past the further side of the obstacle.

Fig. 1. represents the case in which the most convenient position for A, is at the same side of the obstacle with B and C. Fig. 2 represents the case in which the most convenient position for A, is at the opposite side from B and C. (In the latter case, the boundaries of the obstacle may be surveyed by offsets from the sides of the triangle, A B C, in which it is inclosed.)

In some cases it may be advisable to begin by choosing the stations, A and B, then to choose C, and then to range the lines, B C $a$, and A C $b$, as in fig. 1; or, A $b$ C, as in fig. 2.

All the sides of the two triangles, A B C, $a\,b$ C, are to be measured.

Then, *to find the point, c, at the intersection of the main straight line with* A B, compute the distance of that point from B by one or other of the following *formulæ*:—

If $c$ lies in A B produced, as in fig. 1—

$$Bc = \frac{AB \,.\, aB \,.\, bC}{Ca \,.\, Ab - aB \,.\, bC} \quad . \quad . \quad (1.)$$

If $c$ lies between A and B, as in fig. 2—

$$Bc = \frac{AB \,.\, aB \,.\, bC}{Ca \,.\, Ab + aB \,.\, bC} \quad . \quad . \quad (2.)$$

Next, *to find the inaccessible distance*, $b\,c$, use the following *formula*, which is applicable to both figures—

$$bc = \frac{ab \,.\, Ab \,.\, BC}{CA \,.\, aB - Ab \,.\, BC} \quad . \quad . \quad (3.)$$

The same problems may also be solved by plotting the figure, $a\,b$ C A B C $a$, and producing $a\,b$, till it cuts A B, as in fig. 2, or A B produced as in fig. 1. In a purely mathematical point of view, it is unnecessary to measure both A B and $a\,b$, as either of those lines might be calculated from the other, but both should, nevertheless, be chained, as a check on possible errors.*

PROBLEM SECOND.—To measure a straight line across an obstacle which can be seen over, but neither chained across nor chained round. This is the case of a station-line intercepted by a deep ravine or deep and rapid river. The first operation is of course to range and fix a pole at $c$ (fig. 3) in the station-line beyond the obstacle. The next is to find the distance, $b\,c$, as follows:—On the nearer side of the obstacle range the stations, A, and B, in a straight line with $c$, making the angle, $b\,c$ B, greater than 30°, and place them so that the intersecting lines, A $b$, B $a$, connecting them with two points, $a$, and $b$, in the station-line, shall form a pair of well-conditioned triangles, $a\,b$ C, A B C, as in the first problem; measure the sides of those triangles, and compute the inaccessible distance, $b\,c$, by equation, 3, already given.

As a check upon the position thus found for the point, $c$, compute also the inaccessible distance, B $c$, by means of equation, 1.

This problem is solved graphically by plotting the figure, $a\,b$ C, A B C $a$, and producing $a\,b$ and A B till they intersect in $c$.

The calculation represented by either of the *formulæ*, 1, 2, or 3, when each of the given distances is expressed by four figures, has been found to

* The following are the *formulæ* for calculating A B from $a\,b$. With the aid of a table of squares it is easy to use them.

In fig. 1—

$$AB = \sqrt{\left\{BC^2 + CA^2 - \frac{BC \,.\, CA}{bC \,.\, Ca}\left(bC^2 + Ca^2 - ab^2\right)\right\}}.$$

In fig. 2—

$$AB = \sqrt{\left\{BC^2 + CA^2 + \frac{BC \,.\, CA}{bC \,.\, Ca}\left(bC^2 + Ca^2 - ab^2\right)\right\}}.$$

To compute $a\,b$ from A B, interchange the positions of A and $a$, B and $b$, throughout the above *formulæ*.

occupy about six minutes without the aid of logarithms, and five minutes with logarithms.

The preceding methods are founded on the first proposition of Carnot's theory of transversals, which is as follows:—

*If the three sides of a triangle or their prolongations are cut by a straight transversal there will be formed between the transversal and the three angles of the triangle six segments, such that the product of three of them which have no common extremity is equal to the product of the other three.*

For example, in either of the figures, 1, 2, 3, A B C is a triangle whose sides, or their prolongations, are cut by a transversal in the points, $a$, $b$, $c$, forming segments which are related as follows:—

$$\mathrm{A}b \,.\, \mathrm{B}c \,.\, \mathrm{C}a = \mathrm{A}c \,.\, \mathrm{C}b \,.\, \mathrm{B}a.$$

The several *formulæ* already given are consequences of this equation.

Section II.—*Ranging and measuring Circular Curves, of which portions are inaccessible to the chain.*

The method now generally known and practised, of setting-out circular curves by laying off angles at the circumference with the theodolite, was, so far as the author of this paper knows, first published in a paper which he sent to the Institution of Civil Engineers, and which was read on the 14th of March, 1843. He had begun to use the method, and to teach it to others, in 1841; and as no account of it had been published by any other person, he believed himself for a time to be its only inventor; but he afterwards ascertained that it had been independently practised, though not published, by Mr. William Froude (who was at that time assistant to Mr. Gravatt), and probably also by Captain Vetch, R.E.

Before proceeding to range a circular curve by that method, it is necessary, besides the *radius* of the curve, to have the following *data*:—the position of *at least* one end of the curve, and the direction of a tangent at that end; or else, the positions of *at least* two points in the curve, and the length of the arc between them; and the more points, tangents, and arcs are previously determined, the greater will be the ease, speed, and precision with which the curve can be set-out.

The use of *transversals* in connection with setting-out curves is to facilitate the finding of those *data*, when the point of intersection of the tangents to the ends of the curve is inaccessible, and when part of the curve itself is inaccessible.

Problem Third.—Given, the positions of two straight lines whose intersection is inaccessible, and which are to be connected with each other by means of a circular curve of a given radius, $r$; it is required to find the ends of that curve, and one or more intermediate points, and the lengths of the arcs between those points.

In figs. 4 and 5, the lines to be chained on the ground are represented by full lines; those whose lengths are to be calculated only are dotted.

Let $b$ B, $c$ C be the two straight lines, meeting at the inaccessible point, A. Chain a straight line, D E, upon accessible ground, so as to connect those two tangents. The position of the *transversal*, D E, is arbitrary; but it is convenient so to place it if possible that it will cut the proposed curve in two points, as in fig. 4, which may be determined, and used as theodolite stations.

Measure the angles, $b$ D E, D E $c$, which may be denoted by D and E. Then the angle at A is

$$A = D + E - 180^\circ; \quad \ldots \quad (1.)$$

$$AD = DE \frac{\sin E}{\sin A}; \; AE = DE \frac{\sin D}{\sin A}; \quad \ldots \quad (2.)$$

$$DB = r. \text{ cotan} \frac{A}{2} - AD; \; EC = r. \text{ cotan} \frac{A}{2} - AE; \quad . \quad (3.)$$

and by laying off the distances, D B, and E C, as thus calculated, the ends of the curve B and C are marked, and it can be ranged from either of those stations. But it is often convenient to have intermediate points in the curve for theodolite stations; and of these the points, H and K, of intersection with the transversal and the point, G, midway between those, can easily be found by the following calculations; in making which a table of squares is useful.

Let F be the point on the transversal midway between H and K.

If B D = C E, the point, F, is at the middle of D E. If B D and C E are unequal, let B D be the greater, then the position of F is given by either of the two following *formulæ*—

$$DF = \frac{DE}{2} + \frac{BD^2 - CE^2}{2\,DE}; \; EF = \frac{DE}{2} - \frac{BD^2 - CE^2}{2\,DE} \quad . \; . \quad (4.)$$

The points, H, and K, are at equal distances on each side of F, given by either of the following expressions—

$$FH = FK = \sqrt{\left\{\frac{DE^2}{4} + \frac{(BD^2 - CE^2)^2}{4\,DE^2} - \frac{BD^2 + CE^2}{2}\right\}}$$

$$= \sqrt{(DF^2 + EF^2 - BD^2 - CE^2)} \quad \ldots \quad (5.)$$

The equations, 4, and 5, are deduced from the two following, which may be used in order to check the calculations, and are given in a form suitable for the use of a table of squares—

$$\left.\begin{aligned} BD^2 &= DH \,.\, DK = \frac{(DH + DK)^2 - (DK - DH)^2}{4} \\ EC^2 &= EH \,.\, EK = \frac{(EH + EK)^2 - (EH - EK)^2}{4} \end{aligned}\right\} (6.)$$

The point, G, in the curve is found by setting off the ordinate, F G, perpendicular to D E, of the following length—

$$F\,G = r - \sqrt{r^2 - F\,H^2} \quad . \quad . \quad . \quad . \qquad (7.)$$

The angles subtended at the *centre* of the curve by the several arc between the commencement, B, and the points, H, G, K, C, are as follows—

$$\left.\begin{array}{llll} \text{Angle subtended at the centre by } B\,H = 180^\circ - D - \text{arc sin } \frac{F\,H}{r} \\ \text{“} \quad \text{“} \quad \text{“} \quad B\,G = 180^\circ - D; \\ \text{“} \quad \text{“} \quad \text{“} \quad B\,K = 180^\circ - D + \text{arc sin } \frac{F\,H}{r} \\ \text{“} \quad \text{“} \quad \text{“} \quad B\,C = 180^\circ - A = 360^\circ - D - E \end{array}\right\} (8.)$$

And the length of any one of those arcs may be computed by means of the *formula*—

$$\text{Arc} = \cdot 0002909\, r \times \text{angle at centre, in minutes.} \quad . \quad . \qquad (9.)$$

The use of such computations will appear in the next problem.

Cases may occur in which obstacles upon the ground render it necessary to make one or both ends of the transversal, D E, meet the straight tangents *beyond* the ends of the curve. The whole of the *formulæ* already given continue to be applicable, with only the following modifications:— When D lies further from A than B does, as in fig. 5, D B is negative in the first of the equations, 3; that is, A D is greater than $r$. cotan $\frac{A}{2}$; and the point, H, as found by means of equation, 10, lies, not on the arc to be ranged, but on the continuation of the same circle beyond B.

When E lies further from A than C does, E C is negative in the second of the equations, 3, that is, A E is greater than $r$. cotan $\frac{A}{2}$; and the point, K, as found by means of equation, 5, lies not on the arc to be ranged, but on the continuation of the same circle beyond C.

The point, G, always lies on the arc to be ranged. The larger the ordinate, F G, is, the more carefully must it be set off at right angles to the transversal by means of an optical square, or of the theodolite.

PROBLEM FOURTH.—To set out a circular curve of a given radius, touching two given straight lines, when part of the curve is inaccessible to the chain.

If the point of intersection of the tangents is accessible, the two ends of the curve can be determined and marked by the ordinary methods, and also the middle point of the curve, unless it lies on the inaccessible ground and the length of the curve is to be computed by equation, 9.

If the point of intersection of the tangents is inaccessible, the two ends of the curve, and at least one intermediate point, are to be determined and marked by the aid of a transversal, as in Problem Third, and the lengths of the arcs bounded by those points are to be computed by the *formulæ*, 8, and 9.

A transversal may be useful even when the point of intersection of the tangents is accessible, in order to find numerous intermediate points in the curve.

Each of the points thus marked will serve either as a theodolite-station or as a station to chain from, or for both purposes; and the stakes, lying between the obstacle and the next station beyond it, are to be planted by chaining backwards from that station.

Such are a few of the applications of the theory of transversals to engineering field-work; and if engineers and surveyors generally were to turn their attention to that branch of geometry, there can be no doubt that many more such applications would be devised. Their tendency is to make the operations on the ground more simple, easy, and precise, at the cost of certain additional calculations, which, however, are by no means difficult or laborious, especially with the aid of a table of squares.

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The discussion on the preceding paper was postponed until after the reading of the following paper:—

## *On the Junction of Railway Curves at Transitions of Curvature.*

By Mr. William Froude.

It is usually admitted, and will be here assumed, that in laying the permanent way of such portions of a line as lie on a curve, the outer rail should be elevated above the inner, by a quantity proportioned directly to the curvature, or what is the same thing, inversely to the radius of the curve.

This elevation is termed the "cant;" and, if it be calculated in terms of the centrifugal force of the passing trains, on the assumption of some average velocity, V, and neglecting the other considerations which in a minor degree affect it, its value is given by the expression—

$$\textit{Cant} = \textit{gauge} \text{ of line} \times \frac{V^2}{32\,r}$$

V being the number of feet traversed by the train in one second; $r$ the number of feet in the radius of the curve; and the "gauge" and the cant being expressed in feet.

[It may be remarked in passing that as a practical rule for the use of the "plate-layers," the "cant" may be determined by stretching a line of given length, as a chord to part of the curve, and measuring the length of the offset at the middle point: the length of the chord depending on the gauge of the line and the assumed average velocity of trains, would, with a 7 feet gauge, be the space travelled by the train in 1·32 seconds; with a 4·6 gauge, the space travelled in 1·06 seconds.]

It follows from this view that a sudden change in the radius on which a curve is laid, involves a sudden change or discontinuity in the cant; though this conclusion, however obvious when stated, is apt to be disregarded, from the circumstance that mere change of radius involves no break in the tangential direction of the curve, the appearance of which, therefore, fails to suggest the discontinuity of curvature which really exists.

Thus, if there be a sudden transition from a curve on which a cant of six inches is due, to one on which a cant of only three inches is due, the outer rail, if laid accordingly, must suddenly drop three inches at the point where the change of radius occurs. And if, instead of a mere change of radius, a contrary flexure or reversal in the direction of the curve be introduced, and specially when this occurs, as it often does, where the curves are sharp, the discontinuity of cant becomes so much larger in amount that it cannot but be regarded as of serious importance.

Practically, the difficulty is usually dealt with according to methods suggested by the "rule of thumb." When a simple change of radius occurs, the maxim which governs the proceeding is "humour it in." But when the direction of the curvature is reversed, the expedient of "putting in a bit of straight," as a common tangent to both circles, is usually thrown into the bargain to "make things pleasant." And thanks to the experienced eyes and skilful hands that are usually engaged in the operation, the result obtained is, for the most part, not unsatisfactory.

It seems better, however, that the process should be governed by some definite and well-grounded rule; such as will follow from and embody, as near as may be, the same mechanical conditions as those which determine the amount of cant on the arcs which have to be connected. And it is obvious that we shall accomplish this if we arrange that circular arcs of different *radii* shall not meet each other directly, but shall be connected by an intermediate length of curve, having a graduated change of curvature; the gradations being so arranged that the curve shall have the same radius of curvature (or as it is termed osculate) with each circle, where it runs into them respectively, and in its intermediate part shall possess successively every intermediate degree of curvature. We can then at every point along the connecting curve adopt that amount of cant which is appropriate to the degree of curvature at the point.

The simplest law of gradation, and that which earliest suggests itself as the one in accordance with which we should desire the cant to vary, is that it should *vary uniformly* along the connecting curve. That is to say, that the level of the outer rail should change by a uniform gradient (so to call it) from its elevation at one point to its elevation at another. And on reflection this arrangement seems to be very nearly such as to "minimise" the mechanical difficulty which the case involves.

For this difficulty lies principally in the circumstance, that while the outer rail is changing its level, the inner and the outer rail no longer lie in the same plane, or *quasi* plane, but are "winding" with reference to each other, so that an engine or carriage resting on them becomes unequally supported cornerwise; the leading and the trailing wheels on one diagonal, having an excess of support, those on the other diagonal having a deficiency. Now, if we determine that the whole inequality of level—the whole difference of cant—is to be adjusted in a given length of line; that is, that the connecting curve shall extend over that length, we shall find that the minimum degree of "wind" will be secured, if we make it uniform throughout. For the degree of wind is in exact proportion to what was termed the gradient of the outer rail. And if this be so arranged as to be less steep and involve a less degree of wind in one part of the connecting curve, it must be more steep and involve a greater degree of wind in some other part of it, since a given amount of change in all is to be effected.

On this supposition then the problem resolves itself into that of finding and applying a curve, the curvature of which shall vary *uniformly* in terms of its length of arc. And the most complete solution of this problem will result in a curve which shall commence with an infinite radius of curvature, or a curvature = 0, and shall possess at every subsequent point, a curvature directly, or a radius of curvature inversely proportioned to the length of arc which intervenes between that point and the commencement of the curve. Having discovered the curve, we shall have merely to assign to it such dimensions, and select such a portion of it, as will best suit the circumstances of the case to which we desire to apply it.

A proper discussion of the conditions on which the problem rests, shows that the curve which satisfies them approximates very closely to the cubic parabola; or conversely, that the cubic parabola may be used so as to satisfy the conditions with a very close approximation.

The mathematical part of the discussion is better suited to an appendix, and it will accordingly be given there. It may, however, be observed as illustrating mechanically the truth of the conclusion, that the conditions on which it is based are closely analogous to those which govern the flexure of a parallel-sided beam or plank, when it is rigidly fixed at one end and strained transversely at the other. For the curvature at each point in the beam will be directly as the stress, and this again will be directly as the leverage at the point, that is to say, as the distance along the beam between this point and the point where the transverse strain is applied. And it is well known that the elastic curve thus produced is approximately the cubic parabola.

In the application of the curve to the practical operations which are the subject of the present inquiry, the approximation is so close that the curve may be used unreservedly, and, on a full examination of its properties, the application turns out to be as singularly easy as its results are elegant; whilst the properties themselves form instructive illustrations of the mathematical theory of curvilinear contact, and deserve to be studied on that account alone. But in this case also the mathematical part of the discussion will be more suitably given in the appendix, and it will be sufficient here to state the properties *seriatim*, and to point out the method in which it has been found easiest to apply them.

(1.) The cubic parabola is ordinarly described by the equation $y = m x^3$, or, in general language, the interval between the curve and the base from which it takes its departure varies as the cube of the distance from the point at which the curve commences. Thus, for instance, if we take a series of these distances, in chains, and assign ·001 chain (or one-tenth of a link), as the ordinate or interval at the end of the first chain, the intervals at the ends of the second, third, fourth chains, and so on, will be ·8, 2·7, 6·4 links, and so on; multiplying in each case the primary unit (·1 link) by the cube of the number of chains. The term, $m$, in the equation, will in fact equal ·001. It will be observed the curve forms two branches, having a contrary flexure in the origin of co-ordinates; since negative values of $x$ give also negative values of $y$.

(2). The radius of curvature, at any point in the curve within the compass which will be involved in the proposed practical application of the system, is given by the expression $r = \frac{1}{6\,m} \times \frac{1}{x}$. Thus, for instance, in the curve of the dimensions just given, when $m = {}$·001, we should have for the radius of curvature at the end of the first chain, where $x = 1$, $r = \frac{1}{6 \times \cdot 001} = 166{\cdot}67$ chains; half of that, or 83·33 chains at the end of the second chain; one third of it, or 55·55 at the end of the third chain, and so on. Fig. 1, Plate III., shows the curve, plotted on a scale of half an inch to a chain, with the circles of curvature added at the ends of the third, sixth, and ninth chains. The curve is shown in a full line, the circles of curvature in dotted lines.

(3.) For the purpose we have in view, it will be found convenient to determine the series of ordinates which measure the interval between the curve, and the circle of curvature which belongs to it at any point.

Now, it follows from the mathematical theory of curvature and contact, that whatever be the curve we deal with, the interval between it and its circle of curvature varies approximately as the cube of the distance from the point of osculation, measured along the arc; so that for a short distance on either side of this point, either the curve or the circle may be regarded as a cubic parabola, when referred to the other as a base; and this law is characteristic of what is called contact of the second order; just as it is characteristic of contact of the first order (the contact of a curve and a straight line), that the interval varies approximately as the square of the distance from the point of contact.

The peculiarity which distinguishes this general relation, as it exists in the particular curve under consideration, is that at whatever point in the curve we place its proper circle of curvature, the series of cubically growing ordinates which mark the interval between the curve and circle on either side of the point of osculation, is the same series as that which marks the interval between the curve and the base on which it is described, if we assign to these ordinates in the former case the same distances from the point of osculation, measured along the arc, as belong to them in the latter case, measured from the commencement of the curve.

Thus, in fig. 2, let P″ O P P′ be the cubic parabola, and C P C* a circle of curvature osculating it at any point, P.

Let a series of distances, 1, 2, 3, &c., be marked out along the line, O X, measured from O, and a series of equal distances along the curve, each way measured from P; then it will be found that the intervals between the curve and its circle of curvature at any one of these points, will be the same as that between the curve and the line, O X, at the corresponding point; and this proposition is a general one, and is true for any position of P, so long as it is placed within the limits of the approximation; it is equally true whether the ordinates are measured from a flat circle of curvature, osculating the curve near the origin, or from a circle of smaller radius osculating it at a proportionally greater distance.

The rationale (so to call it) of the proposition depends on the condition, that in the curve to which it refers, the curvature varies *uniformly*. For this implies that equal increments of curvature accrue to the curve throughout, in equal lengths of arc. Now, just as the absolute amount of curvature in a line at any point, is measured by the rate at which it departs from a rectilinear tangent, for short distances on either side of that point taken as the point of contact, so the variation in, or growth of its curvature at any point, is measured by the rate at which it departs from its circle of curvature on either side of that point taken as the point of osculation. If, therefore, the curvature grows uniformly, this rate of departure from the circle of curvature must be everywhere the same; and as the original tangential line, O X, is identical with the circle of curvature belonging to the vertex of the curve, where its radius is infinite, the rate of departure of the curve from this line will be identical with that of its departure from its circle of curvature at any other point; and since the series of ordinates marks the rate of departure, this series must be everywhere the same.

It should be remarked in reference to the range, within which this proposition is approximately true, that the amount of error which it involves, depends on the difference between the length of arc up to any point and the length of the corresponding portion of the base, O X; and the error will be sensible when the difference becomes considerable. But no such difference will arise within the range of curve which will be called into use by the practical application of it now proposed; and, moreover, the range of safe approximation may be extended considerably farther, if the distances to which the successive terms in the series of cubically growing ordinates are assigned, be measured not along the base line, but along the arc of the curve itself, an arrangement which it is always easy to make in dealing with a curve geometrically, though analytically it for the most part involves serious difficulties. But farther, a little consideration shows that, in dealing with the subject geometrically, it is easy, by help of the proposition under discussion, and relying only on such an extension of it as introduces no appreciable error, to lay down as far as we desire, a curve of uniformly varying curvature, and this with as close an approximation to the truth as we please.

For if, at a point in the curve at which the error has not begun to be appreciable, we describe the circle of curvature, we may continue the curve for a second such length, using the circle as the base (instead of continuing to work from the original base); we may then again describe a fresh circle of curvature and repeat the operation as often, and extend the curve length by length as far as we desire; and this is exhibited in fig. 3, the curve being shown in a full line, the circles of curvature in dotted lines.

It is not uninstructive to observe, that if we lay down a segment of such a curve on a narrow riband of paper, and draw a series of tangents to successive points in it, and then bend theriband in its own plane, so that every tangent shall become a circle of given curvature, the same throughout, our curve will simply have been converted into a segment of some other portion of its own continuation. For the curvature of that circle will have been simply added to, or deducted from, the curvature of each portion of the original segment; and the law of uniform growth, which its curvature originally possessed, will not have been thus disturbed; since the uniformity of a uniformly growing series is not affected by the addition of a given quantity (the same throughout) to each of its original terms.

(4.) Referring back to fig. 2, it is plain that since O C = P H, the point where the circle of curvature is nearest to the line, OX, is midway between the point at which the curve osculates its base at starting, and that at which it osculates the circle of curvature; and, *pari ratione*, it is plain that the point at which any two consecutive circles of curvature are nearest to one another, is midway between the points at which they respectively osculate the curve, as is exemplified in fig. 3.

(5.) Again, since in fig. 2, the ordinates, 1, 2, 3, &c., measured from the circle of curvature to the curve, are respectively equal to the ordinates similarly numbered, measured from the base, O X, to the curve, it follows that, at the middle point where the circle most nearly approaches the base, the curve will bisect this minimum interval; because the two equal ordinates numbered, 5, meet in the curve at this point, and together span the interval; and, *pari ratione*, the curve will bisect the minimum interval between any two consecutive circles of curvature.

(6.) It follows from these propositions, that at the positions where the connecting curve commences and terminates, the interval between the two circles (or the circle and the tangent) which it connects, is four times the minimum interval between them, because the former is the concluding term in the series of cubical ordinates which define the connecting curve, while the latter is double of the middle term in the same series; and since the series is cubical, the middle term must be one-eighth of the concluding term. Hence, in fig. 4, in the examples, *a*, *b*, and *c*, P Q, P′ Q′, each = 4 M N.

We can thus at once determine the dimensions and position of the curve which will duly connect any two consecutive circles, which have been so placed as to admit of the connection, that is, such as run past each other at a moderate distance without intersecting, as shown in fig. 4; and the same method of proceeding will be found to apply alike, whether the case be that of a reversal of curvatures, as in the example marked, *a*; or of a circle running into a tangent, as in the example marked, *b*; or, lastly, a change of curvature without reversal, as in the example marked, *c*.

The points, P, and P′, the beginning and the end of the connecting curve, are determined by a trial measurement, showing the position where P Q, P′ Q′ = 4 M N.

Having thus determined the position and length of the connecting curve, this length, P P′, must be divided into a series of spaces (it is convenient to make these spaces equal); and to the end of each of them must be allotted its appropriate term in a series of corresponding cubically-growing ordinates; of which the concluding term is P Q, or quadruple the minimum interval, M N. Thus, if we divide P P′ into ten equal spaces, P Q will stand for 1000, and the ordinates at the ends of spaces, 1, 2, 3, &c., will be respectively 1, 8, 27, &c. The ordinates may be set off indifferently from either circle as base, and the resulting curve will be in either case the same.

The operation has been performed in example, *f*, of fig. 5; and the delicacy of the transition from curve to curve approves itself to the eye better than any mere "rule of thumb" sweep could do; and the perception of this is heightened if as in fig. 5, we exhibit in contrast, three methods of uniting two circles of given radius at a part of contrary flexure; (1) uniting them by merely securing identity of tangential direction at the point of junction, as at *d*; (2) uniting them by the recognized *formula* of "putting in a bit of straight," as at *e*; and (3) uniting them by a segment of cubic parabola, as at *f*.

In describing the practical process by which the connecting curve is to be applied, it was stated that the circles to be connected must be so placed as to pass each other, by a moderate interval, without intersecting; and it becomes proper to inquire by what rule the magnitude of the interval is to be governed.

The answer to this question depends on the scale of the cant adopted, and on the "gradient of adjustment," as it may be termed (the gradient, namely, according to which the elevation of the outer rail is to be changed), which may be considered proper in reference to the mechanical difficulties which it involves. If these elements of the question are assumed or determined, the interval which must be allotted to the circles at the point of nearest approach, as well as the total length of the connecting curve, are readily deducible.

The deduction is given in a regular form in the appendix, and it will be sufficient briefly to notice its principle here.

It was shown in the earlier part of the paper that if rails be laid on the line of a given cubic parabola (within the limits of approximation assumed in the discussion), the cant due to the curvature will vary by a uniform gradient; and the proposition may be extended throughout to such an extension of the curve as is exhibited in fig. 3.

Now, in the equation, $y = m x^3$, on which the curve is based, the term, $m$, fixes the gradient, in relation to the scale of cant; for it shows by what length of arc a given curvature, and therefore a given cant, is arrived at. So that the value of $m$ may be made such, that the curve expressed by the equation shall correspond with the proper gradient of adjustment and the proper scale of cant.

In order, then, to determine the proper relative positions for the circles to be connected, we may, in the first place, determine the length, $PP'$ (fig. 4), in terms of the amount of cant to be lost or gained in the transition, and of the gradient of adjustment; and then, taking the value of $m$, determined as above, we at once deduce $PQ$ or $P'Q' = m\,PP'^3$, and $MN = \frac{m\,PP'^3}{4}$. The circles thus placed, in fact, occupy, with reference to each other, exactly those positions which belong to their counterpart circles of curvature, wherever these stand on the curve.

The scale of cant depends on the assumed average velocity of the passing trains, and this admits only of a rough determination. But if the very sharp curves which are adopted within the limits of stations be put out of the question, 60 feet per second (which is just above 40 miles per hour) is suggested as probably not far from the mark; near enough, at all events, to form the basis of an illustrative calculation.

The mechanical difficulty involved in the "gradient of adjustment" is the fact that, when an engine or carriage rests on the part of the line which is affected by it, the leading and trailing wheel on one diagonal are lifted, relatively to those on the other diagonal; and if the frame of an engine were rigid, and the axles unprovided with springs, one of the wheels on the diagonal of least stress would be out of contact with the rail beneath it, by the amount of rise or fall due to the gradient, within the distance between the leading and trailing wheels.

Practically, the result will appear in the shape of an excess of compression in the springs on one diagonal, and a defect of compression in those on the other—each being compared with the compression they would exhibit were the engine or carriage resting on a line, the rails of which lie in the same plane; and the question is, what degree of inequality may safely be permitted.

It is believed that the average compression of the springs on which an engine rests is about 2 inches, as due to the weight of from 5 to 7 tons on each wheel; and probably 20 feet may be taken as the extreme length of engine or carriage in this country. Now, if in this length we suppose the outer rail to rise or fall one inch, as due to alteration in cant, it follows that the springs on one diagonal will be compressed each half an inch more than those on the other diagonal, or quarter of an inch more than when in the mean condition; and this will involve a variation in pressure amounting to about one-eighth part of the average load on each wheel. Such a rate of change will involve a "gradient of adjustment" of $\frac{1}{240}$, and probably this is sufficiently within the limits of safety; yet, bearing in mind that this difference of stress comes in addition to that due to casual irregularities of packing, as well as that due to the oscillatory motion which, in a greater or less degree, every engine and carriage experiences, and under which the springs may be seen to work above one inch in many instances, it may be desirable to take the limit a little farther on the side of safety, and call G the gradient of adjustment $\frac{1}{300}$.

A tabular statement at the end of the appendix gives the requisite *data* for adapting the connecting curve generally to any scale of cant and gradient of adjustment, together with others reduced into simpler terms, on the basis of the scale now suggested; and to illustrate the application of these here given; showing in each case the reversal of a curve of 20 chains radius, founded, however, in the one on *data* appropriate to the narrow gauge; in the other to the broad; but both adopting the proposed scale of cant and gradient of adjustment.

The particulars are as follows, all dimensions being in chains. The letters of reference are those adopted in fig. 4—

$$r = +20. \quad r = -20.$$
$$V = \cdot 91.$$
$$G \text{ (gradient of adjustment)}, = \tfrac{1}{300}.$$

| | | Narrow. | Broad. |
|---|---|---|---|
| | Gauge | ·068 | ·106 |
| | (*m*) | $\frac{1}{307}$ | $\frac{1}{342}$ |
| It follows that— | | | |
| | P P′ | 3·45 | 5·37 |
| | P Q or P′Q′ | ·198 | ·485 |
| | M N | ·0495 | ·1212 |
| | Cant on each circle | ·00575 | ·00895 |

In reference to the general law which governs the value of these terms as depending on the velocity assumed as the basis for calculating cant, on the gradient of adjustment, and on the gauge, it may be observed that P P′, or the length of the connecting curve, varies directly as the square of the velocity and as the gauge, and inversely as the gradient of adjustment; while P Q or P′ Q′, and M N, which measure the interval between the circles, vary as the fourth power of the velocity and as the square of the gauge, and inversely as the square of the gradient of adjustment.

It may be observed, in conclusion, that except in those localities in which an enlargement of the interval between the circles at M N can only be obtained by a detrimental sharpening of their general curvatures, there is no reason for adhering to that value of it which depends on the limiting value of the gradient of adjustment, provided it be not made less than that. The value of M N, determined by the steepest admissible gradient of adjustment, is, in fact, rather a limit not to be transgressed, than a measure to be always adopted; and it will save the trouble of calculation if we take at pleasure such a value of it as we are sure will not be too small. A caution which is easily followed if it be borne in mind that the reversal of a curve of 20 chains radius requires only an interval of 5 links on the narrow gauge, and 12 links on the broad, with cant due to an assumed velocity of 40 miles per hour.

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## *Appendix.*

In the cubic parabola, whose equation is $y = m x^3$, $\frac{dy}{dx} = 3 m x^2$, and $\frac{d^2 y}{d x^2} = 6 m x d x$. Hence, the curve has two equal branches; the one, in which positive values of $x$ give positive values of $y$; the other, in which negative values of $x$ give negative values of $y$. Also, the curve passes through the origin of co-ordinates, running parallel to, or coincident with the axis of $x$ at that point, since $\frac{dy}{dx} = 0$, and having its radius of curvature infinite, with a contrary flexure at the same point, since $\frac{d^2 y}{d x^2} = 0$, and changes its sign.

Taking the ordinary expression for radius of curvature, $r = \frac{d s^3}{d x \,.\, d^2 y}$, it is plain that near the origin of co-ordinates, and with a tolerably extended range of approximation, we may put $ds = dx$ in applying it to our curve, and it follows that $r = \frac{1}{6mx}$. That is to say, the radius of curvature varies inversely as the value of $x$ for the point to which the radius belongs, through the range of the approximation; and, from the form of the expression out of which the conclusion grows, it is plain that the approximation will be closer, and have a greater range, if we make the equation one between $y$ and $s$, and say $y = ms^3$.

It is desired to determine the series of ordinates which express the interval between the curve and its circle of curvature, in relation to those which express the interval between the curve and the axis, O X.

Let S′O S, fig. 6, Plate II., be the arc of the cubic parabola, and R′ Q P R its circle of curvature for the point P, whose co-ordinates are $x', y'$, (P Q, P T); whence, its radius of curvature, C R, $r' = \frac{\cdot 1}{6mx'}$. If $x''$ be the value of $x$ for the centre of curvature C, $x'' = x' - r' \frac{dy}{ds}$; and, as before, putting $ds = dx$, $x'' = x' - r' \frac{dy}{dx}$, the reduction of which expression gives $x'' = \frac{x'}{2}$, whence it follows that $OQ = y'$.

Let the equation of the circle of curvature be expressed in terms of $x_1 y_1$, and let $h$ be the height, M N, of the vertex of the circle of curvature, above the axis of $x$. Then, in the first place, by the properties of the circle, $y - h : \frac{x'}{2} = \frac{x'}{2} : r'$, and putting for $r'$ its value $\frac{1}{6mx'}$, and reducing the equation, it follows that $h = \frac{y'}{4}$; and, in the next place, deducing the general relation of $x_1 y_1$ by the properties of the circle, $y_1 = h + \frac{\left(x_1 - \frac{x'}{2}\right)^2}{2r'}$, and putting $\frac{y'}{4}$ for $h$, and $\frac{1}{6mx'}$ for $r'$, and reducing, we have $y_1 = \frac{mx'^3}{4} + 3mx_1\left(x_1 - \frac{x'}{2}\right)^2$; then the interval between the curve and the circle of curvature, at any point for which the value of $x_1$ is given, will be $(y_1 - y)$, where $y = mx_1^3$; hence,

$$(y_1 - y) = \frac{mx'^3}{4} + 3mx'\left(x_1 - \frac{x'}{2}\right)^2 - mx_1^3,$$

which, reduced, gives $(y_1 - y) = m(x' - x_1)^3$.

The interpretation of which equation is, that if we take distances along the arc of the parabola, each way from any point, P, as the basis of a series of ordinates, which connect it with its circle of curvature for P, or rather which express the interval between the curve and circle, this series of ordinates will be the same as that which expresses the interval between the curve and the axis of X, taken at the same distances, measured along X from O. Observing, however, that the proposition is only true within the limits of our approximation, and that the range of its truth is extended, if the equation be in all cases considered as existing between $y$ and $s$ rather than between $y$ and $x$.

It is desired, in reference to the application of the curve discussed in the paper, to determine the value of $m$ in the equation, $y = m x^3$ or $m s^3$, which will make the curve such as to correspond with the proper gradient of adjustment, G. Observe, then, that $G = \frac{cant' - cant''}{s' - s''}$, $s'$ and $s''$ being the lengths of arc measured from the origin of co-ordinates up to the respective points, at which the radii of curvature are $r'$ and $r''$, and the corresponding values of the cant are $cant'$ and $cant''$.

The general expression for cant, is $Cant = \frac{V^2}{32\,r} \cdot gauge$, expressing all dimensions in feet; but for our purpose it is more convenient to take the chain as the unit of dimension, and, making the proper substitutions, the expression becomes, $Cant = \frac{66\,V^2}{32\,r} \times gauge$; and since $r = \frac{1}{6\,m\,s}$, or $s = \frac{1}{6\,m\,r}$, if these values be substituted in the expression for G, we have

$$G = \frac{66\,V^2 gauge}{32} \frac{\left(\frac{1}{r'} - \frac{1}{r''}\right)}{\frac{1}{6\,m}\left(\frac{1}{r'} - \frac{1}{r''}\right)}, \text{ which, converted and reduced, gives}$$

$$m = \frac{1}{12 \cdot 37} \cdot \frac{G}{V^2} gauge.$$

If, as suggested in the paper, we put $G = \frac{1}{300}$, and V = (60 ft. per sec. =) ·91 chains per sec., and observe that the narrow gauge (4 ft. 6 in.) = ·068, and the broad gauge (7 ft.) = ·106, the values of $m$ come out respectively as follows:—

Narrow. Broad.

$$m = \frac{1}{207}, \text{ or } \frac{1}{322}.$$

By help of these values of $m$, we can determine what must be the values of M N, for any two circles, in order that the relative position may be such, that, when the connecting curve is laid down according to the rules given in the paper, G (the gradient of adjustment) shall have the required value, The corresponding values of P P′ (the length of the curve), and of P Q, P′ Q′ (the reciprocally-placed terminal ordinates), fig. 4, Plate III., are determined simultaneously.

$$\text{Observe that } PP' = s' - s'', \text{ and } \therefore = \frac{1}{6\,m}\left(\frac{1}{r'} - \frac{1}{r''}\right);$$

And putting for *m* its value, and reducing the expression $\Big\}\; PP' = 2{\cdot}06\, \dfrac{V^2\, gauge}{G}\left(\dfrac{1}{r'} - \dfrac{1}{r''}\right).$

Again, P Q or P′ Q′ $= m\,(PP')^3$; and substituting for *m* and PP′, and reducing,

$$PQ \text{ or } P'Q' = \frac{1}{1{\cdot}41}\,\frac{V^4\, gauge^2}{G^2}\left(\frac{1}{r'} - \frac{1}{r''}\right)^3;$$

and

$$MN = \frac{PQ \text{ or } P'Q'}{4} \quad \frac{1}{5{\cdot}64}\,\frac{V^4\, gauge^2}{G^2}\left(\frac{1}{r'} - \frac{1}{r''}\right)^3.$$

The following tabular statement shows all the deductions above at a glance, both in their general form, and as interpreted by the assumed values of V and G, and for the narrow and broad gauges:—

| | General Expressions. | Assuming $G = \frac{1}{800}$ and $V = 0{\cdot}91$ | |
|---|---|---|---|
| | | Narrow Gauge. | Broad Gauge. |
| $m =$ | $\frac{1}{12{\cdot}37}\,\frac{G}{V^2\,\text{gauge}}$ | $\frac{1}{207}$ | $\frac{1}{322}$ |
| $PP' =$ | $206\,\frac{V^2\,\text{gauge}}{G}$ | $84{\cdot}5\left(\frac{1}{r'} - \frac{1}{r''}\right)$ | $53{\cdot}7\left(\frac{1}{r'} - \frac{1}{r''}\right)$ |
| $PQ$ or $P'Q' =$ | $\frac{1}{1{\cdot}41}\,\frac{V^4\,\text{gauge}}{G^2}\left(\frac{1}{r'} - \frac{1}{r''}\right)^3$ | $198\left(\frac{1}{r'} - \frac{1}{r''}\right)^3$ | $485\left(\frac{1}{r'} - \frac{1}{r''}\right)^3$ |
| $MN =$ | $\frac{1}{5{\cdot}64}\,\frac{V^4\,\text{gauge}^2}{G^2}\left(\frac{1}{r'} - \frac{1}{r''}\right)^3$ | $49{\cdot}5\left(\frac{1}{r'} - \frac{1}{r''}\right)^3$ | $121{\cdot}2\left(\frac{1}{r'} - \frac{1}{r''}\right)^3$ |

Professor MACQUORN RANKINE stated that he had lately received from Mr. William Gravatt, C.E., F.R.S., an account of a sort of curve, the application of which to railways had first occurred to that gentleman about thirty years ago. It was the "Harmonic Curve," or "Curve of Sines," and might be decribed as follows:—

"Let B A, C A, fig. 7, Plate II., be the two straight tangents to be connected by means of the curve, cutting each other in A. Lay out the straight line, A D E, bisecting the angle, B A C, and choose in it a point, D, for the curve to traverse. Then, B E C being the chord of the curve, we have $AE = AD \times 1{\cdot}5708 \div {\cdot}5708 = 2{\cdot}75193\ AD$; and consequently,

$$AB = AC = 2{\cdot}75193\ AD \,.\, \sec. \frac{1}{2}\, BAC;$$

which equation enables the ends of the curve, B and C, to be found. Conceive the chord, B E C, to represent a semicircle stretched out straight, and divided into 180 degrees, and lay off ordinates at right angles to it proportional to the sines of the arcs so marked upon it, and the ends of those ordinates will be points in the curve. The value of the middle or longest ordinate is

$$DE = AD \div {\cdot}5708 = 1{\cdot}75193\ AD,$$

and that of any other ordinate, such as that at the point, Y, is given by the equation—

$$y = 1{\cdot}75193\ AD \,.\, \sin \frac{90^\circ \times x}{BE};$$

where $x$ denotes B X; $y$ the ordinate X Y; and the value of B E is

$$2{\cdot}75193\ AD \,.\, \tan \frac{1}{2}\, BAC. \text{"}$$

Mr. Gravatt had invented very ingenious methods of ranging this curve in the field, which, however, appeared to involve somewhat more labour than the process of ranging circular curves and easing the curvature at their ends by Mr. Froude's method. The advantage of the curve of sines consisted in the very gradual way in which its curvature varied. The sharpest curvature was at the middle point, D, where the radius of the osculating circle was

$$1 \div \frac{d^2y}{dx^2} = DE \,.\, \tan^2 \frac{1}{2}\, BAC = 1{\cdot}75193\ AD \tan^2 \frac{1}{2}\, BAC;$$

and from that point in both directions the curvature gradually flattened—vanishing at the ends of the curve. The curvature at different points of the same curve, and consequently the "cant" of the rail, varied nearly though not exactly, as the ordinate, *y*, or perpendicular distance from the chord, B C. The form of the curve was nearly, though not exactly, that of an elastic bow of uniform cross-section, bent by means of a string, B C, connecting its ends; while Mr. Froude's curve was nearly of the form of a spring bent by a force perpendicular to one of its ends.

Prof. Macquorn Rankine, in reply to Mr. J. G. LAWRIE, said that the process exemplified in figs. 1, 2, and 3, Plate II., was designed to be used independently of the theodolite, or where that instrument was not available; but the theodolite must be used in the process exemplified in figs. 4 and 5.

Mr. J. G. LAWRIE said that in reference to figs. 1 and 2, he thought the case was capable of a simpler solution. For example, if the triangles were made equilateral, it would diminish the amount of calculation.

Prof. MACQUORN RANKINE remarked that that was what he wished to avoid. He had supposed the surveyor was in a position where, from the nature of the ground, he could not get an equilateral triangle.

Mr. LAWRIE thought that almost on any ground, if they could get a point they could get an equilateral triangle. Also, with reference to the case exemplified in figs. 4 and 5, he thought what was wanted could be attained in a simpler way than that pointed out by Prof. Rankine. Thus, having got the line, D E, there could be no difficulty in laying it down, and then, by means of the simple equation of the curve, they could get as many points in the curved part as they wished.

Prof. RANKINE said that was in effect what he had done. What he had aimed at was the simplest method of determining the points.

Mr. LAWRIE said it was desirable to have as few *formulæ* as possible.

Prof. RANKINE said that a single *formula* would not suit in this case. His plan was to reduce the labour on the ground at the expense of a few more calculations at home.

Mr. LAWRIE remarked, with reference to Mr. Froude's paper, that the accurate determination of the amonnt of cant, or elevation of the outer rail, depended upon elements comprising the calculation of the height of the centres of gravity of the different carriages composing the train, and which, in the case of all trains, both passenger and luggage, it was really impossible to obtain with that theoretical accuracy consistent with Mr. Froude's method.

Mr. W. JOHNSTONE said he did not think that any engineer could confine himself to strict *formulæ* in laying out railway lines in order to get across inaccessible places. Each engineer must fall upon plans of his own on the spot to get over the difficulties he met with. He thought, with Mr. Lawrie, that the adoption of the equilateral triangle would in many cases simplify the matter. He had no doubt the papers which had been read would be of great benefit to the younger engineers of the Institution. The greatest difficulty that he had ever had in laying out railways was in a case where two curves met at an intersecting point, and not tangentially to each other. Professor Rankine had explained one way of getting over such a difficulty; but he had met with cases in practice requiring four or five different methods. With reference to Mr. Froude's paper, he thought his plan a very excellent one; and that they were all very much indebted to Professor Rankine for his own paper, and for obtaining for them that by Mr. Froude. He thought Mr. Lawrie was quite right as regarded the position of the centre of gravity influencing the amount of cant to be given to the outer rail. He always himself took that into consideration in fixing what the cant should be, whilst, with reference to speed of the trains, a rate must be assumed according to circumstances.

Mr. Lawrie said that there was one consideration worth notice. Supposing the cant of a rail ought by theory to be six inches at one place, and four at another, though it were five inches for a short way at the latter, it was an error on the safe side.

Mr. N. Robson remarked that, in the earlier years of railway engineering, less nicety was required in laying out the curves, and in determining the amount of cant to be given to the outer rail on a curve, as on the great lines such curves were generally of large radii—such as 1 and 2 miles, considerable expense in cuttings, tunnels, or viaducts, being incurred in preference to the adoption of sharp curves. Now, however, railways had to be constructed less expensively, and they were made to wind round hills, and avoid obstacles, instead of being carried straight through them. This required curves of comparatively short radii, such as 10 or 20 chains (that is, $\frac{1}{8}$th or $\frac{1}{4}$th mile); and, in such cases, it was very necessary, not only that the curves should be set out with mathematical accuracy, but also that the cant should be carefully adjusted, and particularly at transitions of curvature, by methods, such as those proposed by Mr. Froude and Mr. Gravatt. He quite agreed with Mr. Johnstone that the papers read would be of great service, especially to the young engineers present.

Mr. Gale said it appeared to him that there was very little difference between the line B, in which the two curves were united by a bit of straight, and the line C, in which they were united by Mr. Froude's curve; and he thought the former was a sufficiently near approximation, and the one generally adopted in practice.

Mr. N. Robson agreed that the bit of straight line between the two curves would do quite well in practice.

The PRESIDENT thought, as these papers treated of such important subjects, as the cant of the rails, the connecting of different curves, the centres of gravity of trains, &c., the discussion upon them should be postponed until members had an opportunity of reading the papers. He thought they would then be better able to go into the subjects thoroughly, as they were far too important to pass over hastily.

The suggestion was unanimously agreed to, and the meeting adjourned.

The Third Meeting of the Session was held in the Philosophical Society's Hall, on Wednesday, 26th December, 1860, the President in the chair.

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The following paper was read:—

*Notes on Stirling's Air Engine.* By Mr. Patrick Stirling.

The subject of this paper may require some apology for being introduced at this time; but at a recent meeting of this Institution there was one of Mr. Ericsson's air engines exhibited and explained, without any account of its performance as to power, consumpt of fuel, &c., being given; and it has been considered that a description and statement of the performance of Stirling's air engine might be interesting to members of the Institution. The engine forming the subject of this paper was constructed by Mr. James Stirling, at the Dundee Foundry, in 1842, for the purpose of driving the machinery there, and was erected in room of the steam engine, by removing the boiler, cylinder, air-pump, and condenser, and making use of as many of the parts of the steam engine as could be made available, which will account for the apparent want of arrangement of the different parts of the engine. In this engine, which is represented in fig. 1, Plate IV., there were two strong air-tight vessels, A, A, connected by passages with the opposite ends of the working cylinder, B, in which last was a piston of the ordinary construction used in the steam engine. One of the air vessels is shown in vertical section in fig. 2. The lower ends of the air vessels were kept at a high temperature by a furnace which was common to both, and the upper ends of the vessels were kept from accumulating heat by a series of water pipes, through which there was a constant flow of water. In each of these vessels there was an air-tight vessel or plunger, shown at C, and filled with a non-conducting substance, such as pounded bricks, to prevent the radiation of heat. These plungers were slung to the opposite ends of a lever, and were capable of being moved up and down in the interior of the air vessels, and their use was to shift a body of air from the hot ends of the vessels to the cold ends alternately, and in such a manner that the quantity in one would be at the hot end whilst that in the other was at the cold end.

If we consider, then, that the movements of the air engine depend upon the well-known principle in pneumatics that air has its bulk or pressure increased when it is heated, and decreased when it is cooled, there will not be much difficulty in understanding that the movement of the plungers up and down will cause a pressure to be exerted on the opposite sides of the piston alternately; and upon the difference of pressure obtained on the opposite sides of the piston depends the power of the engine. It may be mentioned that the plungers were moved by an eccentric or crank on the crank shaft of the engine, in the same way as the slide valve of a steam engine, and at nearly the same angle to the crank.

This engine was made to work on the high-pressure principle, as it was found that engines working at the simple atmospheric pressure gave so little power in proportion to their size as to render them unfit for practical use. It was found necessary, therefore, to apply a double-acting air-pump for the purpose of increasing the density of the air in the air vessels, and the usual minimum pressure was ten atmospheres, which, on being thrown to the hot end of the air vessels, was converted into a pressure of fifteen and a half atmospheres by the addition of heat. The difference, then, in the pressure of the air when hot and cold, constituted the disposable pressure upon the piston for the purpose of producing power. When the pump had got up the full working pressure in the engine, the air, instead of being blown off, was allowed to pass into an air-tight magazine, where a sufficient quantity was kept over night to fill the engine up to full pressure at starting in the morning, and this done, the suction valves of the pump were nearly closed altogether, the leakage of the engine being so small that scarcely any addition of air was necessary.

Having explained in a general way the principles of the air engine, and by what means power was obtained from two opposing volumes of air, it will be necessary to consider the means by which economy in fuel was effected, as it must be evident to the most casual observer, that, were the whole heat that was necessary in making one stroke, taken from the hot end of the air vessel, and thrown away at the cold end, the power produced by its expansion and contraction would be more expensive than that which is gained by the use of steam. To obviate this waste of heat, Dr. Robert Stirling discovered that the air could be divested of its heat to a great extent, on its passage from the hot to the cold end of the air vessels, by dividing the air into a multitude of thin films by means of strips of thin sheet iron kept apart from each other, and presenting a great metallic surface for receiving the heat. Now, as every body by contact will give out heat to one that is colder than itself, the air, when it enters the narrow passages, must give out a portion of its heat even at the hottest end of the passages, and must continue to give out more and more heat in its progress upwards, as the temperatures of the passages diminish, until it ultimately escapes into the cold end of the vessel where there is only a small portion of heat to be extracted to reduce it to the required temperature. Thus, the temperature of the air at the hot end may be 600°, and when it arrives at the cold end it may be down to 150°, so that the whole heat constituting the difference of these two temperatures must have been left in the sheets of iron forming the narrow passages and this being the case, there is no room to doubt that the cold air, when again made to enter the narrow passages, for the purpose of being heated, immediately comes in contact with metal that is hotter than itself, and consequently has its temperature increased by so many degrees every inch it travels downwards, until, on its arrival at the hot end, it requires but a comparatively small addition to its temperature to complete the necessary pressure to move the piston. A portion of the annular space containing the thin metal sheets or strips, is shown in horizontal section in fig. 3. The thin sheets radiate from the centre of the air vessel, and fill up the space between it and the plunger. In this may be said to lie the grand principle of the air engine; and when it was applied to highly-compressed air it produced a large amount of work for the fuel consumed.

The engine under consideration had a working cylinder of 16 inches in diameter, with a stroke of 4 feet, and when tested with a friction brake it was found capable of sustaining a weight of 1,250,000 lbs. raised 1 foot per minute; or 37 horses power for a whole day, on a consumpt of 1000 lbs. of Scotch Chew coals, including the quantity necessary to get up the heat in the morning. This gives a consumpt of 2·7 lbs. per. H.P. per hour, but when the engine was not fully burdened the consumpt was considerably under 2·5 lbs. per H.P. per hour. This was considered a very fair result to be obtained eighteen years ago; and it is not unreasonable to suppose that had the construction of engines of this kind been persevered in, still greater economy in fuel would have resulted. The engine drove the works at the Dundee Foundry for several years at a very small cost for maintenance.

The whole interior of the machine being entirely free from dust and moisture, there was little or no tear and wear of the different parts, and the piston, and piston and plunger rods, did not consume a gill of oil in a week.

The principal cause of the failure of the air engine, was the difficulty experienced in getting the heat to pass through the lower ends of the air vessels, with sufficient rapidity to supply the place of the heat that was carried away by the water pipes or refrigerator at each stroke; and in order to compensate for the slowness of the conducting power of the metal, which was necessarily pretty thick, it was necessary to keep the outside of the vessel at a very high temperature, which induced irregular expansion and contraction, and incipient decay, resulting in the cracking of the metal and consequent destruction of the vessels. Notwithstanding this hitherto unsurmounted defect, the writer is of opinion that small engines upon this principle could be constructed and used with economy, in situations where the use of steam is impracticable from want of room to erect steam boilers, or from other causes. There would be less smoke emitted from the chimney; there would be no noise as with a steam boiler blowing off, or a high-pressure engine exhausting; and accidents from explosion would be entirely avoided, as, when the air vessels did give way, a very small opening made its appearance, which allowed the air to escape in a few seconds, without doing the slightest injury.

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In answer to various questions from different members, Mr. STIRLING said that as long as the plunger was moving up, the pressure kept up well, but of course it did not continue as great as at the commencement of the stroke. The plunger was over the centre before the engine piston. When the plungers were placed at half stroke, the whole was in *equilibrio*, and the engine was set in motion by moving one plunger up and the other down. The heating vessels were four feet internally in diameter, and on every side there were minute air passages formed by metal plates, arranged not quite $\frac{1}{32}$ of an inch apart. The plungers fitted as closely as they could make them, but there was no packing except about the piston and plunger rods. The packing of the plunger rods was peculiar. There was a copper tube filled with a solution of pitch and oil, fixed to the top of the plunger, and into this there dipped a pipe attached to the stuffing box, whilst a leather collar above encircles the rod, so that by no amount of pressure could any air get through. He had not heard of any air engine since this one was made which had been so successful as it. This engine could be made to work at 10, 15, or even 20 horses power, with every satisfaction. For such powers the air vessels were not so large but that they could make their bottoms comparatively thin. If these vessels were efficiently constructed, and with their bottoms thin—for example, not thicker than the upper part of the vessel's sides—the success of the engine would be complete. There was no practical difficulty, except in getting air vessels to withstand the heat. So far as the piston and cylinder were concerned, he had never seen better working machinery. The piston has worked for years without alteration, and it was observed that the sides of the cylinder were polished like mirrors. The piston packing was a pair of common cast-iron rings, such as in ordinary steam engines, and made self-springing. The piston rod was packed with a leather like that of the heating vessel, and exactly like the plunger of a Bramah press. These leathers would work for three or four months. The temperature of the cylinder varied between 120° and 150°. He could not say exactly what was the highest temperature of the air vessels, but the bottoms were kept red hot. The temperature in the cylinder was almost constant, and also in the tops of the air vessels, where it never rose above 150°, but it was not so easily measured at the bottom. It had been assumed, however, that it was 600°. In the practical working of the engine the plates in the side passages of the air vessel took up heat from any body hotter than itself, passing over it, which heat it gave out again in the reverse process. The air entered at 150°, got heated during its descent by coming in contact with gradually hotter portions of the plates, and so by the time it got near the bottom of the vessel, it had become heated to nearly 600°. The great difference between this engine and Ericsson's was this:—The engine of Mr. Ericsson, on board the steamer which attracted so much attention, was a low-pressure one, and it took in fresh air at every stroke, and as quickly threw it away. The blowing of the air through wire gauze was the first thing tried by his father to obtain economy, and for which a patent was taken out in 1816. He might state that in 1827, when his father was taking out his second patent, he met Mr. Ericsson, who asked him if he confined the air before using it; to which he answered that he did. Then Mr. Ericsson said their plans were quite different, and he would not require to oppose my father's patent. The air vessel no doubt might be made of copper, but it would not be so strong; and there was another objection, if it became red hot, it might stretch or get out of shape. No doubt platinum would be the best metal to make it of. He could not arrive at the first cost of an air engine as compared with that of a steam engine; but of course there were no boilers nor slide valves required in the air engine. Diagrams of the engine had been taken, but they could not be depended upon as absolutely perfect, from the fact that there was a great deal of friction with the indicator piston, which required to be very tight on account of the great pressure. They never got a very truthful figure on account of the friction, but the diagram was a good one so far as it went. He had not one of the diagrams now in his possession.

Mr. Milne said he had seen this air engine working, and had never seen any description of engine work more smoothly.

Mr. Stirling, in answer to an inquiry, said that he was not aware of any engine of this kind being now in operation. The engine described had worked for four years, and in that time they had to renew the air vessels once. It took very little water to keep the top part of the engine cool. They allowed it to run down into a cistern, where it cooled, and was then used over again. The temperature of the water rose to 150° or 160° on passing through the refrigerating coils.

Mr. BROWNLEE thought that in some cases one difficulty in connection with this engine would be, that it required more water than a high-pressure steam engine. He considered that it would not require a very high temperature to get a pressure of five atmospheres in this engine; for, the lowest temperature of the air being 150°, with a pressure of ten atmospheres, it would only require a temperature of 455° to get an additional pressure of five atmospheres.

Mr. STIRLING did not admit that more water was required in the air engine than in high-pressure steam engines, as they always got back the water, and so could use it again and again. With regard to the pressure obtained in this engine, he remarked that there was always a pressure of about six atmospheres at the starting, but after working a little it generally went back half an atmosphere, and at that it worked steadily. One great matter to be attended to in the construction of air engines was, to have as little vacant space as possible, anywhere about it, into which the air could be compressed. Of course, great attention was paid to have all the passages in the air vessels as small, and all the parts as close-fitting as possible, so that the air was pumped out very completely every time the plunger came down.

The PRESIDENT remarked, that still there would be a large quantity of air that would never leave the lower parts of the air vessels. The thin plates referred to as inserted in the sides of the vessel, presented great surfaces for communicating heat. They did not, he supposed, assist in the economy of heating the air directly, but they were a means by which the heat applied through the bottom of the vessel itself was more rapidly distributed to the air. They took up the heat and gave it back again to the air when returning to the lower parts of the air vessels.

Mr. STIRLING said that economy was undoubtedly the reason for the use of the plates, as they offered a large surface for picking up heat from the air when it was wanted to cool it, and which heat was given back again to the air when it was wanted to heat it, so that very little extra heat was required to raise the pressure to its maximum. These plates received their heat from the air, and not directly from the fire. They received heat in the same way as Dr. Jeffery's respirator did.

Mr. BROWNLEE said that if the regeneratory surfaces were of sufficient extent, the heat expended would be little more than that requisite to maintain the air beneath the plunger at a constant temperature while expanding, which heat would disappear while the piston was being moved by the expansive effort. But with the lower temperature at 150°, and the higher temperature at 455°, two-thirds of the heat corresponding to the expansive effort, in one heater for example, would be expended in repelling the resisting elasticity of the air on the opposite side of the piston; that is, in expelling the air from the working cylinder, and compressing it with the upper or cold end of the other heater, where it was partly further compressed, as the plunger of that heater rose. By these compressions two-thirds of the heat supplied to the expanding air was reproduced and transmitted to the cold water passing through the tubes in the upper end of the heaters.

Mr. MOFFAT said that these thin plates must be kept at a very high temperature, chiefly from the heat of the fire, and the chief loss of heat was by the refrigerator and by the power exerted upon the piston. He asked what quantity of coal was used in proportion to the air heated and the power obtained.

Mr. STIRLING said there were only about 8 or 9 cubic feet of air in the vessels altogether, but he could not say the proportion of coal to the power obtained. If this process of abstracting and giving up heat by the plates were absolutely perfect, they would throw away no heat. They had only to make up for loss of heat by radiation.

Mr. BROWNLEE did not quite agree with that; for they knew that when air was compressed it gave out heat, so that when the piston returned, and the plunger partly returned, the consequent compression of the air must raise its temperature. If they could utilize all the heat of the fuel it would require only about a ¼ lb. of coal per horse power per hour. He believed that this engine might be made to work with 1 lb. of coal per horse power per hour.

Mr. LAWRIE asked what was the cause of the total failure of Ericsson's engine. He thought it was very extraordinary, seeing the high success of Mr. Stirling's engine.

Mr. STIRLING replied that he could not say, as no *data* had been published. All that they could get were newspaper notices.

Mr. D. ROWAN said, if the economy of this engine was so great why did they not continue to work it?

Mr. STIRLING answered, because they could not get the vessels to stand any length of time. The thickness of the vessels was about four inches. Possibly thinner metal would have stood, and they would have lost less heat from the outside. The vessel was the one difficulty of the engine.

The PRESIDENT drew attention to the principle of a new furnace, whereby fire-brick was used to save the wrought-iron vessel from being burnt. He thought an air vessel might be got to stand, made on that principle.

Professor MACQUORN RANKINE said that one very great advantage Stirling's engine had over Ericsson's—although they were generally much the same in principle—was that the latter took in a fresh supply of air at every stroke, so that the air had to be taken into the engine at the atmospheric pressure. This gave a very small effective pressure in pounds upon the square inch, so that for a given power it was necessary to have very large engines. Hence, though the engines of the ship *Ericsson* were economical, they were of so vast a size, and took up so great a proportion of the capacity of the ship, that there was little room left for cargo. They propelled the ship at only seven miles an hour, and had they been capable of driving it at double that speed, they would have left no room for anything else. The advantage of Stirling's engine was that it worked with compressed air, which was used over and over again. By that device they were enabled to use air compressed to, say, twelve or twenty-four atmospheres if they wished—indeed, there was no limit except the strength of the metal; and thus a large amount of work was done by a machine occupying a small space. The air engine of Mr. Stirling was even more compact than the ordinary steam engine. He agreed with Mr. Brownlee that this was the best air engine that had been put in operation, and he thought it was a pity that it had been laid aside. Perhaps if the use of it had been persevered in, improvements might have been devised through practical experience. An attempt was made by Mr. J. R. Napier and himself to improve upon this engine, by giving the air vessels a larger heating surface. They formed the bottom of the vessel into a number of cylindrical tubes with hemispherical ends, and having a number of plungers of the same figure working in them. They made a pair of those heaters, and found them very rapid in conveying heat to the air. Air being a much worse conductor than dry steam, and very much worse than moist steam, of course it followed that a greater surface was required for the purpose of communicating a given quantity of heat to a mass of air, than either to steam or water. Mr. Napier and he succeeded in communicating heat rapidly to the air, but they never got the length of testing the efficiency of their engine, as unfortunately circumstances came in the way to prevent them. It seemed to him, however, that it would have been worth while to persevere in this device for increasing the heating surface, which was the only improvement they proposed to introduce. The engine was to have been similar in other respects to Mr. Stirling's, which they considered the best existing air engine.

Mr. Moffat asked whether any experiments had been made to determine the quantity of air heated with a given quantity of coal. In smelting furnaces, the consumption of coal for such a purpose had been ascertained in some cases to be as low as 1 lb. of coal to heat 50 lbs. of air from 60° to 600°.

Professor Rankine said that the heating of the air to that extent with 1 lb. of coal showed very great economy. In experimenting with their engine they had not measured it, but they satisfied themselves that the communication of heat to the air was almost instantaneous.

Mr. STIRLING remarked that in Stirling's engine the air was not heated altogether in the bottom of the vessel. It got considerable heat in coming down through the regeneratory plates.

Professor RANKINE said Mr. Napier and he had intended to retain the use of the regenerator.

Mr. DOWNIE asked if, in Stirling's engine, any means of protecting the bottoms of the air vessels by fire-clay or other refractory material had been tried.

Mr. STIRLING said the fire did not act directly on the vessels. The furnace was in a central space, from which the fire gases entered the two heating chambers containing the heating vessels, which chambers, with their fire-brick lining, were converted into a red-hot bath. There were slips of fire-bricks between the furnace and the chambers, so that no part of the vessels were directly exposed to the fire; all the heat was got at second hand.

Mr. DOWNIE said it occurred to him that if the bottom of the air vessel had been concave, and with fire-bricks built close up to it, it would have given better results.

Mr. STIRLING said they had tried a number of bottoms, and amongst them one having a bottle shape, which gave good results, but the hemispherical one was found to stand best.

Professor RANKINE said, that taking Mr. James Stirling's paper—which he communicated to the Institution of Civil Engineers—as a basis, he had made a calculation of the economy of that engine, which he had afterwards published. From that calculation it appeared to him that the proportion of heat transferred from the coal to the air, was not much less than the proportion transferred from the flame to the water in a good ordinary small boiler, with no special provision for economizing fuel.

Mr. BROWNLEE said one would scarcely think that so much heat could be communicated to the air, as the heating surface was so small compared with that of a steam-boiler.

Professor RANKINE replied that the heat was less, but not much less.

Mr. STIRLING said that the damper of the furnace flue was always kept nearly shut, so that the coal lay there for three hours at a time; it was very different from the draft of a steam-boiler furnace.

The PRESIDENT said that he thought there was as little loss of heat in the air engine as in the oven of a gas retort.

Mr. BARTHOLOMEW said that the heat from the furnace passed through flues round about the retorts, and by the time it reached the last flue very little of the heat was left. He considered that was owing to taking the heat from the last flue away downwards. If they took it away from the upper part there would a larger quantity of heat escape.

Mr. D. ROWAN thought there was no comparison between a gas retort and the air engine. In the gas retort it was like heating a brick, but it was different with the engine, in which the air was continually absorbing heat, and communicating it to the cold water in the refrigerator, by which it was carried away.

The PRESIDENT, on the contrary, thought it was much like a gas retort. A great quantity of heat passed into the retorts, and was absorbed in the formation of the gas.

Mr. YOUNG said, with reference to the expansion of air, he recollected that when he was attending to these matters the law was stated to be, that, if they took air at 32° it doubled its bulk by the additional heating of 480°; but Regnault had shown, a few years ago, that air at 32° had its bulk doubled by the addition of 493°; so that when they added one degree to the air, it became $\frac{1}{493}$ more under all pressures. Now, it appeared to him, with regard to the air engine, that the best way would be to work it at a very high pressure. Suppose they used air at a pressure of 20 atmospheres to begin with, and supposing they were heating it the half of 493°, it would be 247°, and by adding that heat they made two volumes of air into three, that is, they would get 10 atmospheres in reality, and get it by only 247° of change of temperature. He thought metals could be got to last a long time at that temperature. The air would be then of about 310° at its maximum, and he supposed the metals would stand pretty well up to 400°. He thought that would be a likely way of getting great power. There was little doubt, in his mind, that the air engine was the real instrument, and he had often wondered it had not come into use; and, from what he had heard that night, he had great hopes for it. It got quit of the great loss in the steam engine—the latent heat.

Mr. STIRLING said they always found the engine worked the better the higher the pressure was raised. It unfortunately happened, however, that when they came to increase the pressure, they largely increased the difficulty of making good joints and good tight castings. If they increased the pressure, the ordinary fitting joints would permit air to blow out. They had great difficulty in making them tight up to 10 and 20 atmospheres, and even supposing they got over that difficulty, then the piston-rod packing might get troublesome. These were the difficulties they had had to contend with—and also the probability of perhaps dropping off the bottom of the air vessel. There was no danger of explosion. He had been present on two occasions when the air vessel cracked, but the only inconvenience he felt was getting a little black smoke thrown in his face. The air all escaped in about two seconds. It occurred in the vessels with bottle-shaped bottoms. The vessels used were made of cast-iron, with a little copper in it, which greatly increased their strength.

The PRESIDENT said he had intentionally allowed this subject to be fully discussed, with the view of having the matter clearly brought before them. It was quite evident that many engineers besides Mr. Young—if he would permit him to call him an engineer—did not understand why this air engine was not in use. The great interest in this subject in the mind of engineers, made it quite excusable for them to have occupied the whole evening in discussing it. It might lead them to think a little more of the air engine, and how to get over those difficulties respecting it which Mr. Stirling had so clearly pointed out. It was satisfactory to know that the difficulties were not in the principle or contrivance of the engine itself, but in the structure and nature of the materials of which they had to make the engine. The chief difficulty seemed to be a mechanical one. Now, in these days engineers scarcely allowed that mechanical difficulties existed, and so he did not fear but they would overcome this one, if they laid their minds to it. They might, by immensely increasing the pressures, greatly increase the power of the air engine, without requiring a high temperature. In that way they escaped one difficulty, but then they ran into another connected with the packing and the joints. A while ago they used to think a great deal of working locomotives at a pressure of 50 lbs.; but at present they were worked at 150 and 200, and the joints were now made as good as ever. They might, therefore, make some such improvement in the air engine. He proposed a vote of thanks to Mr. Stirling for bringing this matter before them.

The vote was unanimously given, and the meeting separated.

THE FOURTH MEETING of the Session was held in the Philosophical Society's Hall, on Wednesday, 23d January, 1861—the PRESIDENT in the chair.

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The adjourned discussion on

*Railway Curves* *

was commenced by Professor RANKINE, who communicated the following additional particulars from Mr. William Gravatt, C.E.,F.R.S., respecting the application of the *Curve of Sines*:—

"As from the construction of the curve, $y = p$ sin. $x$, and $dx : dy = 1 : p$ cos. $x$, $\therefore d^2y = -p$ sin. $x\,dx^2$; whence, radius of curvature, $r = \frac{(1 + p^2 \text{ cos. }^2x)^{\frac{3}{2}}}{p \text{ sin. } x}, = \frac{(1 + p^2 \text{ cos. }^2x)^{\frac{3}{2}}}{y}$. When $x = 0$, $r = \infty$, and when $x = \frac{1}{2}\pi$, $r = \frac{1}{p}$.

"In the diagram, fig. 3, Plate V., let B A, C A be two tangents, and let D be some point fixed by circumstances. Let the angle, $\alpha$, and the distance, A D $= a$, be determined from the actual survey; and let A E $= h$. Then when $x = 0$, cos. $x = 1$, $\therefore dx_0 : dy_0 = 1 : p = b : h$, $\therefore p =$ tan. $\beta$, $\left(\beta = 90° - \frac{1}{2}\alpha\right)$, or $p =$ cotan. $\frac{\alpha}{2}$. Now, if $b$ be put $= \frac{1}{2}\pi$, we have $a : h = \left(\frac{1}{2}\pi - 1\right)p : \frac{1}{2}\pi\, p$, $\therefore h = 2{\cdot}75193\, a$, $b = h$ tan. $\frac{1}{2}\alpha$, $c = h$ sec. $\frac{1}{2}\alpha$. Call $b$, for convenience, 90 degrees, and also call $\Delta x$, $\frac{1}{q}$th of 90 degrees; enter the tables with the so-called $\Delta x$, $2\Delta x$, $3\Delta x$, ... $q\Delta x$, and take out the sines; then $\left\{\text{sin. }(x + \Delta x) - \text{sin. } x\right\} p = \Delta y$. Now, $\Delta y : \Delta x = \Delta y : \frac{\pi}{2q}$ tan. $\theta : 1$; or log. tan. $\theta =$ log. $\Delta y +$ log. $2q -$ log. $\pi$. Enter the tables with log. tan. $\theta$, and take out $\theta$, and log. sec. $\theta$. Then the log. of the chord of the curve in chains $=$ log. sec. $\theta +$ log. $\Delta x$; $\Delta x$ being taken in chains, as being $\frac{b}{q}$ chains, or log. $\Delta x =$ log. $b -$ log. $q$.

* See Report of Meeting on 28th November, 1860.

"Having divided the curve into as many or as few parts as convenient, and having a little table of the values of $\theta_{,}$ $\theta_{,,}$ $\theta_{,,,}$, &c., and also of the corresponding chords, we may set up the theodolite at B, with the verniers arranged so as to take up the angle, $\theta_{,}$, and then run out the first chord. At the end of that chord again set up the theodolite to take in the angle, $\theta_{,,}$, run out the second chord, and so on. As to the cant of the rails, we have the exact radius of curvature at as many points as we please, but it will generally be sufficient to make the cant vary directly as the ordinate, having previously determined it, for any one speed we may fix upon, for the minimum radius, $r = \frac{a}{\cdot 5708\, p^2} = \frac{a}{\cdot 5708\, (\text{sec.}^2\, \beta - 1)}$. If the curve were an arc of a circle we should have $\text{sec.}\, \beta - 1 : 1 = a : r$, or $r = \frac{a}{\text{sec.}\, \beta - 1}$, so that our curve is, at a minimum, sharper than a circular arc; but a bare circular arc certainly ought not to be used in any case, although it is every-day practice. But who knows how many accidents have arisen from that practice?

"As for a reverse curve, there is evidently no more difficulty, or, at any rate, but little more difficulty, in setting it out than in setting out a curve without contrary flexure. You must in both cases have a *really good skeleton survey taken*, and laid down by the method of "latitude and departure," or by what is sometimes called the "back-angle" method. My theodolites are all on transit arms, with a hole completely through the main vertical axis, to which there is sometimes attached a small object glass, cross wires, and an eye-piece, for the purpose of setting the centre of the instrument accurately over any point. When not fitted up with a small vertical telescope, I use a soft, rather stout copper wire, sharpened to a point at the lower extremity, and bent into a serpentine figure: the instrument being set upon a steady *untwistable* stool, with a large opening through the top, and over that a kind of false top that may be slid about so as to set the point of the copper wire nicely over a centre-punch mark in a nail driven into a rather substantial oak-stake, which should be marked with a number or with a letter. Now, as the copper wire is soft, and turns altogether with the divided circle of the instrument, there is no difficulty in bending it a little this way or that, and so setting the theodolite over a given point with a degree of accuracy not to be approached by the ordinary plumb-bob method. The limb of the instrument is divided into degrees and sixths of a degree, or ten-minute spaces, and the verniers read minutes and *tenths of minutes* (not seconds)—(4½ inches is sufficient for such reading). The liability of error in working with an instrument so divided is very much less than when divided in the ordinary manner.

The divisions are, and always should be, upon gold. It is false economy to divide upon silver. What I now send you is from what I invented, or think I invented, in 1828–29."

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The Secretary then read the following remarks by Mr. FROUDE in reply to observations made at the former discussion of the subject:—

"I must declare myself unable to perceive on what grounds it is said that the amount of cant should depend on the height of the centre of gravity of the engine or carriage.

"So far as the cant is to supply a correction of the effect of centrifugal force on the train, it should be such that the plane of the rails will be at right angles to the direction of a plumb-line attached to any point on the train; and if we disregard the difference of curvature of the inner and outer rail, the direction of the plumb-line will be the same whatever be the level of the point of suspension, depending solely on the radius of the curve and the velocity of the train.

"And if the length of the plumb-line be equal to the gauge of the railway, the cant ought to be equal to the distance by which the plumb-bob deviates from a true vertical line drawn through the point of suspension. The *formula* given in the paper is constructed on this principle.

"Since, however, the velocity with which a given curve is traversed by different trains is not the same, it must be admitted that cant can furnish only an approximate remedy for centrifugal force; for the cant which suits an express train, travelling at fifty miles per hour, is four times as great as that which would suit a luggage train travelling the same curve at twenty-five miles per hour.

"It should be observed, however, that centrifugal force is not the only force which tends to cause a pressure against the outer rail.

"In the first place, the greater length of the outer rail, operating on wheels keyed to their axles, produces, or tends to produce on the carriage an effect analogous to that of backing water on one side of a rowing boat and pulling on the other. It is true that the conical figure of the wheels tends to furnish a rough correction of this operation; but any one who has watched the real motions of a running train must feel that the correction is necessarily very rough indeed, and that (in virtue of another cause to be presently mentioned) it operates even at the best very unequally on the leading and trailing wheels of each engine or carriage.

"This second collateral cause of pressure on the outer rail exists in the direction of the planes of the several wheels of a given carriage, which cannot *all* of them lie tangentially to the direction of the rails, unless the carriage be vertebrated, and bent so as to make all its axles radiate to the centre of the circle.

"If we suppose that at any moment the flanges of the outer leading wheel and outer trailing wheel are both in contact with the rail, it is obvious that the planes of the wheels will have such directions respectively, with relation to the rail, that the flange of the leading wheel will continue to push outwards against the rail, while that of the trailing wheel will deviate inwards from the rail—each in fact trying to follow the direction of the *chord* which connects the points of the curve on which the wheels respectively rest. The trailing wheels will thus, in fact, deviate inwards from the outer rail, and will give a more biting angle of direction to the leading wheels. The tendency to this inward direction of the trailing wheels will not cease until their plane has become tangential to the curve; and if the curve be a sharp one, the amount of inward deviation will be such as to bring the flange of the opposite trailing wheel into contact with the inner rail, so as to reverse the corrective effect assumed to lie in the conical figure of the wheels, and thus neutralize the advantage derived from its more proper action on the leading wheels. The result on the whole is such, that if we watch the consecutive carriages of a train running on a sharp curve (say of ten or fifteen chains radius) we shall observe that (to use a rather nautical phraseology) each carriage in turn appears to be 'luffing up' against the outer rail, while its trailing wheels are 'dropping to leeward' against the inner rail. And I am inclined to think that, especially when the velocity of the train is small, the bite of the flanges of the leading wheels against the outer rail, due to this cause, is very considerable, and demands a not inconsiderable amount of cant.

"I must, however, admit that I believe, not only that the corrective effect of cant is but at best approximate, but that the object to be guarded against by its use, is rather the waste of power due to friction than the danger that for want of it carriages or engines will mount the outer rail. At least, unless the curve be so sharp that the *cutting* edge of the flange is enabled to bite against the side of the rail with a clear, *shearing* action, it seems to me plain that the tendency to mount the outer rail derivable from the forces called into play (even at the very highest velocities ever attained by trains) is really insignificant; or, rather, I do not see how on any known principle the tendency can be shown to be of dangerous magnitude. Take, for example, the case of a curve of fifteen chains radius, and a velocity of forty miles per hour; in this case the centrifugal force is barely 1·8th of the weight in motion at the centre of gravity of the carriage. And granting that the whole of this pressure would have to be resisted by the flange of the leading wheel (if the line were without cant) while the insistent weight on that wheel might happen not to exceed, say, 1-8th of the whole weight of the carriage, it would follow that the lateral pressure on the flange would be only equal to the insistent weight on the wheel; while if the coefficient be taken at 1-10th, which, under the circumstances, is an ample allowance, it would follow that the friction due to the lateral pressure could not, even in so extreme a case, enable the wheel to exert, in an attempt to rise, more than 1-10th of the weight which actually presses it downwards.

"But though it seems plain to me that it is not essential on the score of safety that the cant on any curve should be correctly proportioned to the centrifugal force, it does seem important on the score of safety that its proportion should not undergo irregular variations, such as must occur if either the cant or the curvature is changed, one irrespectively of the other.

"For if the cant be incorrectly proportioned, assuming only the proportion to be uniform, it will only follow that the springs on one side or on the other of the carriage will experience a corresponding excess of compression; and so long as this is invariable, no harm will ensue.

"If, however, the proportion undergoes rapid changes, the compression of the springs will be changed also, and will thus tend to set up an oscillation. (Indeed, it would be possible to assign such a series of changes in curvature with a uniform cant—by adapting their recurrence to the natural period of oscillation of a given carriage—as to develope oscillations of the most formidable magnitude.) It is to correct this tendency that (as it seems to me) every change of curvature should receive, as near as may be, a corresponding change of cant; and in suggesting the arrangement described in the paper, I do not contend for the pursuit of unattainable niceties, but I have endeavoured to suggest an easy method of approaching with fair practical accuracy a result which is theoretically correct. For to point out how the cant and the curvature may be made to undergo properly corresponding variations, involves no greater pretence of refinement than to point out how the cant should be kept constant while the curvature is constant.

"It should be observed that it is not only at reversals of curvature that a proper method of effecting this variation is required. There is as much cant to be eliminated in changing from a fifteen chain radius to a forty chain radius (both having their curvature in the same direction) as there is in a reversal of curvature, where the radii are both forty chains; or, again, as in dropping from a twenty chain radius to a tangent: and if the change is to be correctly effected, there must be in each case the same length of connecting curve and the same gradient of adjustment.

"The careful diagram furnished by Mr. Bell, Plate V., figs. 1 and 2, which shows very accurately an existing reversal of sharp curvature, traversed daily by trains at from thirty to forty miles per hour, independently of its value as a full record of an existing instructive fact, is interesting in relation to the method I have recommended. It proves, indeed, that an exact adherence to that method is not necessary; but it also shows how far in the practical handling of the curve the workmen in charge of the line have felt their way towards the method—deviating into it by mechanical instinct from the original type of two circles with "a bit of straight" between them. But while they have arrived at this result roughly, and by a painstaking use of the rule of thumb, I think it clear that a better result would have been attained, and with less trouble, had the method which is recommended in my paper been adopted at the outset.

"The cant adopted, based on the practical rule of adjusting it until the flanges no longer mark the sides of the rails, will be found to accord closely with that given by the *formulæ* in the paper, while the general gradient of adjustment will be found to be just that which seemed to me, and I mentioned as about the steepest that could be safely ventured on."

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The Secretary then read the following:—

*Description of Diagram, showing a Reversal of Curvature on the South Devon Railway.* By Mr. William Bell.

"The curves in this case being of small radii, and with a somewhat small amount of separation between their prolongations, were considered to offer a good example of a sharp reversing point on the broad gauge, and one which has worked with safety for many years. The curve has been taken in the state in which it is kept by the men working on the line, and minutely surveyed—offsets or ordinates being taken every ten feet along a straight base line, and the cant of the rails also observed every ten feet, for some distance on each side of the reversing point.

"The radii of curvature in chains, marked in figures on the plan, Plate V., fig. 1 (*a* and *b*), were derived by calculation from the second differences of the ordinates.

"The end portions of the central line, A B—B C, on the plan, are circles, coinciding, as nearly as they could be drawn, with the actual curves up to the points, D E, of maximum cant. The part of the line between these points is a portion of a cubic parabola, drawn as explained in Mr. Froude's paper. The centres of the black circle being points in the actual curve, and these circles being drawn of one foot diameter, the eye can readily appreciate the amount of divergence between the actual curve and the cubic parabola.

"The diagram (fig. 2 *a* and *b*) of the cant of the rails shows a very good approach to regularity, in what Mr. Froude has called the 'gradient of adjustment.' By comparing the ordinates of this diagram with the radii of curvature marked on the plan, fig. 1, to which they ought to be inversely proportional, it will be found, that although upon the whole length, the average cant is very nearly the same as on the other running portions of the line, yet there are considerable differences at particular points between the actual amounts of cant and the amounts determined from the curvatures; and these differences are more than can be accounted for by errors of observation. It would thus seem that, to some extent, deviation from the correct amount of cant may exist with impunity. At the same time there can be no question but that the amount of cant should be proportional to the amount of curvature, and *vice versâ;* for it has been found that upon different curves, when the amount of cant is determined praccally, by giving to the outer rail such an elevation that both rails wear fairly and evenly, and without getting rubbed sideways, the amount of cant is then (on the broad gauge) equal to the amount by which the curve is hollow upon a length of from 66 to 70 feet, thus corresponding to a train velocity of from 34 to 36 miles per hour."

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Professor RANKINE remarked, with respect to the position of the centre of gravity of the carriages of a train above the rails, that it was perfectly correct to say that that had no influence upon the centrifugal force; but there were certain cases in which it should be considered in the adjustment of cant, which, however, did not often occur. The cases he referred to were where cylindrical (not conical) wheels were used. His father and he had used such wheels on a horse railway, and they found it necessary to give more cant than corresponded to the centrifugal force, because the wheels had no taper, and consequently no deviation to counteract the necessity of making the outer wheels slide upon the rails. The plate layers gradually attained the requisite amount of cant by rule of thumb. On studying the results they thought that, besides balancing the centrifugal force, they had to do something more—they had to make the outer wheel to slide over a longer distance than the inner one. Now, in order to do that, it was necessary to make the resistance to the motion of the carriage less at the outer than the inner rail; and additional cant did that, by throwing the centre of gravity inwards. They had found a *formula* for this portion of the cant. He had published the *formula*, with the experiments made at the time. That was a case in which the elevation of the centre of gravity was a main thing to be considered; but when they used

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coned or tapered wheels, it was unnecessary to attend to it in that way. They found the friction generally of cylindrical wheels much less than that of tapered wheels, which he ascribed to their running upon straight lines without oscillation. The friction, which was constant at all speeds up to 12 miles an hour, was only 4½ lbs. per ton, or 1-500th of the weight. Now, the lowest friction with tapered wheels was 6 lbs. per ton, or a third part more than that of cylindrical wheels. He thought that was principally owing to the absence of oscillation of cylindrical wheels on a straight line. There was another cause, also, to be found in the extreme smoothness of the axles, produced by end play. In answer to questions, Prof. Rankine said that in the case he had cited the higher the centre of gravity the less cant was required, as the carriage was thrown over to the inner side of the curve. He had made experiments to determine the additional resistance due to curvature, with cylindrical wheels, and he found that a curve of a mile radius increased the resistance by 1·4 lb. per ton, and the increase was inversely as the radius of the curvature. There had been some experiments made in America with tapered wheels, and they gave a less amount of additional friction on curves.

Mr. Lawrie said he still disagreed with Mr. Froude as to the height of the centre of gravity having nothing to do with the cant of the rails. If a line were drawn from the centre of gravity to the outer rail, it would be seen that, as the elevation of the centre of gravity was varied, the angle of that line with the vertical became changed.* This angle was an

* The manner in which the height of the centre of gravity affects the cant is this:—If the cant be made proportional inversely to the radius of curvature and the centre of gravity, to put an extreme case, unusually high, it will, for a high speed, be brought within the inner rail, where, if any diminution of speed takes place, the train will fall over. The true measure of cant is that in which the train will have an equal safety to avoid tumbling inwards with a minimum speed, and tumbling outwards with a maximum speed. It follows also that, consistently with safe working, the highest practicable speed in a curve depends both on the curvature and the height of the centre of gravity. These are the strict limits, but this class of question does not appear one to which the analysis—of which Mr. Froude is so much master—can be advantageously applied.—J. G. Lawrie, 1st Feb., 1861.

Reply by Mr. Froude:—

In reference to Mr. Lawrie's remarks of the 1st inst., I need hardly express my assent to his proposition that a carriage, if placed as described by him, will tumble over; and assuming—what, however, I do not admit to be in any practical sense true—that the danger of upsetting is that against which it is intended to guard, by canting the rails, I should join him in stating that the "true measure of cant is that in which the train will have an equal safety to avoid tumbling inwards with a minimum speed, and tumbling outwards with a maximum speed."

But, bearing in mind what I have already pointed out to be the relation between the direction of a plumb-line attached to a carriage travelling round a curve, and the degree important element in the determination of the cant. There were some curious considerations connected with the conical form of the wheels. It was a prevalent belief that it assisted the carriage round the curve. It could only do so on condition that the axles were nearer together on the inner side of the curve. By merely making them conical, the action was scarcely altered, unless the axles altered their angles. Another element in the determination of the cant of the rails had not been taken into account by the author of the paper. Everybody knew that the moment a train entered a curve the speed slackened until a balance was attained between the motive force and the increased frictional resistance; so that in point of fact the cant should vary, not only with the curvature, but with the difference of speed, if it be wished to come to accurate results.

The SECRETARY explained that the "angle" Mr. Froude referred to was different from that on which Mr. Lawrie considered the cant to

of cant due to that curvature and that velocity (the cant, namely, which will exactly neutralise the outward tendency of the centrifugal force), it will be found that if the proper medium velocity be assumed as the basis of the calculation in using the *formula* given by me, the condition of safety above laid down by Mr. Lawrie will exactly hold good; and this, quite irrespective of the height of the centre of gravity, so long as we suppose (and it is the only average which can be assumed) that its position is somewhere in the vertical central plane of the carriage

The proper medium velocity is obviously that, under the action of which the plumb-line will bisect the angle between the positions assumed by it under the action of the maximum and minimum velocities respectively; and the corresponding cant will bring the rails into a line at right angles with this medium position. Now, whatever be the height of the centre of gravity, if we attach the plumb-line to it, and try the result at the maximum velocity, and again at the minimum velocity, it is obvious that, since the central plane of the carriage bisects the angle between the extreme positions of the plumb-line, and since the line from rail to rail is at right angles to this, the plumb-line, when the experiment is tried with the maximum velocity, will point exactly as near the outer rail as it does to the inner rail when the minimum velocity is adopted; and if the centre of gravity is so high that, at the maximum velocity, the line falls just beyond the outer rail, so that the carriage will fall outwards, it follows that, with the minimum velocity, the line will pass just beyond the inner rail, and the carriage will fall inwards. Practically, indeed, such an extreme position need not be contemplated; but in whatever degree it is approached, and whatever risk of upsetting is thus nominally called into existence, the risk will be equally divided between the inward and the outward tendencies when the cant is laid in accordance with the rule which I have given, and which thus, though quite independent of the height of the centre of gravity, provides the best security against the ill effects of its extreme elevation. I will only add, I do not in any sense claim the rule as specially my own. In substance, at least, it is the one universally accepted, as far as my experience enables me to judge; and it is only in reference to such practical considerations as those suggested by Professor Rankine—considerations wholly irrespective of centrifugal force—that I have ever heard any deviations from it suggested.—W. FROUDE, 7th Feb., 1861.

depend: it was the inclination which a plumb-line assumed in consequence of the speed and degree of curvature, and which continued the same whether the plumb-line was suspended from a high or low centre of gravity, or from any other point of the carriage.

Mr. W. Johnstone remarked that conical wheels were now seldom used. If any taper at all was given to the wheels, it was extremely slight.

The President, in bringing the discussion to a close, remarked that if they had had more time they might have enlarged the discussion on the different subjects these papers had brought before them. They would, however, require to content themselves at present by tendering the thanks of the Institution to Mr. Froude, Mr. Gravatt, and Dr. Rankine, the authors of the papers; and to Mr. Bell, for his interesting diagram and description.

The votes of thanks being passed, the following paper was read:—

## *On Pumps.* By Mr. George Simpson.

In submitting the following observations on pumps, the writer's object has been simply to glance at the system of pumping as practically developed, more particularly in connection with mines. Exact mathematical *data*, bearing on the dynamical effect necessary for the elevation or transposition of liquids, cannot be obtained on account of friction, which invariably accompanies motion under such circumstances, so that an approximation to the force absorbed by passive resistance is all that can be obtained. In the writer's opinion, the periphery of a pump-bucket or piston, however well constructed, when moving in contact with the working barrel, experiences about one half of the friction, and the other half arises from the motion of the water through the suction pipe, working barrel, ascension pipe, and accompanying valves. Of course, the efficiency of a pump altogether depends on the accuracy of the working barrel, on the nature and construction of the bucket or piston and valves, and on the free and direct course of the water in the suction and ascension pipes. Assuming these points to have been properly attended to, then to the force requisite to support a piston, sustaining a column of water, there must be added about 1-12th to produce motion or to move the piston. At the ordinary velocity of mine pumps, of about three feet per second, the augmentation must be about 1-6th. This velocity is, however, much under the rate at which water will pass through suction pipes and valves of ordinary construction, when the top of the working barrel is kept more than two feet under the height to which a column of water rises in empty pipes by the weight of the atmosphere. It is almost unnecessary to state that long-stroke pumps of a given velocity are taking the place of short-stroke ones, since it must be apparent that as often as water is made stationary in a pump, a corresponding increase of inertia follows; whilst, with the long-stroke, the valves and pipes are less subject to be put out of order.

In the pump now proposed, buckets, which are highly objectionable from the great expense of tear and wear and loss of time, are not adopted, but a ram or plunger, A, fig. 1, Plate VI., has been substituted; whilst, in order to avoid the necessity of having pump-rods of greater weight than the pressure due to the height of water against one-half the area of the whole piston or plunger, and also to fully employ the engine on both inward and outward strokes, the writer has hollowed out the ram, A, to the extent of one-half of its area, so that on the rods being depressed, one-half the contents of the working barrel is displaced by the solid part of the ram, whilst, on the ram being raised, the other half is carried up by the lifting action. In the modification shown in fig. 1, the rod, B (which may be constructed of malleable iron, so as to occupy less room), is made hollow or tubular, to serve as the uptake or discharge-pipe. And in fig. 2, the proposed plunger is represented as it may be applied to pumps now in operation, and as it is, perhaps, better adapted for a permanent fitting.

In the modification shown in fig. 1, instead of the ordinary clack-valve in the uptake or discharge-pipe, there is a kind of equilibrium valve, C, of a cylindrical form, but which has its seat on a flat, annular surface. Doors, D, are provided for access to this valve, which is made in two halves to get it into its place. In the modification shown in fig. 2, a different uptake valve is used. Openings communicating with the discharge-pipe, E, are formed in the upper part of the plunger, A, and these are closed at the proper times by an internal plug, F, the seat for this plug or valve being a ring just below the openings in the plunger.

In the present system of arranging the valves in the suction pipe, the valve seat is generally a vertical extension of the working barrel, and when so placed, repairs can only be done to it upon the ascension pipe being emptied of its whole contents. To obviate this inconvenience and loss of time, the arrangement of valves, G, shown in fig. 1, is proposed, whereby one valve can always be in use when the other is under repair, so that the pump can continue in operation. The valves in present use (except those with the "double beat") for this purpose are made very heavy, in order to resist the pressure of the superincumbent column of water; and at each stroke the water between the valve and its seat is a loss. The valve, G, shown in fig. 1, are made of less specific gravity than the water, by means of floats, and are expected to remedy this defect.

In making a comparison of the new pump with the most approved pumps at present in use for draining mines, the writer finds that for a lift of fifty fathoms, an ordinary pump, with working barrel, containing two cwt. of water per vertical foot, and one ton stroke, and with corresponding rod, suction, and ascension pipes and valves, costs £1200. The arrangement shown in fig. 1, including the suction pipe, working barrel, pumps and valves, adequate to lift as much water the same height, and in the same time, with less power, will cost about one half. The pumping gearing shown in fig. 1 is for a 10-feet stroke, and may be worked by a horizontal steam-engine applied directly to the crank.

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In the discussion which followed—

Mr. Ferguson thought the President had spoken to him about a similar arrangement of pump some two years ago.

Mr. NEIL ROBSON said the hollow pump-rod of wrought-iron appeared to be the chief novelty in this pump. The obtaining of a double action by means of a solid plunger was in practice already; but he had never seen the hollow plunger, as now described by Mr. Simpson, in operation anywhere, although perhaps that idea might not be quite new. They knew that the rods at present used were of timber, in lengths, connected by wrought-iron, and that they were very expensive, massive, and of great weight for large pumps, such as those at Crofthead pit, where, he believed, the rods were some 14 inches square, working a solid plunger 27 inches in diameter. He understood Mr. Simpson intended to do away with wooden rods altogether, and to use a kind of malleable iron tube, to act both as rod and discharge pipe. He would like to know what was the weight and thickness of the metal, for, say a 300-feet column, and whether any extra power would be required to move such a rod; also, how it was to be kept watertight and to be repaired.

Mr. SIMPSON said the tube would be about three-eighths of an inch in thickness at the lower part, but a good deal lighter than that at the top. The weight for a column 300 feet high, of the diameter mentioned in the paper, would be about 12 tons, not including the plunger.

Mr. FERGUSON thought they could not get a better thing. He was perfectly satisfied that the wrought-iron tube would do, as he had already made calculations regarding it.

Professor RANKINE said it seemed to him that there was a good deal of improvement in this pump. In it there was constantly a column of water rising, and thereby the advantage of a double-action pump, in continuity of action, and freedom from shocks, was obtained with less expense. It seemed to him that there must be economy of material and expense in this pump, because the same thing acted as a plunger-rod and as a water-pipe.

In answer to questions by Mr. Robson, Mr. SIMPSON said he supposed that a square pipe would do as well as a circular one for the ascending tube. He did not see any objection to making it rectangular, except that it would involve a little more friction and a little more material.

The PRESIDENT said that, instead of boring the barrel, it would be better to turn the plunger, and make it work through a stuffing-box.

Mr. D. MORE said there was one benefit in using a stuffing-box at the top, that it did not waste so soon, and was more easily kept in order.

The PRESIDENT said the principle upon which this pump was made, was certainly quite novel, and was a favourite scheme of his own, and he did not see why it should not have been in use before this time. For his own part he saw no difficulty in its adoption, as he considered it a very excellent and economical plan. In pit pumps it was well known that the rods constituted a great part of the weight; and it occurred to him that a light tube of very good iron might well be substituted for those at present in use; and he felt inclined to guarantee its success—its well-working and economy. Of course it would be wise to try it in a small pit first.

Mr. D. MORE thought the weight of the column of water would prevent the pump-rod from being any lighter. They would have to overcome the weight, although, of course, the pump would have other advantages.

The PRESIDENT said, of course in all lifting pumps, the water was a dead lift, just as if it were in a bucket, except that its friction in the pipes had to be overcome.

Professor RANKINE said they must lift the water, or something as heavy.

Mr. ALEXANDER asked, whether it would not be necessary to have the pipes of large diameter, as in working in a pit of considerable depth they would be apt to buckle or bend. He was of opinion that in practice it would be difficult to maintain the joints, and that a column of pumps, say of 27 inches diameter, 400 feet in length, unsupported, and travelling in a shaft at the rate of 120 feet a minute, would be something rather novel.

Mr. SIMPSON said, that at Crofthead the present rod was 14 inches square, whilst a tubular rod on his plan would not require to be more than 16 or 17 inches in diameter for the same pump.

Mr. JOHNSTONE thought the constant surge that would come upon the rods would act injuriously; but Mr. Simpson replying that the surge was expected to be done away with in this pump, he did not see any other difficulty likely to occur with it.

The PRESIDENT said, there was one peculiarity about the tubular or water rod; it required almost no guiding; for when it was raised, the greatest weight was at the bottom; and then in lowering it the greatest weight was again at the bottom. Of course the thickness of the tubes at the top must be very slight—one-eighth of an inch might be enough.

Mr. MILNE said that, with the same weight of metal in the pump-rod, it would be stiffer, and less liable to bend, in a tubular form, either cylindrical or square, than in the solid.

Professor RANKINE said, the pressure of the water inside would have a tendency to keep it in its shape, and would counteract any tendency to buckle in a cylindrical tube.

Mr. ROBSON said that he thought the idea embodied in this pump, and the model before them, a very ingenious one, and would like to see it practically tried on a large scale. He hoped that his friend, Mr. Ferguson, or some other spirited coal-owner, would ere long give Mr. Simpson an opportunity of showing that it would succeed in actual practice. He had often wondered why wrought-iron was not more used than it was for pump-rods for working the ordinary kind of force and lift pumps in mines, but it never occurred to him to cause the water to flow up through the rod at the same time that the rod itself was kept in motion in the shaft.

Mr. SIMPSON said, that lifting and forcing sets of pumps with plungers combined with buckets were in existence now; but the hollow plunger and rod were intended to do away with the use of buckets altogether.

On the proposition of the President, a unanimous vote of thanks was given to Mr. Simpson for his paper, and for exhibiting a working model of the pump.

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The following paper was then read:—

*On the Ventilation of Mines.* By Mr. George Simpson.

In ventilating mines it is of vital importance that each workman receives an adequate proportion of the fresh air introduced therein. It is too often the case that the inlet or downcast current is made to pass all along the working faces in the mine, and sometimes from one seam to another—so that the workers who are farthest from the point where the inlet current first reaches the face, receive the air in a used-up state, and, in many mines, very much contaminated. This defect has been so far remedied in very extensive mines, by dividing the workings into sections; and what is technically termed "splitting the main air current" is applied, but until each section is separated from those adjoining by barriers of unwrought parts of the seam (which may be afterwards wrought), the object of splitting will not be properly obtained, as artificial divisions consisting of buildings, stowage, or wooden or other brattices, are subject to derangement. A very large supply of air may be made to enter a mine, but the question arises—of what may this return current be composed by the time it reaches the outlet or upcast? If it contains 7 per cent. of hydrogen gas, then it is explosive. The miner may still work with an unprotected flame when 6 per cent. of hydrogen gas is diffused, but this almost imperceptible margin between him and destruction is no more indicated by the Davy than by a common lamp; and the object of the present paper is, to point out the necessity of having some intermediate indicator. The writer is aware that any such test however complete falls far short of the great desideratum, namely the keeping of mines at all times safely ventilated. There is no difficulty in keeping mines free from water, and were the same efforts made to drain the gases therefrom by preparatory drain mines, the obstacles to thorough ventilation would be overcome.

The extent to which the Davy lamp should be used is another important question. Its legitimate application appears to the writer to be in the hands of the fireman who examines the mine before the workmen are allowed to enter, and in the hands of those employed to make exploring and other mines beyond the general face, more especially in the more elevated parts of the seam. When a mine is in such a state with hydrogen gas that the naked lamp cannot be allowed, it must be much against the health of the workmen, whilst they are exposed to very much risk, as the Davy is subject to be damaged by falls, or otherwise, over which they have no control.

In testing the air of a mine, it might in some cases be considered more satisfactory to do so on the surface, by bringing samples of the circulating current from one or more points, by pipes of small diameter, to a small receiver and exhauster above. Of course the pipes would require to be extended as the workings progressed, and should be properly protected.

In place of ascertaining the component parts of the current as now done in the laboratory, the apparatus represented in fig. 4, Plate V., may be used. This apparatus comprises a closed chamber, A, with an inlet, B, and outlet, C, for the mixed gases from the mine. In this chamber there is a delicate balance, D, to one end of which is suspended a light sphere, E, of considerable size, which displaces a given quantity of the gases. To the other end of the balance is suspended a hydrometer, F, immersed in water contained in a vessel, G. The sphere, E, and hydrometer, F, are adjusted to exactly balance each other when the chamber, A, is filled with atmospheric air, at a known temperature, and the index must then point to zero. Then if the chamber is filled with air from the mine, and this air contains hydrogen, the weight displaced by the sphere, E, will be proportionately lessened, and the sphere will consequently descend until balanced by the portion of the hydrometer, F, thereby raised out of the water. In this way the position of the balance will indicate the specific gravity of the mixture of gases, which in the cases of gases taken from mines is tantamont to indicating the amount of hydrogen present, and consequently the more or less near approach to an explosive condition.

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In the discussion which followed—

Professor RANKINE approved of this application of a sort of hydrometer to indicate the specific gravity of a mixture of gases.

Mr. ALEXANDER asked, if a Davy lamp did not sufficiently indicate the condition of the gases, or if the proposed apparatus would be a more sensitive and reliable test than the Davy?

Mr. SIMPSON said, the Davy lamp was only of use when the air of a mine was explosive. The new apparatus was designed for use long before that.

The PRESIDENT understood Mr. Simpson was making an instrument on this plan, and probably it would be well to ask Mr. Simpson to make some experiments, and bring them before the Institution.

Mr. D. MORE said, that the air was different in different parts of the mine, so that it would not be sufficient to keep the instrument only in the ascending shaft.

Mr. SIMPSON replied, that pipes could be laid so as to draw the gas to be tested by the instrument from different parts of the mine at pleasure.

Mr. Ferguson said, that if it were made portable, so that it could be put upon a truck or into a basket, and carried into any part of the mine, then it would confer a great boon on the miner. He thought it might be made quite portable.

Mr. Ramsay inquired whether the instrument would not give similar indications for quite different mixtures of gases?

Mr. Simpson said, this instrument was specially designed for use in mines where mixtures with hydrogen had to be provided against, other mixtures not being generally met with.

Mr. More suggested that the instrument might be made self-registering.

The discussion was then adjourned.

THE FIFTH MEETING of the Session was held in the Philosophical Society's Hall, on Wednesday, 20th February, 1861—the PRESIDENT in the chair.

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The following paper was read:—

*On the necessity for Surface Condensation, and on different methods of effecting the same.* By Mr. THOMAS DAVISON.

A great number of plans have been devised, and many different forms of apparatus tried, for the purpose of condensing the steam from marine engines, and supplying the boilers with the pure water so obtained, instead of using sea-water, which is the only supply when the common jet condenser is used; and it is singular that so few plans have even approached success. So many objectionable forms have been tried, and so much trouble has been experienced with them, that many engineers are afraid to trust their own judgment of plans new to them, and have not studied the subject sufficiently to ascertain whether the difficulties experienced with the apparatus tried have been overcome by the new plans; this, together with erroneous ideas of what the objections really were to those tried, has no doubt been the cause of much delay in the use of surface condensers, as few marine engineers of the present time are ignorant of the great saving of fuel consequent upon the use of fresh, instead of salt water, to supply the boilers of steam-ships. This saving is easily calculated, when we know under what conditions boilers are supplied with water at sea.

Sea-water, containing about one thirty-second part of its weight of common salt, is fed into the boilers; and this salt not passing off with the steam, would, if permitted, accumulate in the boilers of large steam-ships to the amount of twenty tons of salt per day. Large as this quantity is, it is not the removing of it that gives so much trouble to engineers, it is the salts of lime and magnesia, which the sea-water contains in but very small quantity, that are so troublesome, in consequence of the property they possess of separating themselves from the water when it comes in contact with the heated surfaces of the boilers, and depositing upon such surfaces in a hard insoluble scale, which, if allowed to accumulate, would soon cause the destruction of the boilers. Even when the thickness of the scale is not sufficient to allow the plates to become dangerously heated, it retards the passage of the heat from the fire to the water, and consequently causes much loss of fuel. Many methods have been tried, both chemical and mechanical, to prevent the formation of scale where sea-water is used; but no means have yet been found successful.

The rapidity with which scale forms depends upon the temperature of the water in the boiler, and the quantity of salts it holds in solution; and the method adopted to prevent the accumulation of these salts is, to feed a large quantity of water into the boiler, in addition to that required for steam, and to blow this water out again, carrying with it the salts contained in the water evaporated. As this process of feeding and blowing is continuous, it is evident, that the proportion of salts the water in the boiler contains, will depend upon the quantity of water blown out, in proportion to the whole quantity fed in, and the great loss of fuel when sea-water is used is owing to the heat carried off by the water thus blown out.

The amount of this loss depends upon circumstances. Boilers used in the North Atlantic, with steam of 20 lbs. pressure, cannot be kept sufficiently free from scale, if the water in them contains more than twice the salts in sea-water. To maintain this condition it is necessary that one-half of the water fed into the boilers should be blown out; this corresponding to the graduation marked 2 on boiler hydrometers. The loss of heat in consequence is as follows:—

With steam of 20 lbs. pressure, the temperature of the water in the boilers will be 261°; the temperature of the water fed into the boilers from the hot well of the engine will be 110°. As the heat required to convert water from zero into steam is 1210°, it is evident, if two pounds of water at 110° be fed into the boiler, it will require 1100 units of heat to convert one pound into steam, and 151 units to raise the temperature of the second pound from 110° to the temperature at which it is blown out, 261°—this latter amount, of 151 units, is what is lost by blowing. As 151 units, the amount lost, is 13·7 per cent. of 1100 units, the amount required for steam, it follows that under this circumstance 13·7 per cent. more fuel is required than would be used if there was no occasion for blowing. This may be taken as the least amount of loss, as it ranges from this to a much greater proportion; for in the West Indian waters and other southern latitudes, it is found necessary to blow out two-thirds of the water fed into the boilers—this corresponding to the graduation marked 1½ on boiler hydrometers. Under this condition, the increase of fuel required to heat the water blown out will amount to 27·4 per cent. The practice ranges between these two extremes; and, notwithstanding that every care be taken in blowing, the boilers will still form scale, which requires much time and labour to remove. This trouble from scale is much increased when the pressure of steam is great; because, as it forms both harder and in greater quantity, an increased amount of blowing is required, and this also involves a greater loss in proportion, due to the higher temperature of the water blown out. When sea-water is used the boilers require to be constructed so that men can get inside to clean them; they are therefore larger, and cost more than if no cleaning was required.

When surface condensers are used, all the loss of fuel from blowing off is avoided, and this being a variable quality, as before stated, the saving will vary in like proportion; in addition to which, there will be a still farther saving owing to the boilers being entirely free from scale. This saving is variously estimated, but seldom at under 5 per cent.

There can be little doubt that boilers supplied with fresh water will last much longer than those fed with salt; and hence the expense of new boilers, and time required to put them into the ship, will be saved.

Another saving by the use of surface condensers is, the reduction of power required to work the air and feed pumps. As the friction of an air pump is not great, the power required to work it will depend upon the quantity of water it delivers. Under ordinary circumstances steam requires about twenty times its weight of water to condense it in a jet condenser, all of which must be withdrawn by the air pump; while in a surface condenser all that is necessary is to remove the condensed steam; the power required must therefore be much less; and as the feed pumps require to pump but one-half the quantity of water, the power to drive them will also be diminished. To drive the circulating pump for the surface condenser will, of course, consume power, but as this water does not require to be withdrawn from a vacuum, but merely taken from one side of the ship and delivered at the opposite, the power required is only that necessary to overcome the friction in the pipes.

All the saving by surface condensation is in addition to other economies in the use of steam. We may super-heat high steam, use it expansively, heat the feed water, and employ all refinements for its economical use;—if we add a surface condenser, we still save the same proportion of fuel as if it were applied to an engine using low steam full stroke.

The saving of fuel may be realized in three different directions; first, by running the ship at the same speed and distance with less coal, leaving room for a corresponding extra amount of freight; secondly, by running the same distance, with the same coal as formerly, at an increased speed; thirdly, by running at the same speed a greater distance with the same coal; or, we may have any intermediate proportion of the three. And to steam-ships with a deficiency of boiler, the relief obtained from a surface condenser is very great.

Surface condensation was attempted at a very early period in steam navigation. A condenser was fitted to a boat called the *Postboy*, in the year 1821, by Mr. David Napier of Glasgow. It consisted (as I have been kindly informed by Mr. D. Napier) of a number of copper tubes about ⅝ of an inch diameter and 12 feet long, brazed or soldered into tube-plates at each end. The steam entered the tubes from a chamber inclosing the tube-plate at one end, and the opposite ends, similarly inclosed, were connected with the air-pump of the engine. The whole placed in an open box was supplied with cooling water from the sea. This condenser was in use but a short time, having been constructed only for experiment.

Condensers were subsequently fitted to many boats, according to a plan —the invention of Mr. Hall—represented in fig. 1, Plate VII. It consisted of copper tubes about half an inch in diameter, placed vertically, their lower ends rivetted into a lower tube plate. Where they passed through the upper tube plate they were fitted each with a screw gland, so as to admit of expansion or contraction without injuring the joints of the tubes. The steam was admitted into the tubes at the upper end, their lower ends being in communication with the air-pump. The cooling water was admitted to the outside of the tubes at their lower ends, and passed off at the upper.

In all the figures the arrows indicate the various directions, those for the water being marked W; those for the steam, S; and those for the water of condensation, C.

After this another form was made by Mr. David Napier. It is represented in fig. 2, consisting of tubes about one inch diameter, placed horizontally. Each tube was packed at one end by a ring of india rubber, placed in a chamber or groove made to receive it, round the hole in the tube plate, through which the tube passed. This ring was first sprung into the chamber, and then the tube forced through it. The other ends of the tubes were fitted with glands similar to Mr. Hall's plan. The steam was inside the tubes, and they were placed in a wooden box, which was supplied with cooling water through openings in the side of the ship, furnished with projecting flanges, so arranged that, when the ship was in motion in either direction, a current of water was caused to flow through the box.

Fig. 3 represents a condenser, the invention of Mr. Pirsson of New York, many of which the writer has seen in use. It consists of thin copper tubes about ⅝-inch in diameter, rivetted into light copper heads at each end; a chamber, also of copper, incloses each head; the whole is placed in a strong cast-iron case; and one end chamber communicates through the outer case with the exhaust passage from the cylinder, the chamber at the other end communicating with a small fresh-water air-pump. The cooling water, admitted through the outer case at the upper side, with suitable scattering plates, is sprinkled as uniformly as possible over the outside of the tubes; and falling to the bottom of the outer case, it is removed by the ordinary air-pump. Small openings are made through the end chamber next the fresh-water air-pump, to prevent any difference of pressure between the inside and outside of the tubes. The steam, in passing through the tubes, is in a great measure condensed, but the uncondensed portion passing through the equilibrium openings, mixes with the cooling water, and is, of course, lost. Although this arrangement overcomes the difficulty of the joints of the tubes, as a leak in any of them is not very material, the pressure being the same on both sides, it does this at a great loss of condensed water; as the best examples the writer has seen do not return more than three-fourths of the condensed steam; and, of course, all the cooling water requires to be pumped out against the atmosphere as in a jet condenser. The ordinary-sized air-pump is still sufficient for this purpose.

Fig. 4 represents a plan the writer has seen in use, consisting of tubes of about 2½ inches in diameter and 10 inches long. One end is securely fastened into a tube plate, and inside of this tube is placed a taper tube, closed at the small end next the tube plate, the larger end being of such diameter as to fit the opposite end of the outer tube, to which it is brazed. The cooling water is admitted to the outside of the outer tubes and the inside of the inner ones, and the steam to the inside of the outer tubes and outside of the inner ones.

The next diagram, fig. 5, represents a plan invented by Mr. Sewell of New York, consisting of tubes placed horizontally, the tubes passing freely through the tube plates, and projecting about half an inch at each end. A thin sheet of india rubber, with holes punched to receive the tubes, is then passed over their ends. The holes in the rubber are much smaller than the diameter of the tubes, and the rubber in consequence turns out around each tube like a hydraulic cup-packing. The rubber is held in place by a plate bearing on it between and around the tubes, but with holes corresponding to the tubes, and large enough to admit their ends and the cup portion of the rubber, but enough smaller at the outer side to prevent the tubes from getting out of place. The cooling water passes through the tubes, and the steam is condensed on the outside of them.

Fig. 6 represents a plan used by Mr. Du Tremblay in France, made of solid drawn copper tubes, flattened to an eliptical section of about 1 inch broad by ¼ inch across. They were placed vertically, their ends attached to the brass tube-plates, by having the brass cast around them—which they succeeded in doing so well that the tubes seemed as well attached to the plates as if brazed in, both ends being fixed in the same manner. The steam was inside, and the cooling water outside, the upper tube-plate being free to move as the tubes expanded, as the only connection was through the gland as represented.

Fig. 7, Plate VIII., represents a plan tried by Mr. Carpenter of New York. The tubes were bent like the letter U, both ends being attached permanently to the same tube-plate, and each succeeding row being bent to a larger circle so as to form concentric lines at the bent portion and parallel at the straight. The cooling water was inside the tubes, the steam on the outside.

Fig. 8 represents a plan adopted by Mr. Spencer of Newcastle, the tubes being placed horizontally, the ends passing through the tube-plates. The holes in the tube-plate to receive the tubes are bored out on the outer side enough larger than the tubes to receive rings of india rubber, which are passed over the ends of the tubes and forced into the recess thus formed, and so prevent leakage around the tubes. The cooling water is inside the tubes, the steam on the outside.

Fig. 9 represents the arrangement of Mr. Rowan of Glasgow, the tubes being placed vertically in a cylindrical case, and a space being left in the centre, which is occupied by a fan, the shaft of which passes out through a gland in the bottom of the condenser. The water passing in around the shaft at the bottom is made to circulate amongst the tubes by the action of the fan, and to pass off at the top. To assist the water still further in its circulation, air is forced into it on its way to the fan. The steam is inside the tubes. The tubes are kept tight in the tube-plates by glands at both ends similar to Hall's plan; but, instead of screwing down each gland by itself, they are held down by plates which cover a number of them; the bottom plates at the same time serving to prevent the tubes from falling out of their places.

Another method which has been sometimes tried for effecting the same purpose as surface condensation is that of cooling the water delivered by the air pump, and returning it for use in the common jet condenser. The cooling is effected by passing it through tubes, to the outside of which cold water from the sea is supplied. Many different forms of this have been devised, and a good cooling arrangement of this kind is at present in use, the plan of Mr. Howden of Glasgow.

Judging from the great number of plans that have been tried, and the still greater number that have been patented, during the last thirty years, and the comparatively few condensers at present in operation, notwithstanding the saving effected by their use, we cannot but come to the conclusion that there has been some very great practical difficulty in their construction. In looking at the various plans, we find them in principle very similar, being generally a number of tubes with steam on one side and water on the other; but, when we come to examine more closely, we find great difference in the details, and in one particular they almost all differ, that is, in the method of forming the joints between the tubes and tube-plates. This fact seems to point out that part as being the most difficult. The methods of forming these joints in the different plans here described are shown full size in Plate VIII., so far as it is necessary to illustrate them. The number opposite each tube corresponds to that of the diagram of the condenser to which it belongs. At various times we find plans patented for securing the tubes to the plates so firmly as to defy the efforts of expansion,—none of those could be better than that of Du Tremblay's before described. But, even with tubes but three feet long, the writer has seen much delay in finding those that gave way by splitting, and as they could not be replaced the holes were plugged.

It is evident that a number of tubes as arranged in a condenser must be subject to unequal expansion, and if this be not provided for, either the joints or the tubes will soon give way and leak. It may, therefore, be considered as a condition inseparable from a good practically efficient surface condenser, that each tube be free to expand or contract independently of the others.

A second evident condition is that each portion of the surface should be supplied with an equal amount of cooling water, otherwise those parts not receiving their full proportion are comparatively ineffective, and more surface will be required than is otherwise necessary. This difficulty is inseparable from condensers, with the cooling water outside the tubes.

A third condition is, that the condenser shall occupy as little room as possible; this being of great importance, particularly when condensers are added to ships at present running, as in most cases the unoccupied space around the engines is very limited.

A fourth condition is, that the condenser must be easily kept in order, and that cleaning, examination, or repairs, must not occupy too much time. This question of time is of much more importance than those unacquainted with such manipulations would suppose; and the writer believes the time so occupied has been the most fruitful cause of failure of the plans tried. This is not strange when we consider the time required to pack the tube-joints of a large condenser. Suppose that it only occupied five minutes for each tube, or two and a half minutes for each end—the writer is having a condenser made at present that at this rate would require seven weeks' time; and as the tubes in all condensers are so close together, there is not room to employ many hands at the same time. The joints of the condenser referred to are, however, so made that they can all be packed in about four hours.

A fifth condition is, that all the joints shall be perfectly tight, and that the whole apparatus shall cost as little as possible.

Keeping all these conditions in view, which are the results of the writer's own observation of many forms of condensers which he has had an opportunity of testing, he has found but one plan that fulfils them all; this is represented by fig. 5, before described, and it will be easy to point out how perfectly it fulfils all the necessary requirements of a practical surface condenser. It provides for the separate expansion of each tube, at either end, without the amount of friction accompanying any other form of packing, as the india rubber stretches in the direction of the tube's length, instead of compelling the tube to pass through it. It thus saves the wear of either the tube or packing, and consequent liability to leak, which must occur in other slip joints; and it does not require the very great care and skill necessary in packing other slip joints—to avoid screwing them either too tight or not sufficiently so. The pressure of the water also operates to assist the tightness of the joint, as the greater the pressure the more perfectly the rubber is kept in contact with both tube and plate. Secondly, as the cooling water is inside the tubes, it can easily be caused to pass through different portions of them in succession, so as to insure uniform current throughout, and cause every tube to do its duty. Thirdly, the tubes can be placed more closely together than with other arrangements, a distance of five-sixteenths of an inch between their external diameters being sufficient for the packing; this permits the condensers to be made of very much smaller size than others, and capable of being fitted to engines, when other forms could not be applied. Fourthly, the facility of taking out the tubes to examine or clean them is very great, as the packings can be taken off and replaced on both ends of a thousand tubes in about an hour, and as the act of drawing the tubes out of the tube-plates and of replacing them, will sufficiently clean them, it would seem impossible to lessen the time required for such purposes. This is a most important consideration, and a quality possessed by no other form of condenser. Fifthly, this condenser admits of the use of long tubes, consequently saving expense in constructing; and the cost of the rubber packing is but trifling. The writer lately saw one taken off that had been in use for six months in the steam-ship *Mona's Isle* (the first steamer to which the condenser has been applied in this country). The tubes were cleaned, and the same rubber packings replaced, to all appearance as elastic as when new. Finally, the condenser is easily arranged, so that in case of any accident to the tubes, circulating pump, or other parts, a few minutes only are required to render it available as a jet condenser.

The other plans which have been described illustrate the leading features of nearly all the condensers that have been tried, and it is unnecessary to point out their defects in detail, as it is easily seen that none of them fulfil the conditions named, nor is there to be found in any of them any other advantage not posessed by the one recommended. And the writer is happy to add, that his opinions in this respect are sustained by eminent engineers of both Glasgow, Greenock, and Liverpool, who are at present making condensers on this plan for seven of the prominent steam-ship companies of the country, and also for the Royal Navy.

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In the discussion which followed—

Mr. Davison in answer to various questions, said that the amount of cooling surface was not in proportion to the horses power of the engine; but to assist in forming an opinion upon this matter he wóuld give the size of one now in use. The vessel had engines of 123 nominal horses power, and there were 1400 square feet of surface in the condenser. The cylinders were 42 inches in diameter, with a four-feet stroke. The boilers were ordinary horizontal tubular ones, the working pressure being from 15 lbs. to 20 lbs. of steam above the atmosphere. The condenser described (on Sewell's plan) had been in use since the beginning of last summer. The vacuum ranged from 24 to 25 inches. The speed was from 32 to 36 revolutions per minute. He could not tell accurately the temperature of the feed-water, but had observed it to be about 140°. The tubes of the condenser were less than one-sixteenth in thickness; their outside diameter was three-quarters, and they were 7½ feet long. There was no super-heating nor expansion beyond that given by the ordinary slide valve. The engine was doing a full amount of work for its nominal horses power.

Mr. Gilchrist thought it was a pity to lose sight of the first condenser which Mr. David Napier had made in the *Postboy*. Out of respect to their old friend and father, he thought an effort should be made to get a drawing of it before the Transactions were published.

Mr. Davison replied, that he thought he would be able to get the drawing yet, want of time only having hitherto prevented him.

Mr. Gilchrist remarked that a condenser with the tubes fastened in a way similar to the one represented in fig. 2, Plate VII., was made by Mr. Napier, and used in the *Koh-i-noor*.

Mr. Davison said one was also used in the *Plover*.

Mr. Gilchrist thought it right to state, that Mr. Wingate, who was about the first to use condensers in the Clyde and who fitted up one of Hall's in the *Sirius*, the first steam-vessel which crossed the Atlantic, had informed him that the boilers gave way at about the surface of the water, caused, it was supposed, by a galvanic action occasioned by the copper tubes of the condenser. The condenser was quite perfect at the end of two years;

but a deposit of black balls was found at the bottom of the boilers, which were believed to be in some way eating off the heads of the rivets. That condenser was packed, as shown in fig. 1, Plate VII., with little stuffing boxes. It was believed that the verdigris and tallow combined was the cause of the destruction of the sides of the boilers.*

The PRESIDENT could not see how the effect on the boilers and bolts could be properly traced to the condenser, the two being so far apart.

Mr. GILCHRIST could not explain it, but possibly the water being so pure it would have a great affinity for the copper pipes, and when combined with the tallow would be very destructive to the boilers. At all events, they took out the condenser for that reason, as that was their idea at the time.

Mr. DAVISON said he had seen condensers all of copper in use for seven or eight years without any complaint whatever; and as to tracing oxidation of the boilers to galvanic action arising from the condenser tubes, he thought there was room for mistake. He believed they had all seen boilers corrode in peculiar ways, when there were no condensers on board. He instanced the case of two sister boilers, where the tubes of one had to be taken out after ten months' wear, and the other continued all right for eight years, no condenser being used with either. He had also seen the parts around the feed pipes and other places of boilers seriously corroded in one vessel, and no appearance of corrosion in another similar ship, engaged in the same trade and treated in the same way. In one case where it was thought that galvanic action had been induced by the copper feed pipes, they were taken out and were replaced by cast-iron ones, and corrosion did not show so much afterwards; but in a sister ship, alike in every respect, there was no corrosion at all, and the copper pipes were allowed to remain. He had also seen in ships with no condensers, the larboard boiler corrode, whilst the corresponding part of the starboard boiler was not at all corroded; so that if they attributed the mysterious corrosion of boilers where condensers were used to galvanic action, he thought they were apt to be led astray. Engineers were sometimes like doctors, who when they did not know what was wrong and did not wish to confess it, said the patient was bilious. So engineers when they did not understand the cause, set it down to galvanic action, which had to bear the blame of it. Now, if boilers corroded without condensers as well as with them, and especially when he saw them in use, as in the *Mona's Isle*, with not the slightest corrosion of any part after six months' wear; he thought he was justified in not giving much attention to the alleged effects of galvanic action. He had also taken care to consult with

* See further remarks by Mr. Gilchrist at the following Meeting.

engineers in Glasgow who had had most experience with surface condensers, and he found most of them had observed nothing of the kind. They generally said that if the condenser would remain tight, they would take care of the galvanic action.

The PRESIDENT said he was sorry to have to bring the discussion on this important subject to a close for the present; but he would do so on the distinct understanding that they would take it up and thoroughly discuss it at the next meeting. In the meantime he would propose that they record a vote of thanks to Mr. Davison for his paper.

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The following paper was then read:—

## *On Gas Engineering.* By Mr. David Laidlaw.

The importance of the branch of engineering relating to illuminating gas will be freely admitted, when it is stated that the estimated capital employed in the manufacture and distribution of this now most necessary source of artificial light is upwards of £30,000,000; and that to this large sum must be added the capital employed in mining and conveying coal, in iron and brass founding, and in the various branches of business in connection with these which give employment to many thousand individuals. Again, when we take into consideration the immense demand for artificial light, and which could not have been supplied had we still to depend upon oil and candles—the estimated quantity of coal consumed being about 3,500,000 tons, and the income derived from gas, £5,000,000 annually—it is evident that this is a branch of engineering that deserves careful study and attention; whilst the more thoroughly the manufacture of gas is understood, the better and cheaper will it be supplied to the public.

Gas light is comparatively a modern invention; for, although inflammable gas issuing through fissures from coal or other carbonaceous matter has been known from the earliest ages, and although a few experiments had been made on coal gas as early as the beginning of last century, it was not until the year 1790 that Mr. William Murdoch (who at that date resided in Cornwall), having had his attention called to inflammable gas issuing from a neighbouring mine, made several experiments in distilling gas from coal, and in 1792 conveyed tubes through his dwelling-house and office, and was the first who succeeded in practically introducing this most invaluable discovery. In 1798 he lighted with gas a portion of the Soho works, Birmingham, and early in this century a few private works were erected for lighting manufactories. Comparatively little progress, however, was made in the extension of gas lighting until after the year 1814—no doubt owing to the many difficulties that had to be contended with in manufacturing and purifying the gas, and also to the cost and insufficiency of the fittings; but the great improvements that have taken place in all these departments, and which have also reduced the prices, have for many years past rendered it indispensable. Not only is it used in our large cities and towns, but also in palaces, country mansions, and dwelling-houses of all classes; in our shops, warehouses, manufactories, and streets; and also in our manufacturing processes, to a considerable extent. Nor is it confined to towns only, but many villages, some with less than a hundred consumers, possess it; and these works, when properly managed and constructed, yield not only a superior light at a cheap rate, but good dividends to the shareholders.

Glasgow, as might be expected from the enterprising character of its citizens, was amongst the first to erect public gas works. A charter was obtained in 1817; the works were constructed by J. B. Neilson, Esq., and for many years were managed by him.

It was suggested by our respected President, that the writer should in the present paper give his experiences of gas engineering in St. Petersburg. As the contract there is not nearly completed, it will, in the meantime, be sufficient to mention that it embraces 600 retorts, with all the necessary purifying apparatus, steam-engines, four telescopic gasometers, each 100 feet in diameter and 40 feet deep, and two 60 feet by 40 feet deep, together with iron roofs, station meters, &c., and about 10,000 tons of main pipes, from 3 to 36 inches in diameter, besides many hundred lamp posts. In September last a very successful start was made, and gas was distributed through upwards of 50 miles of main pipes, chiefly those of the larger sizes.

The city is built upon the banks of the river Neva—three canals intersecting the city. These have all to be crossed at numerous points, the pipes being taken below their beds. This is a tedious work. The inclemency of winter in that region requires to be duly guarded against. The condensers, purifiers, and every portion of the apparatus, including the gasometers, must be placed in houses, with the means of heating them. The pipes are all laid five feet below the pavement; and as it is almost impossible in any part of the city to dig more than four feet without being inundated with water, the engineering difficulties are not trifling. But above all, the greatest difficulties to contend with are the theoretical opinions of the Russian military engineers; the delays in getting any matter decided upon, and the innumerable obstacles presented by those whose duty and interest should be to promote expedition; and also the very short portion of the year (about five months) in which out-door work can be carried on.

The first duty of an engineer on being employed to erect a gas work, is to endeavour to procure the most suitable site. This should be chosen at or near the lowest part of the town, and, if possible, should have a communication with a railway, river, or canal, to lessen the cost of conveying coal and other materials into the works. Ample ground should be secured not only for present but future wants. The efficiency and economical management of many gas works have been neutralized by selecting too small a piece of land, with the view of saving the cost of a few hundred yards of main pipes, and hence additional ground has to be secured at an enormous cost, or additional works have to be erected at an opposite side of the town, which necessarily greatly increases the annual charges by a double managen ent and other expenses.

The next duty of an engineer is to arrange the various buildings with due regard to convenience and economy in working. In all manufactories where the routine is daily the same, a saving of much labour may be effected by proper arrangements, and the annual charges on the business consequently greatly lessened. In the plans made out by the writer when in St. Petersburg, particular attention was paid to this. The coal stores were in connection with the retort houses; but the Russian military engineer, Colonel Von Okle, who was appointed for the building department, altered this arrangement, and placed the coal stores at a distance of twelve or fifteen yards, and the supply of coal has first to be deposited in these and then wheeled across to the retort house for each charge of the retorts, thus entailing an enormous unnecessary annual expense. The buildings should be constructed either of stone or brick, whichever is cheapest in the locality. A few years ago, when the writer contracted to light Gibraltar, the governor, Sir James Ferguson, allowed him to take all the stones required merely for the expense of quarrying them. A calculation was made of the cost of hewn-stone walls and cast-iron walls; and it was found that although labour was nominally cheaper there, as in most places abroad, than in this country, it was in reality more expensive, in consequence of the small amount of work done; and that the principal buildings could be erected of cast-iron of a more elegant design, and at less cost than with stone, and accordingly this was done.

The writer has also, in erecting some works abroad, used cast-iron framing, and filled in the spaces with brick-work, which makes a very strong and durable structure. The retort and purifying houses should all have roofs with iron rafters covered with slates or other incombustible material.

The first portion of the apparatus is the retorts. These are made of various forms and different materials. Cast-iron was exclusively used for many years. Some engineers have used wrought-iron retorts, and Mr. King of Liverpool used some made of cast-iron, with wrought-iron tops. During the last twenty-five years fire-clay retorts have been extensively introduced, and are now very generally used in large gas works.

The introduction of fire-clay retorts gave rise to much discussion between gas engineers, on the respective merits of iron and clay retorts; but the writer has no hesitation in saying that no gas work should have clay retorts, except those which have a sufficient number in use to pay the expense of keeping a steam-engine and exhauster at work.

Another kind of retort is built with fire-bricks. These are about 20 feet long, 5 feet wide, and 18 inches high. Retorts of this class, however, are used in very few works. The writer prefers the clay retorts for large works to be 18 feet long, 18 or 20 inches wide, and 12 inches deep, with a lid and ascension pipe at each end.

The construction of the ovens, and the number of retorts that should be placed in each, have also been much discussed; some engineers prefer three, others five, some seven, and others even as many as nine. Some engineers use clay and iron retorts in the same oven, but the great object is to carbonize the coal in the retorts with as little expenditure of fuel as possible.

In old gas works the ascension pipes and bridge pipes used for conveying the gas from the retorts to the hydraulic main, seldom exceeded 3 inches in diameter, and were easily closed up. Now we make the ascension pipes 6 inches at the mouthpiece, tapering to 5 inches at the top, and the bridge and dip pipes 5 inches. Gas should not be retarded on its passage through the apparatus; all pipes and passages should be of ample capacity, with as few bends or knees as possible; and all knees should have flanges that can be taken off, for cleaning the pipes.

From the hydraulic main the gas passes through a condenser, where it is freed of the tar; it then passes to the exhauster, a species of pump, which draws the gas from the retorts and forces it through the purifying apparatus, and thus reduces the pressure in the retorts. It next passes through the wash-vessels or scrubbers, which free it of ammonia, and next to the lime purifiers, where it is freed of the sulphur. To the various methods of purifying gas it is unnecessary here to allude, whether by wet lime, dry lime, or a combination of both, or by the use of oxide of iron, or other chemical substances. Wet-lime purifiers are now rarely used, in consequence of the inconvenience of the mixture of lime requiring to be kept in constant agitation. They also greatly increase the pressure, and there is great difficulty in getting rid of the lime-water. In consequence of these objections dry lime is now almost universally used. The most convenient arrangement of dry-lime purifiers is in sets of four, with the change valve in the centre so made that three purifiers are always at work, leaving the fourth disengaged to be prepared with fresh lime for use; each purifier is thrown out of use in succession, as the lime gets saturated with sulphur. In this arrangement the gas passes first through the foulest purifier, then the second, and lastly through the pure lime. Purifiers have been by some engineers enlarged to a most inconvenient size of late. Those vessels should not, however, exceed 12 feet square, whilst there should be a sufficient number of sets for the quantity of gas that has to be purified. From the purifiers the gas should in all cases pass through a station meter, which registers the quantity made, and from it to the gasometers or gas-holders.

In large works the gas-holders are now generally made telescopic, as they hold nearly double the quantity of gas that the single-lift holders do in the same size of tank; they are more economical in construction, in proportion to their cubical contents, and occupy less ground. The largest gas-holder in Scotland, and that the writer believes has yet been in full operation anywhere, was lately erected in our own city, under the superintendence of Mr. Bartholomew, engineer to the City and Suburban Gas Company. It is represented in Plate VIII., and the particulars of its construction and capacity, kindly supplied by Mr. Bartholomew, are given at the end of this paper. This gas-holder is a decided advance upon the first one used by Mr. Murdoch, which was only a bladder he was in the habit of filling with the gas which issued from a coal pit, a piece of a tobacco pipe being inserted into it to serve for a burner. Placing this below his arm, which answered for the pressure regulator, he thus lighted his way home in dark nights.

Tanks for containing the gas-holders are frequently a source of great annoyance and expense to gas companies, and in their construction the utmost skill of the engineer is often taxed. When the ground is firm, stone or brick tanks are easily made water-tight when well built and puddled with clay carefully; but when the ground is soft or marshy, it is often next to impossible to construct them, except with iron; and when of large diameter, the writer prefers to make them on the annular principle. These do not require the entire diameter to be excavated, and a comparatively small foundation of concrete or other materials is required.

When making plans for St. Petersburg, the tanks, which are 102 feet in diameter, were designed on the annular principle, being best adapted for the marshy soil of that capital. The Russian military engineer already alluded to, however, insisted that he could make brick tanks for one-half the price of iron ones, and he was allowed to build one. The result was that it cost an immense sum more than the estimate for the iron one, and, being a complete failure, an iron one had to be placed inside of it—a proof to the directors that Russian theory was much more costly than British practice.

A source of very great loss to gas companies is the condensation and leakage of the gas in the street mains. In some instances as much as one-third of all the gas manufactured is thus lost; and the writer believes that the average loss is not under 15 per cent., and in no case under 10 per cent., although some gas managers have stated a less quantity. This is a department which should have the engineer's careful attention, and much may be done to lessen the loss; but to bring it down to 1 per cent. is an impossibility, for a much greater loss must occur from condensation alone. The quantity and sizes of the pipes, in proportion to the amount of gas consumed, must also materially affect the amount of loss. When the towns are compact and the consumers close together, the loss will be smaller than when the consumers are scattered at a distance from each other, as often occurs in small towns. Much, however, can be accomplished to reduce the loss, by the sizes and quality of the pipes, and the way in which they are jointed. When the main pipes are too small in diameter to give an ample supply of gas, a heavy pressure must be put on at the gas-holder to force the gas quickly through the pipes. The pressure should not exceed in level towns 1 inch of a column of water; but it in some towns exceeds 4 and even 5 inches, the loss of gas increasing with the pressure. All sizes of pipes, from 1½ inches upwards, should be cast vertically in dry sand moulds; pipes thus made are free from pores, and the metal is closer in the grain than when cast in green sand, and on an angle or bank: for although the latter quality of pipes will stand the test of the hydraulic press, yet there is no doubt they do allow gas to escape through the pores of the metal. It is a well-known fact, that where gas pipes have lain for a number of years, the surrounding earth is impregnated with gas to a considerable thickness. Another cause of loss frequently arises from the pipes being made thin and light, and in some soils they are very soon corroded. This is false economy. The methods of jointing pipes generally adopted are those with spigot and faucet packed with hemp or rope yarn and lead, and spigot and faucet bored and turned joints. The latter kind, when properly made, have the advantage of being quickly laid, as the joints require only to be coated with red lead paint, and knocked home with a mallet. They make a very perfect joint.

The quality of the gas is a very important matter, and requires careful attention. The chemical tests are now well known and easily applied. On the quality of the coal depends in a great measure the illuminating power of the gas. Cannel coal yields the largest quantity and richest quality. The price of gas should be regulated by its illuminating power. To compare the gas of one town with that of another, by the prices charged per 1000 cubic feet, gives no true result, because the illuminating power of the one may be double that of the other.

Gases are sometimes tested by comparing their specific gravities; but as this may be affected owing to the presence of carbonic acid or atmospheric air, this method is not a sufficient test, and the photometer test is therefore preferred, as by it the quantity of light actually yielded is measured.

The meter by which the quantity of gas used by each consumer is measured and registered, is a most important instrument. Previously to its invention in 1816, by Samuel Clegg, Esq., recently deceased, each burner was charged for according to a scale of prices, and had to be paid for whether in constant use or not. With the meter the consumer only pays for the quantity of gas that he actually consumes. This instrument has therefore been the means of greatly extending the use of gas. There are two descriptions of meters in use, generally known as wet and dry meters, examples of which are now before you. The accurate registration of the wet meter is determined by maintaining the water at a fixed level. The legislature have had this matter before them for nearly two years, to the very serious loss of the trade, and have passed an Act which cannot be carried into operation, and which Act has been suspended until further information is obtained. The arrangement of the front box of the meter shown, was introduced by the writer in 1844 to obviate an objection that existed in nearly all meters, which was that the water could be raised above the true level, and thus diminish the measuring portion of the drum—to the loss of the consumer. In the meter referred to, it was rendered impossible that the indication could ever be greater than the actual quantity passed through; and for this reason the City and Suburban Gas Company adopted it at the time they commenced business, and have since fixed upwards of 25,000. No gas can be extracted from these meters without being registered; gas companies may, however, be losers to the extent of two or three per cent. of gas, owing to the evaporation of water from the meter before the valve closes, but the public can in no case suffer. Mr. Allan of Perth took out a patent about eighteen months ago, to convert the space in the front box of the meter, above the water line, into a reservoir for water to supply the loss by evaporation. This arrangement can be seen in one of the meters shown. By means of tubes the water is taken from the reservoir to the back part of the meter, into the chamber in which the drum works, and supplies any evaporation that takes place. By a very slight alteration upon the writer's meter he has, with Mr. Allan's concurrence, taken advantage of this reservoir, as shown in the meter exhibited, and the exceeding simplicity of the arrangement will be at once observed. Several trials were made by Mr. King of Liverpool, and the results were so satisfactory that he has adopted the arrangements. The Liverpool Corporation Inspector also made several trials on a five-light meter on this plan, the result of which was also very satisfactory; showing that, after abstracting 80 cubic inches of water, the registration only varied ·25 per cent.

The writer has to apologize for this very crude and imperfect paper; but the subject is of so expansive a nature that, not to tax the patience of members, he has been obliged to condense it into as small a compass as possible.

### *Description of the Large Gasholder and Tank recently erected by the Glasgow City and Suburban Gas Company.* By Mr. HUGH BARTHOLOMEW.

Gasholders are now erected of much larger sizes than when gas was first introduced. In the year 1814 the Royal Society of London recommended government to restrict gas companies from erecting gasholders that would contain more than 6000 cubic feet. That society came to the conclusion that London would not be safe if they permitted them to be erected of a larger capacity. Gasholders, however, gradually increased in size until about the year 1840, when telescopic gasholders were introduced, which doubled their capacity at once. This was a great advantage to gas companies by the saving of so much ground. They were then made capable of containing 250,000 cubic feet.

Figs. 1 and 2, Plate VIII., are a vertical section and a half plan of a gasholder which the City and Suburban Gas Company of Glasgow erected in 1860, and which is the second largest in the country. The upper part is 160 feet in diameter, the under part, 161 feet 8 inches; with two 26 feet lifts. Its working capacity is 1,024,000 cubic feet, and the pressure it gives is equal to a column of water of $3\frac{7}{8}$ inches. Its weight is 211 tons, but 24 tons of counter-balance weights are attached to the under lift, which reduces the weight upon the gas to 187 tons. The crown sheets, which are supposed to be removed in fig 2, are only rivetted down at the outer edge, no part of them being made fast to the interior framing, and when working they never bear on it. The outer row of the sheets of the crown are half an inch thick, and the thickness is gradually reduced to No. 12 wire gauge, and completed at that thickness. The side sheets are No. 12, except the upper and under sheets of each lift, which are a quarter of an inch thick. A very great improvement is introduced at the cup iron. It was formerly formed with a plate and angle iron rivetted on both edges; it is now got by forming the plate and angle iron in one piece.

There are sixteen pillars round this gasholder, each 50 feet high. The shaft of each is cast in one length, which is of 45 feet, and weighs 9 tons. The base of each pillar is made fast to a plate built into the brick-work, 10 feet down, by 4 bolts $2\frac{1}{4}$ inches diameter.

The tank is 165 feet in diameter and 28 feet deep. The trench for the foundation was cut 3 feet 9 inches lower, and 9 feet wide. Scotch timber was laid in close together; the exact length of the width of the trench and two feet of concrete put on the top. The brick-work was started at 7 feet 6 inches wide, and reduced by three scarcements on each side to 5 feet 2 inches, and carried up 10 feet at that thickness, and then gradually reduced to 2 feet 10 inches at the top. There were also thirty-two abutments brought up with the wall, 7 feet from the face of the wall by 7 feet the other way. The one half of them were reduced with the wall, and the other half were carried to the top for the foundation of the pillars. The concrete was composed of clay and Arden lime, the under half of the tank being built with one part of Roman cement to one and a half of sand, and the upper half with one half Roman cement and one half Arden lime to one and a half of sand.

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In the discussion which followed—

The PRESIDENT remarked that the paper read opened up an excellent field for discussion and useful conversation. The making and selling of gas were interesting to every one, as gas was not only a luxury, but an absolute necessity, and it was right that they should get it as cheap and as good as they could. Mr. Laidlaw necessarily had to condense the subject very much; for in fact, every apparatus connected with the making of gas might yield a very good paper itself. The retorts have ever been a matter of discussion; and then condensers had been made of various forms, but the best he had ever seen was one made on the tubular form, in which the gas passed through the tubes, the cold air being outside. With regard to the purification of gas, he might observe that there were now scarcely any wet-lime purifiers in existence.

Mr. BARTHOLOMEW thought it right to state that it was the president's father who first introduced fireclay retorts in order to cheapen their cost; but now since iron retorts cost under £4 per ton, there was not so much need to make them of fireclay. There had, as the President remarked, been a great deal of discussion about retorts; but he maintained that the quantity of gas which escaped through the sides of fireclay retorts would soon amount to the cost of renewing them. The cast-iron retorts used in the City and Suburban Gas Company's works did not cost more than 1d. per thousand feet of gas made in them. Those who used fireclay retorts required to fill up the cracks which might occur in them; and it was well known that if carbon was permitted to commence collecting, it gathered very quickly and choked the retorts; and indeed, if they did not keep removing it, it would soon fill up the retort altogether.

The PRESIDENT asked Mr. Laidlaw if he had witnessed where the soil around gas pipes was much impregnated with gas—which was generally understood to arise from leakage of joints—whether the iron pipes were like plumbago, and could be cut with a knife?

Mr. LAIDLAW said he had.

In answer to Mr. Moffat, Mr. BARTHOLOMEW stated that the Rev. Mr.

Bowditch's patent for the better purification of gas had never been tried on a large scale, but only in the laboratories of several eminent chemists, who had reported very favourably upon it. The great difficulty in its application, was the heating of the lime or gas, which would involve the use of enormous apparatus and great expense.

In answer to the President, Mr. DAVISON said that the American ferry boats were lighted by gas contained in a small portable dry gasometer, with India rubber sides, like a pair of bellows. He had never observed how the large vessels were lighted. Railway cars were lighted with gas compressed into a cylinder placed underneath each carriage, from which pipes were led to the different parts of the car. Gas was found more economical than oil.

The PRESIDENT remarked that Mr. Laidlaw had not alluded to one of the first modes of distributing gas to people in a city, by means of portable vessels into which the gas had been compressed.

Mr. LAIDLAW replied that these were spherical vessels of iron or copper. At present Moscow was partly lighted in that way; but it was a most inconvenient plan, as well as expensive, as a great loss resulted from condensation of the gas in the vessels. They filled large jars, and conveyed them to their customers every morning. It was oil and resin gas which was formerly used in this country for portable gas, but that was only for a short period, as it proved a complete failure.

The PRESIDENT then said that he must bring the discussion to a close, as it was getting late. He requested a vote of thanks to Mr. Laidlaw, which was given.

THE SIXTH MEETING of the Session was held in the Philosophical Society's Hall, on Wednesday, 20th March, 1861—the PRESIDENT in the chair.

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The discussion was resumed

*On Surface Condensers.*

The SECRETARY read the following extracts from communications received from Mr. DAVID NAPIER, now residing at Worcester:—

"I do not recollect the date at which I tried the experiment of surface condensation in the *Postboy*. I think it was about the year 1818 or 1820. It was while the *Postboy* was running on the Clyde, where she did not remain above two years. The tubes were about 12 feet long and ⅝ths of an inch in diameter; as like those I have just put into an experimental steamer I am at present engaged with (with two screws in the stern partially immersed) as two eggs are like each other; with this difference only, that those in the *Postboy* were soldered or brazed (I forget which) into the tube plates or copper boxes at each end, while those in the *Kilmun*, my present experimental steamer, are made tight at the ends with india rubber. The experiment in the *Postboy* was only a temporary affair, to try the effect. The only place I could try it in was that occupied by the stoker, and I was consequently obliged to remove it after I satisfied myself it would answer. Being convinced of its utility, I followed it up afterwards in various ways. Among others, I applied the bottom of the ships for the purpose of condensation, which I patented, and about twenty years ago constructed the *Eclipse* and *Isle of Thanet* on that principle; but unfortunately both of these vessels plied between London and Dover, and the latter at that time being a rocky dry harbour, in grounding both of these vessels strained their bottoms, and the condensers consequently became leaky and useless. If I am successful in getting the two screws in the stern to work to my mind, I intend sending the *Kilmun* round to the Clyde. I am at present engaged in an alteration, from which I expect good results. I must warn you not to look for great speed—although I expect that it will be fair—far less for anything good-looking, as she is the ugliest steamer that ever was built, having been done by a blacksmith in Staffordshire, twenty miles from the river, who had never done anything of the kind before—at double the price I could get it done at in London.

"The principal drawback I have experienced latterly is the tallow from the engines forming itself into small round balls and clogging up the condensers and boiler tubes, to remedy which I have had bags made of hair, which I intend to be attached to the discharge from the air-pump, for the double purpose of preventing the tallow getting into the condensers or boilers, as well as of saving the tallow to be used again, by throwing the dirty bags into a boiler or pot and boiling them clean; but whether the people on board will take that trouble is another question."

Mr. Gilchrist corrected a remark he had made at the previous meeting respecting the *Sirius.* The vessel in which the corrosion and the tallow balls had been observed, was not the *Sirius*, but another vessel which Mr. Wingate had been employed to inspect. Mr. Wingate did not recollect the name of the vessel, but it was one fitted with engines by Symington.

Professor Macquorn Rankine asked whether Mr. Davison could give any statement as to the weight of steam condensed per square foot of surface per hour in Sewell's condenser.

Mr. Davison answered that experiments had been made with an engine indicating 70 horses power, and the result obtained was 6 lbs. of steam condensed per square foot of surface per hour, with cooling water received at 70° and discharged at 100°, the vacuum being 27 inches. The condenser of the *Mona's Isle*, with vacuum of 24 and 25 inches, condensed 9 lbs. of steam per square foot of surface.

Mr. J. F. Spencer said he had given his time exclusively for the last seven or eight years to the subject of surface condensation, being satisfied that it was an important improvement. He had first given attention to the matter in 1847, and since then he had been a strong advocate for the adoption of surface condensers; but in bringing such things before the public he had found it, like many others, up-hill work; however, he was satisfied that truth would triumph, and that the time was coming when surface condensation would be adopted in all marine engines. He had not been present to hear Mr. Davison's paper read, but he had had the advantage of looking carefully through the report of it, and he would now make a few remarks on some parts of it. He differed entirely with Mr. Davison in regard to the loss by blowing off in marine boilers—that it could be calculated by estimating the heat necessary to raise the water from its normal state in the hot well to the temperature in the boiler. He believed that gave no correct indication, from the fact that in blowing-off, a great quantity of steam was mixed with the water. If only solid water were thrown out, then that would be a fair calculation; but, from some opportunities he had had of fairly comparing the two systems, he found 20 per cent. to be the least saving, proving that such calculations as the one referred to were altogether fallacious. The difference might be accounted for from the fact that steam was constantly being formed in all parts of the boilers; and this steam absorbed a great amount of latent heat, which was blown out along with the solid water; and hence it was that the loss was above 20 per cent. of the total heat imparted. He had had many good opportunities of observing the economy realised, and no other way of accounting for it occurred to him; for although a little less power was used to work the air-pumps, yet it was not to be compared with the saving that actually took place. In a vessel that he had fitted four years ago with a surface condenser, the original air-pump was 13 inches in diameter, with a 12-inch stroke, and was connected with an injection condenser. No other change was made, except the putting in of a 9-inch pump instead of the 13-inch one. He obtained an inch more vacuum, and he improved the speed of the ship with the surface condenser, and the practical result was a saving of from 20 to 25 per cent.; and this saving could not be calculated from the difference between the boiler temperature and that of the feed-water. Everything remained as previously, except the introduction of the condenser—the same boilers, coal, the same engineer, the old air-pump left standing, and simply the connecting rod thrown off; for the proprietor, who was sceptical about surface condensers, would not have any of the old parts removed, lest he should have to return to them—but they had all been removed bit by bit. In the case of the *Frankfort*, he had had a good opportunity of seeing the effect of the condenser. This ship, of 100 horses power, had been running for some years with the usual air pumps and injection condenser; and the owners supplied him with all the particulars of the working of the engines during that time. The practical result of substituting a surface condenser and new air pumps, worked by a pair of small engines, was a saving of about 4 tons of coal a day, or fully 20 per cent. In the *Frankfort* there were originally two 25-inch air pumps. He put in two 14-inch ones, with about an inch less stroke, but of course working a little faster—yet a better vacuum was got than before. They had taken a series of diagrams of the ship previous to and after the condenser had been put in, and the result was that they found the indicated power had slightly increased, together with this saving of 4 tons of coal per day. The success of, and satisfaction given by that condenser, might be understood from the fact that the same company were fitting other 16 ships, with engines averaging 200 horses power, with condensers on the same principle. He thought that, with reference to the power required for the pumps for the condensing water, the idea that they had merely to make it circulate was a mistake. He found that there was sometimes a pressure in these circulating pumps equal to a head of 40 feet of water, namely 20 lbs. to the square inch, which seemed quite contrary to the idea of the circulation requiring little power; it was however true that less power was required to work the pump for surface than for injection condensers. On another opportunity he might perhaps be able to bring before them additional facts, and the diagrams taken from the pumps, when these statements would be better understood. It was his practice to take diagrams from the pumps as well as from the cylinders, and he made his deductions from a fair comparison of the working of the two systems. Of course, Mr. Davison's paper was designed fairly and justly to show the great advantage of the condenser which that gentleman advocated; but there were always two sides to a question, and he might not be ready to admit all his claims. He had always looked at simplicity in the construction of a condenser as being of the greatest importance. If they could get rid of screws it was always well. In his own condenser he had succeeded in making each tube independent of the others, so that it could be got out and put in again without touching the other parts of the condenser; and if any of the washers came out, they could be refitted without any trouble. To show how tight these tubes were, he might state that he had tried the 1200 tubes in the condenser of the *Hibernian* with 12 lbs. steam on the reverse side, and only 4 joints showed slight leakage, although the steam being on the reverse side had a tendency to drive the washers out. He never had had a case of leakage after a condenser commenced working. One ring was almost as efficient as two, but two were put in as a matter of safety. With regard to Mr. Davison's assertion that it would take seven weeks to shift the tubes in a condenser, he would undertake to have the whole of them changed in six days—say in a condenser for engines of 700 or 800 horses power. He thought Mr. Davison must have made a mistake on this point; but at the same time it must be remembered that a condenser was not required to be retubed all at once. His condenser was so arranged that when the vessel was in port a man could pull out a few tubes, clean, and replace them as occasion offered; for it was quite unnecessary to pull the whole affair to pieces at one time. He did not know, but wished to be informed, whether a tube could be put in singly in Mr. Sewell's condenser without removing others?

Mr. Davison said that it could.

Mr. Spencer continued—He had had a condenser working in a vessel constantly for the last 3½ years, partly with that packing and partly with tubes rivetted into the plates, and now he was making a new condenser, with the whole of the tubes packed with india-rubber washers. This was rendered necessary, because the grease had so collected that the vacuum had been reduced about 4 inches. He thought it was very important to keep the tubes clean, as grease being a non-conductor, when they became coated with it the power of condensation was reduced, and therefore it was necessary to clean the tubes as occasion offered. With reference to the external and internal systems of condensation, the water inside with the steam outside, and *vice versâ*, he had never but one opinion upon the practical superiority of the former plan; but he thought it was a matter upon which they should not be dogmatic, for although he had never seen anything to change his opinion, still facts might yet arise to influence it. Accessibility at sea for repairs was a very great point, and also the inspection of the tubes without breaking the connection between the condenser and the engine, and these points were attended to in his own condenser. He had fitted up 14 condensers altogether on that principle. The first he had put in was in the bilge of a ship in 1849, and at that time he had not heard of Mr. Napier having done so previously. Although this situation for the condenser did very well in small vessels, yet it was objectionable in large ships, as when repairs were required the vessel had to be docked or beached. There were about 26 condensers made, or being made, with his plan of packing the joints; therefore he thought Mr. Davison, in saying none but Sewell's could answer, had a little overstated the matter. At present 16 of his own condensers were being fitted up by one company. He trusted that there was room enough for all; and by not assuming entire wisdom, he thought they would have a far better chance of getting right in the end.

Mr. Davison, in answer, said he was very glad that Mr. Spencer's experiments showed a greater saving than appeared from calculations. Regarding the conditions of blowing, he would, however, like to know at what strength Mr. Spencer carried the water?

Mr. Spencer said there was passed a third more than was required. He used two pints of water out of three he put in. It was the ordinary hydrometer that was used, and the water showed $\frac{2}{32}$nds of salt.

Mr. Davison said the theory of Mr. Spencer, that steam was blown out along with the water, could scarcely be correct, as the blow-pipes were under the surface of the water, whilst the shell not giving off steam, and the blow-pipes being placed as far as possible from the parts where steam was mostly formed, they could scarcely blow much out. There might indeed be unusual conditions, occasioning some loss of steam by the blow-pipes.

Mr. Spencer said, that in ordinary cases this loss could not be helped altogether. Above and near the furnace there was a mass of water and steam.

Mr. Davison said, that, notwithstanding this, if Mr. Spencer made the calculations from his own *data*, he would find that the allowance for water alone would bear out the calculations in the paper. When keeping the water in the boiler at a strength of $\frac{1}{32}$nds, Mr. Spencer supposed that he blew off a third, whereas if he calculated it correctly, he would find that he blew off one-half.

Mr. SPENCER here admitted that his figures had been wrong on this point.

Mr. DAVISON remarked, that in the paper he gave a range of from 13·7 up to 27·4 per cent., so that the saving would be between these two, and might be more or less if the conditions were different from those on which the calculations were based.

Mr. SPENCER had simply said that no calculation could be made from the heat of the hot-well to the heat blown out. The calculation was no argument.

Mr. DAVISON thought it was at least a *safe* calculation—that the saving could not at any rate be less—to which Mr. Spencer agreed.

Mr. DAVISON, in continuation, remarked that, with reference to the time required for taking out and putting in the tubes, he had based his calculation on allowing 2½ minutes to each tube, which would give seven weeks in the case referred to. Now, was 2½ minutes too much? Mr. Spencer reduced it to one week, but he did not say how many tubes could be dealt with in a week. What was the exact time required? He had remarked that water on the outside of the tubes might possibly prove to be the best. Had Mr. Spencer any example?

Mr. SPENCER would be sorry to make a statement which was not based upon actual experiment, and as he had not the exact *data*, he could not say. He would simply say that, from his experience, he was convinced Mr. Davison had named too long a time. He had no hesitation in saying, although it might seem to be against his own interests, that Hall's, which was similar to Rowan's, was by far the best *theoretical* condenser. He believed that a condenser with the largest proportion of cooling surface in a given bulk would be the most economical one. He said it was the best for getting a theoretical result, but for practical requirements the other was infinitely superior. He preferred a simple and common thing, because he had often careless men to deal with.

Mr. DAVISON asked what were the results obtained from Hall's condenser which led him to say it was a superior one?

Mr. SPENCER, in reply to this and further questions, said he happened to know three working engineers who had worked it, and was also acquainted with Mr. Seward, who had fitted up some of them, and from their evidence he had come to his conclusion. They got a better vacuum, he believed, but he did not know how much. He simply stated these things on his firm belief and past experience, being persuaded that a better *theoretical* condenser did not exist. He believed that it was Dr. Joule who had made some careful experiments, showing that the body of cooling water, when it bore a certain proportion of bulk, was then always the most efficient.

Mr. JOHN SCOTT (Youngest, of Greenock) had not the advantage of being present at the reading of the paper; but having carefully perused it since its publication in the Transactions, would make a few remarks generally on the subject, and specially to join issue with its author in reference to the conclusion which he expressed at its termination. He had for several years devoted very considerable attention to this subject, and had carried out a very extended series of experiments on a large scale with a view of determining whether a revival of the system of surface condensation was not practicable, and, while he was prepared to admit that many difficulties beset the path of the practical engineer, he was not disposed to endorse the assertion made by Mr. Davison, that the plan of surface condensation which he advocated was the only one entitled to bear away the palm. He could not consistently with the brevity which a discussion of this nature necessitated, better explain his reasons for coming to this conclusion, than by endeavouring to point out that one of the very condensers described by Mr. Davison not only fulfilled all the conditions which he considered essential to a perfect surface condenser, but that it, at the same time, surpassed in the most important of them the condensers of the type which he considered *ne plus ultra.* He referred to the arrangement of Mr. J. M. Rowan (fig. 9, Plate VIII.), in the construction and working of which he had had a very considerable experience; and as there were at present in operation, or in course of construction, above 20 of these condensers, he felt himself in a position to speak with a very considerable amount of certainty, whilst endeavouring to show that this arrangement at least, among those described by Mr. Davison, was not open to the sweeping condemnation with which he terminated his paper. He would test the merits of the Rowan condenser by the standard laid down by Mr. Davison himself, and where he found he could not accord with his statements, he would endeavour to maintain his position by reference to experiments carefully conducted by Mr. Rowan and himself, and for the accuracy of which he could vouch. Presuming that the general system of construction of the Rowan condenser was familiar to the members of the Institution, he would remark in reference to Mr. Davison's *first* condition, that its tubes being jointed at both ends with india-rubber washers, acted upon by individual metallic glands, which were pressed inwards by packing plates in sections of convenient size, were perfectly free to expand or contract independently of each other, and that in no instance had the slightest inconvenience resulted from this feature of the arrangement. Although, in consequence of a perfectly equal temperature being maintained throughout the whole condenser, at any given height, by the means to which he would afterwards refer, the tubes were not liable to unequal expansion, taken collectively; still, should such from any unforeseen cause occur, each tube being perfectly free to move through the india-rubber washer at each of its extremities, was entirely at liberty to adjust itself to the exigencies of expansion or contraction. The *second* condition imposed by Mr. Davison was, that each portion of the cooling surface should be supplied with an equal amount of cooling water, so as to render a minimum of surface effective. Mr. Davison added, that to obtain this was a difficulty inseparable from all condensers with the cooling water outside of the tubes. In making this assertion Mr. Davison was no doubt influenced by a knowledge of the fact, that in Hall's condensers after a short period of working, in consequence of the mode of introducing the cooling water, and in consequence of no provision being made to compel the water to take other than the shortest course from the entrance to the exit, those portions farthest from the entrance nozzle become hotter than the other portions, causing in time a furry incrustation to settle on the outside of the tubes by the deposit of a portion of the salt contained in the cooling water. This deposit when once commenced, naturally impaired the transmission of the heat from the steam within the tubes to the cooling water without, and by thus increasing the heat of the external water in the more stagnant portion of the condenser continuously aggravated the evil, which in time spread inwards until the efficiency of the whole remaining available surface was neutralized or destroyed. Such a result would most probably occur in any condenser constructed on Hall's type, which was not provided, 1st, with a means of equally distributing the steam after its entrance into the condenser, so that each tube should have to perform its own share of the duty and no more; and 2nd, with a simple mechanical means of securing an equal distribution of the condensing water throughout the body of the condenser, and of providing that a fresh molecule of water should be brought into contact with every portion of the surface with extreme rapidity. These functions he would submit were most satisfactorily fulfilled in the Rowan condenser; the first of them by means of holes through the pressing plates corresponding with each tube, but of a less diameter, and so proportioned that they were unitedly capable of passing the required amount of steam; the second, by the fan placed in the central portion of the condenser, and made to rotate rapidly by mechanical appliances from the engine; the cooling water at the same time being impregnated with a large portion of atmospheric air for the purpose of rendering the water more easily propelled by the fan. To show that these objects were entirely gained by the means described, he might state, that from most carefully noted experiments on the condensers of the steamers *Thetis* and *Guajara*, no perceptible difference in the temperature of the condensing water could be detected at any given height in the condenser; and that in the former vessel, with a steady vacuum of 26½ to 27 inches, when the temperature of the sea-water admitted into the condenser was 56°, it could be drawn from the outside and top of the condenser, at the part most remote from its point of entrance and nearest the entering steam, and where consequently if any undue heat could exist it should have been discovered—at a temperature of 86°. In the latter vessel, with a vacuum of 27½ inches, an initial temperature of sea-water of 42° produced 80° at the opposite extremity. With these respective initial and final temperatures of cooling water, the temperature of the condensed steam when discharged by the air pump was 92° and 75°; and in the latter case, by increasing the amount of cooling water, this could be brought as low as 60°. He observed that Mr. Davison stated that the corresponding temperature from Sewell's condenser in the *Mona's Isle* was 140°; and it would be instructive if he could inform them at what temperature the water of condensation was then escaping. By a comparison of these corresponding temperatures was the efficiency of a surface condenser to be measured; and the condenser which, with a given amount of surface, could reduce a given amount of steam to a minimum temperature, was clearly the most efficient in working; and he would submit that he had amply proved from the *data* just given, that Mr. Davison's allegation of the imperfection of condensers of the Rowan type from deficiency of circulation must fall to the ground. The *third* condition laid down was, that a perfect surface condenser should occupy a minimum space. Mr. Davison did not inform us what amount of cubical area Sewell's condenser required for any given amount of surface or power, and he was therefore unable, except by inference, to judge whether in this respect that plan had the advantage over the Rowan system or not. He might mention, however, to enable Mr. Davison to make the comparison, that a Rowan condenser he was at present making, and which should be sufficient for condensing the steam of an engine to indicate 400 horses power, occupied 65 cubic feet; and that another, just started in the steamer *Italia*, to indicate 450 horses power, occupied 80 cubic feet. The *fourth* condition prescribed involved, perhaps the most important considerations of the whole, especially when contemplated in a mercantile as well as an engineering point of view; and holding, as every engineer who had given the subject attention ought to do, that surface condensation was but a means to an end, and not to be desired so much for the advantages which it primarily presented, as from the fact that its successful introduction and successful continuous working would give the power of utilizing for marine purposes steam of a much higher pressure than had hitherto been deemed expedient or prudent—from the use of which agent alone, he was convinced, any considerable measure of economy in the consumption of fuel was to be looked for. The use of high-pressure steam at sea, which the introduction of a perfect system of surface condensation would render not an impossible problem, of itself removed one of the greatest stumbling-blocks which had hitherto impeded the usefulness of the surface condenser. He referred to the difficulty which had been so largely experienced in keeping the tubes of condensers, however disposed, free from the injurious deposit of the fatty matter used in the lubrication of the working parts of the engine, and he might extend the remark to the injurious action of the same deposit in the boilers. He took this opportunity of stating that, from a very careful study of the working of the engines of the steamer *Thetis*, using steam very expansively from an initial pressure of 100 lbs., and from careful observations extending over a period of twelve months, during which period the vessel steamed over a distance exceeding 17,000 miles, he was in a position to affirm that it was practicable to work engines continuously at sea without the use of any lubricating matter other than distilled water; and he might mention that the Rowan condenser, with which these engines were worked during that period, was at its expiry in as good working order, and as clean externally and internally, as on the day on which it was started. If, however, it should be necessary to work this condenser where lubrication was used, the tubes could be brushed down without removing them from the case, on simply removing the top cover; and, if from any cause it should be found necessary to remove the tubes from the condenser, he could state from actual experience of the construction of several of 100 horses power nominal, that they could be tubed by two ordinary mechanics in ten hours. He observed, in reference to the cleaning of tubes, that Mr. Davison referred to the cleaning of the tubes of the condenser of the *Mona's Isle*, and he thought it would be desirable to learn from him what was the nature of the deposit found on them, and whether that deposit was both external and internal, or external only; and after how many miles steaming it had formed, and to what thickness? There could be no question, if the reintroduction of surface condensation was to become general in engines worked at the ordinary pressure and lubricated in the common way, that the proper elucidation of the action of the decomposed lubricating matter in the condenser, and ultimately upon the boiler, was one of no little importance, and one which demanded serious attention and consideration. It was this deleterious action which, twenty-five years ago, led to the abandonment of the system, and unless a remedy could now be found, it was evident that the result could not be dissimilar, even although the machinery we have to work with was superior in design. From what he had just stated, it would readily be believed he was convinced that the only remedy lay in the abandonment of lubrication, which could be safely carried out only by working high-pressure steam very expansively and without the adjunct of superheating. In reference to the *fifth* condition—that all the joints should be perfectly tight, he need make no remark in addition to what he had already stated in reference to the continuous working of the *Thetis'* condenser without exhibiting the slightest declension of power or sign of decrepitude over a distance of 17,000 miles, to show that this condition, as all the others, was fulfilled to the full. In concluding, he would remark that what he had stated was sufficient to prove that with the Rowan system of condenser they had obtained, in steady working, a higher average vacuum from a less amount of cooling surface; that they had produced, nevertheless, a lower temperature of condensed steam, with a higher temperature of escaping cooling water, than any other condenser whose performances had been brought under public notice; and he would, therefore, without wishing to prejudice the claims of the system which had been so ably brought before them by Mr. Davison, or to detract from the merits of the analogous arrangement which Mr. Spencer had just described, ask permission to claim for the Rowan system, the practical results obtained from which he had so imperfectly endeavoured to describe, the due consideration which its merits so well entitled it to receive.

The PRESIDENT remarked that they had now heard statements in favour of the plans severally advocated by Messrs. Davison, Spencer, and Rowan; but he wished the members to remember that they had not undertaken the subject in order to give an arena for the discussion of priority of patent rights. They had taken up the subject in order to get at the practical merits of each individual plan, and merely wished to get at the facts arising in actual experience.

Mr. GILCHRIST said that at last meeting he had made a statement, which was controverted by his friend Mr. Davison, regarding the galvanic action. He might be wrong in describing it as galvanic action, and that perhaps it would have been better to have simply called it corrosion. He had seen Mr. Wingate since last meeting, and asked him whether he was right in what he had asserted about the *Sirius*. That gentleman replied, "that he had put in Hall's condensers in that vessel, and that they were used for a couple of years, but for what reason they were taken out he could not say." He was also correct in what he had said about corrosion, or galvanic action. Mr. Wingate informed him that he had been called upon by the late Mr. Thomas Barclay of the Leith and Hull Steam Packet Co., to go and see a steamer at Hull, the machinery of which had been constructed by Symington. He did go, and found that the boilers were supplied with fresh water in a similar manner to that patented by Mr. Howden of Glasgow. The injection water, together with the condensed steam, was cooled by passing through two coils of copper tubes outside of the vessel (the surfaces of which were completely exposed to the sea), and then returning to a receiver inside, from which the injection water was taken. The boiler was supplied with a portion of this water previous to being cooled. In examining the boiler he (Mr. Wingate) found a curvilinear belt of what appeared to him to be grease and verdigris all round the inside; it was about a quarter of an inch thick at the centre, tapering off to nothing at the upper and lower edges, and of a corresponding breadth to the high and low water levels in the boiler, the thickest part being about 3 inches below the highest level. He picked off portions of it in different places, and found the plates very much corroded, and looking as if etched out with a very strong acid. Mr. Symington was asked if he could not adopt something to prevent the corrosion, and the answer was that he knew of nothing, and that nothing but copper tubes would do outside. With reference to what Mr. Scott had said about Mr. Rowan's condenser, he (Mr. Gilchrist) might remark that he had had occasion lately to examine the machinery of a vessel which had one of these condensers, and he could corroborate what had been said about the vacuum. He had got on the upper side 27½ inches, and at the bottom 28¼, and that for a whole day. The upper cock was leaking a little, which might account for the difference of vacuum. In 1765 or 1766, James Watt tried the same kind of condenser with small tubes, but, of course, he had not the same means then of making the ends tight. He had no doubt about the superior vacuum to be got from this condenser, and his opinion was that the smaller the tubes were, the more perfect would be the vacuum, provided the tubes could be kept clear.

Mr. Spencer remarked, with reference to the cleaning or corrosion of the boiler, he had fitted a condenser in the *Alar* four years ago, and after three years' running there was no corrosion, except when they put in some land water. The vessel was at Brighton, where the land water was impregnated with lime, and it was found that when she was filled with land water there every voyage, the deposit in the boiler appeared to corrode the angle-iron, and directly they left off filling her with this water no further corrosion took place. He might also mention that in the case of the *Alar* the temperatures were—57° the injection water, 92° discharge water, 135° the feed-water from the hot well. His opinion was that, with any good surface condenser, there was no difficulty in getting 28 or 29 inches; and he might mention that Mr. Macnab had no difficulty in getting a 28-inch vacuum with one of his condensers. In a vessel working with low-pressure steam, from Newcastle to London, 26½ inches had been got, and it was now working regularly with 26 inches. The engines were of 100 horses power, with two 14-inch air-pumps, 15 inches stroke.

Mr. D. Rowan said the fouling of the tubes seemed to be the great difficulty. Now, he remembered reading in the *Journal of the Society of Arts*, when Hall's condenser had been put into a vessel sent out to the coast of China, a letter from the engineer on the condition of the condenser at various times. In reference to the fouling of the tubes, he said he cleaned them by filling the condenser with an alkaline solution of potash and soda. Whether that affected the tubes or not he did not say, but the condenser was kept in good order, and they were saved all trouble with it. He did not know whether any of the members present had ever used such a solution?

Mr. Spencer said he had used it. He found that by putting the solution in, and having it well shaken, nearly all the grease was taken out.

Mr. Macnab said he had had recently started a pair of engines with surface condensers, and from all appearances he thought they would turn out well. The vacuum obtained came up to 28 inches, with a pressure of 16 or 18 lbs.

Mr. Scott said he happened to have some acquaintanceship with John Drinnan, whose brother was the second engineer of the *Sirius*, and he had mentioned to him (Mr. Scott) the same occurrence of balls forming in the bottom of the boiler—caused by some general sediment, or oxidised iron, gathered together by the tallow, and forming into these round globules at the bottom; and their action seemed to be to cut furrows in the bottom of the boiler, so that it was deemed prudent to take out the condenser and also the boilers. In answer to the President, Mr. Scott stated further, that these were hard balls, so that the furrows might possibly be cut by their mechanical action. The same action had been found in two steamers with Hall's condensers which had been sent to India, where the condenser became one mass of salt.

Mr. Lawrie thought that, when the advantages of surface condensation were so manifest, some mechanical remedy might be applied to get over its defects. There was no reason why every vessel should not have a spare condenser, so that one could be cleaned out whilst the others were working.

Mr. J. M. Rowan said there would be no need for such a remedy if no fatty matter was introduced into the cylinders for lubrication. When used in that way, the fatty matter, being decomposed at a temperature of 250°, not only damaged the condenser, but also the boiler. The only way to get rid of the evil was by altogether abolishing its use for lubrication, which could only be done by using high-pressure steam very expansively, or low-pressure steam *not* superheated.

Mr. D. ROWAN noticed one difference between Mr. Rowan's and Mr. Spencer's plans. Mr. Rowan's did not foul, and Mr. Spencer's did. Now, neither had used tallow about their condensers.

Mr. SPENCER said that there was tallow used in the boilers, and it might have found its way to the condenser.

Mr. J. M. ROWAN said the outside of the tube would foul in some cases, but by improving the circulation of the water this would be prevented.

Mr. SPENCER said he had always found the insides of the tubes through which the water flowed to be bright and clear when examined.

Mr. GILCHRIST remarked that in the condenser tried by James Watt, the tubes got furred; but it was not mentioned where the furring took place. Mr. Gilchrist then suggested that as the subject was so interesting the discussion should be adjourned until another evening.

Professor MACQUORN RANKINE had been present at the earlier experiments in the *Thetis*, and he could corroborate all that Mr. Scott had said respecting the efficient condensation and the vacuum it produced; and he could likewise confirm the remark made by Mr. Scott as to the use of surface condensation, in enabling boilers to be employed consisting of a number of small water spaces, which were favourable to economy of fuel. As to the heat that was said to be wasted by blowing off, there was a well-known method of passing off the hot water through a box or passage containing pipes or passages through which the feed-water passed, and so communicating the heat to that water. Mr. James R. Napier, whose absence was to be regretted, had improved that apparatus by giving it a larger surface, and had saved almost the whole of the heat of the brine in an engine made for one of his ships by the President. But the indirect advantage of a more economical boiler, with small water-chambers, was not to be obtained without a surface condenser. He wished to call attention to the experiments of Dr. Joule, part of which was communicated to the British Association at Aberdeen in 1859. Dr. Joule had obtained from 40 lbs. to 100 lbs. of steam condensed per square foot of conducting surface per hour. Now, Mr. Davison's experiments gave 6 lbs. per square foot of surface, and it would be found that most other surface condensers gave nearly the same result. At the only experiments with Rowan's condenser at which he was present, the condensation took place at the rate of about 4 lbs. per square foot per hour; but the vessel was going very slowly, and the engine was using little steam; and it was evident to him that during subsequent experiments in the same vessel, more steam must have been condensed with the same surface; and probably it would turn out that it was 6 lbs. per square foot per hour, or thereabouts. Dr. Joule employed tubes in pairs—a small tube inside for the steam, and a large tube outside for the water, with a spiral wire between the two. The steam descended inside, and the water ascended outside, taking a spiral course. The contrary motion of the currents of water and steam was of great importance to ensure complete transmission of heat between them. The efficient transfer of the heat depended chiefly on this, and on the rapidity of motion of the currents over the metallic surface. A deposit of lime would take place from the cooling water, if there was lime in it. The power of water to dissolve lime was greater at a low temperature than at a high one, so that at a high temperature lime was deposited. The corrosion from an admixture of tallow and verdigris was a natural consequence of verdigris coming in contact with the iron.

Mr. Davison said, with reference to the circulation of the water about the tubes in Mr. Rowan's condenser, he could easily show that it could not be equal, for mathematical reasons. The tubes were arranged in an annular space, the water entering at the centre, and passing out in radial directions. Now, if they even admitted that a uniform flow of water could be produced from end to end of the tubes by the action of the fan, it was still evident that the same water when passing from the centre to the circumference was filling an increasing space, which it could only do by moving at a decreasing speed; consequently, the current amongst the tubes could not be uniform. With regard to the pressure which Mr. Spencer found with his circulating pump—of 40 feet, or about 20 lbs. to the square inch—he might mention that he had put a pump in the *Mona's Isle*, in which the extreme pressure was 7 lbs., and the general average pressure was about 3 lbs., so that the power could not be very great. He believed it would be impossible to prevent tallow from reaching the boiler if it were used in the engine, as he found the deposit on the tubes was quite uniform, and must have gone in in minute particles, if not in a semi-vaporised form, so that no filtering arrangement could be applied to intercept it. The condensed water in the hot-well seemed to contain tallow in solution, as it had always a slightly milky appearance. The deposit in the *Mona's Isle*, after running six months, was 1-16th of an inch in some places, and consisted of a black greasy matter, whilst in other places there was none. He might mention some experiments with condensers of this class, with the view of showing its operation under various circumstances. In one case the pressure of steam was 37 lbs. in the boiler, the engine cutting off at about half-stroke: the circulating water entered at 44° and left at 85°, and there was a vacuum of 28¾ inches. With 44° entering, and 115° at the exit, the vacuum was 24 inches, and the feed-water 135°. With circulating water entering at 70°, and leaving the condenser at 100°, the vacuum was 27 inches, and the feed-water

100°; and with circulating water entering at 80° on board ship, the vacuum was 26 inches, the feed-water being at 116°. He asked whether Mr. Wingate had done anything to prevent corrosion other than removing the condenser; also whether it was in a wooden ship?

Mr. GILCHRIST answered the first question in the negative, and said that the ship was a wooden one.

Professor MACQUORN RANKINE recommended that the discussion should be adjourned, as it was late, and the subject was evidently not exhausted.

The PRESIDENT remarked on the importance of the discussion, and on the mass of *data* that had been brought forward, and having expressed a hope that Mr. Davison would be able to attend the meeting to be held a month hence, adjourned the discussion.

THE SEVENTH MEETING of the Session was held in the Philosophical Society's Hall, on Wednesday, 3rd April, 1861—the PRESIDENT in the chair.

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The following paper was read:—

## *On Underground Mineral Transit.* By Mr. JAMES FERGUSON.

ILLUSTRATED BY PLATE X.

THE writer has been induced to contribute the following paper to the "Transactions of the Scottish Institution of Engineers," by the repeated solicitations of the President. He believes that the President has an earnest wish to embrace, within the Transactions of the Institution, papers relative to the several branches of engineering of which it is composed; and as this can only be done by the co-operation of members in their several departments, the writer gladly responds to the President's request by contributing these observations and remarks upon Underground Mineral Transit, as his quota to the Institution's general fund of accumulated facts and useful information.

It is not the writer's intention to attempt giving a history of the subject under notice, or to do more than allude, in the most general way, to several of the modes of underground transit now successfully in operation. On the contrary, he proposes to limit the remarks almost entirely to what has come under his personal observation.

Before entering upon any details of the subject, reference may be made to the numerous and peculiar difficulties intimately connected with all kinds of underground mineral transit—which has for its object the conveyance of coal and other minerals from the place where they may be dug, along the passages of a mine to the earth's surface. We may advert to—

First, The various angles of inclination which mineral beds and mineral veins are found to exhibit, and at which they are worked—from a dead level, or undulated plane, upwards through every degree of inclination to the vertical.

Second, The "breaks," "shifts," "hitches," or dislocations to which all mineral deposits have been subjected—met with in all mining operations—whereby the bearing and inclination of the *strata* may be at once so much disturbed, as to necessitate an entire change in the direction of the roads.

Third, The direction and gradients of underground roads as further influenced and, in some measure, determined by the course of the "backs, cracks," &c. These, in sedimentary rocks, are natural vertical divisions of the *strata*, which must be attended to in mining as a matter involving the safety of the workman, and also the economy of the mine.

Fourth, The characteristics of the rocks forming the roof and pavement of the mine, which may be such as to preclude the formation of an economic drawing road. This may arise from two totally different causes:—The concomitant beds may be so very soft, or friable, that for safety they must be secured by timbering; or so very hard, that the construction of a proper road would cost more than the amount of benefit which it would yield.

Fifth, The very small amount of daily traffic which the greater number of the roads in any mine require to accommodate, even when the aggregate produce of the mine is very great.

These are some of the difficulties peculiarly incidental to underground mineral transit, which must have occupied the attention of the miner in his earliest operations, as they do at the present day. Notwithstanding this, in so far as regards the conveyance of minerals from the working faces, where the inclination of the *strata* is great, science has hitherto done little in the way of improvement. With these introductory and explanatory remarks, an attempt shall be made to give a brief sketch of the commencement and progress of underground mineral transit.

I. *Bearing System.*—This system was in operation at the collieries on the "Edge" seams of coal, to the east of Edinburgh, so late as the year 1831—the only time and place where the writer had an opportunity of seeing it. The bearing system is said to have been peculiar to Scotland. Whether this statement is correct or otherwise, there is little doubt as to its having prevailed there from time immemorial up to the passing of Lord Ashley's bill in 1843, whereby all women and boys under ten years of age were excluded from working underground. It is probable that the system had its origin in the "Edge" seams alluded to, and was confined chiefly to that locality, as there are no records of it in the west of Scotland.

This mode of transit, if not the earliest, is certainly one of the rudest that can be imagined. Boys, young women, and mothers were usually employed at the beastly labour, the mode of carrying the load being precisely the same as that followed by the Newhaven fish wives at the present day. All the plant necessary for conveying minerals underground by this system was a basket or creel, capable of containing from 1½ cwt. to 2 cwt. of coals, and a strap, or broad belt, of sufficient length to pass from one side of the creel to the other, and round the forehead of the bearer, when the creel was upon her back; and these the bearer had to provide. In this manner was the coal taken in back loads from the place where it was dug to the surface of the mine. At first this would be done by means of "in-going eyes," or roads from the "out-crop" of the seam; latterly pits were sunk, and the load was carried not only along the floor of the mine, but also up the pit to the surface by means of ladders or stairs, and in some cases these stairs were cut in the sides of the shaft, like a cork-screw. This latter portion of the labour was early displaced by the rope and windlass, horse-gins, water power, and the other modes of raising loads vertically. When the coals, "water free," became exhausted, and the seams were drained by shafts sunk down under the level of the natural adit, the usual method was to sink a shaft midway between the highest and the lowest portion of the breast of coal which had to be worked out. To this intermediate shaft all the coals drained were carried *down* from the upper section, and *up* from the lower section, to the pit's bottom. At the bottom of the pit the creels were emptied into round tubs, baskets, or boxes of sufficient size to contain two or more back loads, and from thence were taken by the winding engine to the pit bank. The bearing system is illustrated in fig. 15, Plate X.

The first step taken to improve this system was the introduction of rails, and the conveying of the large baskets or tubs, upon a truck, along the level roads to stations, where the bearers were sooner relieved of their load.

Mr. Dunn, at present one of the Government inspectors of mines, in his work on the "Origin and Progress of Coal Mines," states that the load carried by the bearer was from 200 to 240 lbs., and the distance which it was conveyed was about 2800 yards per day; in other words, 40 loads per day carried a distance of 70 yards. For performing this labour the bearer was paid from 1s. to 1s. 2d. per day.

The following statement, which has been obtained for the purpose of preparing this paper, is somewhat different from that published by Mr. Dunn, and corresponds with what is published by Mr. Bald in 1812:—

1. Average distance carried, ........................ 400 yards.
2. " weight per load, ........................ $1\frac{1}{2}$ cwt.
3. " number of loads per day, ............. 24

Which calculated at 1s. 2d. per day, gives 34·1d. as the rate per ton per mile for cost of conveyance. Whilst in this statement the details of labour are different, the rate of remuneration is the same as given by Mr. Dunn—namely, 1s. 2d. per day—when colliers were being paid at the rate of about 2s. 6d. per day.

Mr. Bald, mining engineer, Alloa—the worthy father of the profession in Scotland—in a work entitled "Inquiry into the State of the Women who carry Coals underground in Scotland—known by the name of *Bearers*," published in 1812, says that—carrying $1\frac{1}{2}$ cwt. as a load—the daily labour performed for five days each week was—

| | | |
|---|---|---|
| On the level at the pit bank, ......................... | 480 | yards. |
| On a rise of 1 in 12 feet—that is, a rising gradient at the rate of a little more than 146 yards per mile, | 3,600 | " |
| The vertical distance being, ............................ | 936 | " |

Mr. Bald adds, the wages paid for this work was *eightpence per day.*

Another statement is given, which, as well as the above, came under Mr. Bald's personal observation, in which a load of $1\frac{1}{2}$ cwt. was conveyed 8400 yards, with a perpendicular rise of 700 yards, as a woman's daily work, the distance passed over with the load being at the rate of 38·9d. for conveyance per ton per mile. The bearer, in addition to the labour of carrying a load at the rate of 38·9d. per ton per mile, raised 5 cwt. to the height of 200 yards—being one-fourth of a day's work for an able-bodied man.

In an article which he contributed to Brewster's Edinburgh Encyclopedia, published in 1830, he says, "The weight the women carry is from $1\frac{1}{2}$ to 2 cwt., and in some cases they have been known to carry 3 cwt. At several collieries in Scotland 60,000 tons a year have been carried in this way."

The writer has alluded to the mode of bearing under its most favourable aspect; that is, when there was sufficient space to carry the back load in the easiest manner for a human being; but the wicked abuse did not stop short at this stage of degradation for the bearer. Being reduced into a system, it was introduced into the thin coal seams also, where the body had to be bent downwards and distorted whilst the heavy load was put upon it—the poor bearer performing the task in a manner perfectly disgusting even to think about. The following description of how a load was carried in these thin coal seams is from the mouth of one who in her youth had been so employed:—"The creel was first filled, and whilst the bearer was stooping, and bending forward, the loop or bight of the strap fixed to the creel was passed over her back and forehead, and thereby was the load sustained—the length of the strap being so adjusted as to allow the creel to hang down behind over the body, partly resting upon it, but only kept from falling by the strap pressing against the forehead." In such a position as we have attempted to describe—with the highest part of the back and the top of the load nearly on the same level—the head and shoulders of the bearer were necessarily still farther depressed. An addition to the load was now made by placing a block of coal upon the neck between the shoulders, whereby the muscular action in operation to keep the head down was materially assisted, and the tendency of the overhanging load to draw the head upwards was in a certain degree met and provided against; or as our informant stated, "it helped to balance the creel."

Whatever evils yet linger amongst us of this sort, that one is now gone for ever, and with it several curious incidents of social life which it engendered. The supply of bearers being limited almost entirely to those who had been trained to the labour from early youth, there was a constant demand for them; and a stout lass who could carry a few pounds more than her neighbours, could *choose* her husband from the young colliers of the mine. It is also told that upon those interesting occasions, which are from their nature peculiarly feminine, the husband rested until his wife was able to resume her share of the underground toil.

II. *Sledge System.*—The first step taken to lessen the labour of underground transit by the application of mechanical skill, was the introduction of the sledge or "slipe-hutch"—the name given to any kind of box, with cradle feet, used for conveying mineral underground. The sledges were drawn along the natural floor of the mine by men, women, and boys; and where animal power could be profitably applied, that power was also made use of. The sledges were shod with iron, and contained from 1¼ to 5 cwt., according to the inclination of the road, the nature of the pavement, and the motive power. Where the pavement or floor of the mine was soft, slabs from round trees, wattles, and other such things were laid down across the line of road to reduce the friction.

The harness used for this kind of work, when manual labour was applied, consisted of two straps passing over the shoulders—the four ends being connected with a chain to which the load could be attached. On a well-kept road, with a rise of about 1 in 8, the labour of dragging a gross load of 7½ to 8½ cwt. downwards, is nearly the same as the taking of an empty hutch in the upward direction—the weight of the empty hutch being from 2 to 2½ cwt. On a level road it requires the utmost exertion of an able-bodied man to drag a gross load of 8 cwt., and the labour cannot be maintained for any considerable distance at one time.

This mode of transit upon a level road is most laborious and exhausting, involving a continuous dead pull, where not a single inch of ground can be passed over without a corresponding effort. When engaged in it the drawer may be seen stretched forward nearly into a horizontal position, his hands clutching at the pavement, or pressing against the sides of the passage, to aid his slow progress, every muscle as rigid as iron, and strained to the utmost. This mode is shown in fig. 16, Plate X.

The sledge mode of transit was the only one in use at a considerable colliery in Scotland within the last fifteen years, and as the labour of drawing the coals was performed by contract, and perfectly unconnected with the labour of digging them, a correct idea is obtained of the cost of conveyance by this system. The quantity conveyed in the hutch or sledge at one time was little more than 1¼ cwt. *less*, it may be noticed, than the weight which the collier put upon his daughter or wife for a back load. Without going into the reason why such light loads were drawn, we shall at once state that, for the drawing of twenty score—21 being considered a score—that is, for the drawing of 420 of these light loads the distance of 60 yards, the sum of 8*s.* 4*d.* was paid, and also that these 420 loads only weighed 26 tons 5 cwt. For every additional 24 yards which the 26 tons 5 cwt. was conveyed, the sum of 4*s.* 2*d.* was paid. Thus, with wages at about 2*s.* 6*d.* per day, we have—

| | | *s.* | *d.* |
|---|---|---|---|
| 1. | Rate per ton per mile when conveyed a distance of 60 yards, | 9 | 3½ |
| 2. | " " when carried a distance of 84 yards, | 9 | 11½ |

At Auchinheath colliery, about thirty years ago, the system in operation was a combination of sledge work and railway. The flat long boxes weighed about 2½ cwt., and when carefully filled carried a load of 5½ cwt. The price paid for drawing 300 yards, or thereby, upon the level railway, with 100 yards of sledge work to the rise of the level, was 1s. per ton, or about 3s. 8½d. per ton per mile, wages being 4s. per day.

The increased remuneration for sledge work was at the rate of 4d. per ton per 100 yards, or at the rate of 5s. 10d. per ton per mile.

*Horse Sledges.*—Horses, mules, &c., were from an early period made use of in coal mines to drag the sledges instead of men. The horse sledge contained from 5 to 6 cwt., and were sent direct from the working faces up the shaft to the pit-bank, as filled by the colliers. This was a step in the proper direction, animal labour being substituted for severe manual toil, and refilling was dispensed with. Being without details of the cost of sledging by horses, it is only from general recollection, the writer states, that he is satisfied that this mode of transit was by no means an economical one; and of all the kinds of labour to which horse power has ever been applied, underground sledge work was one of the most wasteful and cruel. The drawing chains of the horses' harness being attached direct to the ends of the cradle foot of the sledge, jolted from one side to the other, as it proceeded along the uneven track, striking against the pillars; or as it was hurriedly conveyed down the rugged inclines, the horse was tugged and twisted in every direction, and cut and bruised in every possible manner—now lashed forward to keep clear of the descending sledge, and the next moment straining to take it onward over some newly-fallen portion of the roof—first one drawing chain and then the other having all the strain upon it, as the load was shifted from one galled shoulder to the other, in taking the dark angular passages of the mine. The drivers were usually boys, all tasked to a certain number of "raiks" per day, each striving to outstrip his neighbour, if by lashing and reckless driving he could possibly do it.

*Sledge and Rail.*—The first step towards improvement upon the sledge system, as in the case of "bearing," was the introduction of rails upon the level roads, a low-wheeled truck being used to carry the sledge or box containing the load. The men or horses, as before, dragged the sledges from the working faces to a station upon the main road, where a bench the same height as the truck gave facility for placing the loaded sledge upon it.

The gauges of the early underground railways were exceedingly narrow —in some cases not more than 15 inches—and on account of this circumstance, it is presumed, men were at first employed to push the wheeled truck, with the loaded sledge upon it, from the station to the bottom of the shaft. As the advantages of railways were very soon seen, the introduction of a wider gauge, and a horse to drag a train of loaded trucks, naturally followed. In addition to this, the railways were extended from the stations on the main roads into each of the working faces, the sledge work being restricted to the rise workings where, from the steepness, a truck with the sledge upon it could not be taken. The use of sledges is now entirely confined to mines where the inclination of the strata is more than 1 in 6, and in very few cases are the sledges sent up the shaft to the bank, as was done until very recently almost everywhere. Where the inclination of the sledge track approaches the angle of 40°, the drawer finds it to be less laborious to carry the sledge upon his back than to drag it behind him up the steep incline. In such cases two sledges are sometimes used in each of the working faces, with a chain and pulley, whereby the empty sledge is dragged up the incline by the full one, the drawer guiding the full one in the descent. The chain and pulley are fixed to a tree, which is jammed hard up between the roof and pavement, and is removed upwards from time to time as the working face advances.

III. *Barrow System.*—Previous to the introduction of four-wheel trucks and rails, wheel-barrows were partially in use as an improvement upon the sledge. "The inconvenience felt in the transfer of the coals from the barrow to the tub or basket in which they were to be drawn up the shaft," says Mr. Dunn, "originated the tram, with wooden wheels, upon which the coals could be conveyed in a tub or basket from the working faces to the top of the pit without transfer. The barrow-ways suitable for the tram consisted of three planks, the upper one forming the guide for the tram wheels."

IV. *Railways as now chiefly used underground in Scotland.*—It is foreign to the object of this paper to attempt giving a history of the many rude appliances which were the prelude to the railway of the present day.

Wooden rails and sleepers were introduced in the north of England between 1632 and 1649. In 1676 they are described as being made by laying rails of timber from the colliery to the river, exactly straight and parallel. Within the last twenty years, railways formed with hardwood timber alone, or of timber covered with thin bars of iron, were to be met with at many of the small collieries in Scotland, and also the carriage with its timber axle and wheels.

The first certain account of cast-iron being used for rails is met with in the books of Colebrooke Dale Iron Co. From these it appears that on the 14th November, 1767, between five and six tons were cast as an experiment, under the superintendence of Mr. Curr. Mr. Curr, in his "Coal Viewer and Engine Builder," published in 1797, claims to have invented and introduced cast-iron tramways or plate rails, at the Sheffield colliery, in the year 1777, that is, twelve years after the experiments made by him at Colebrooke Dale in Shropshire.

The earliest notice which we have of malleable-iron being used for rails is at Walbottle colliery, near Newcastle-upon-Tyne, partially laid down as early as 1794, and completed by Mr. C. Nixon in 1805. John Neilson of Oakbank, near Glasgow, laid the first malleable-iron rails in Scotland at Hurlet about the year 1818.

The general introduction of railways underground did not at first very much modify the arrangements for collecting and conveying the produce of the mine. The low-wheeled truck was long retained, with the basket, tub, or sledge placed upon it containing the load; and, where horses were employed two or more loads were placed upon one truck, being lifted from the small truck and placed upon the large one by means of a small crane. The inconvenience of this method is evident; and it is again to Mr. Curr of Sheffield colliery that we are indebted for the next step in the way of improvement by the introduction of wheeled carriages as now used —a most decided improvement upon the truck with the detached basket or tub containing the load. Previous to the wheeled carriages being sent up the shaft, an arrangement had to be made to prevent breakage, and at first they were guided by conductors of iron stretched from the pit-head framing to the bottom of it, and made as tight as practicable. These conductors, formed of iron bars, united by means of links or screws, have been used in some of the English collieries from the time of their first introduction until the present day, and such conductors are still partially made use of, with wire ropes substituted for the bars of iron.

The invention of the cage was necessary to perfect the plan of taking the loaded wheel carriages up the shaft, and by it this can now be done at any speed with the utmost safety. These cages or platforms may be made to contain any number of wheeled carriages, and are made to carry from one to eight at a time. They are permanently attached to the winding ropes, and kept in their position by perpendicular wooden guides fixed to the sides of the pit. The cage and guides first introduced into Scotland about twenty years ago, are now almost universally used along with the wheeled carriages for conveying the load direct from the working faces to the pit bank. It does seem strange why the fixed wooden guide was not first discovered, being at once the best, the simplest, and the cheapest.

While the guides or conductors have been improved, our underground rails and railways throughout three-fourths of the Scottish mines are very much what they were when first made by Mr. Curr about seventy years ago. The cast-iron sleepers introduced by Mr. Curr have been for a long time abandoned; in other respects they are precisely the same. The reason why so little attention has been paid to so important a matter may be found in the fact that hitherto the greater number of the pits in Scotland have been so easily sunk that it was more profitable to sink a new than to make and maintain an extended system of good roads from an old one; and this the more from the irregularity and disturbed character of the mineral fields in Scotland, rendering any uniform plan of working an utter impossibility.

With few exceptions, cast-iron plate rails and wooden sleepers are used in the railways of the mines in Scotland. These rails weigh from 50 to 60 lbs. per lineal yard of railway, and cost just now about 85s. per ton; and including sleepers, nails, and laying down, the mile of railway costs only about £220. From the difference of weight in the rails when malleable-iron is used, the cost per mile is nearly the same. The gross weight carried upon these rails is seldom more than 10 cwt., and even with that load the breakage of cast-iron rails is very considerable. The carriages used in the coal mines of Lanarkshire weigh from 2 to 2½ cwt., and are calculated to contain 4½ cwt. of riddled coals, free from dust and small coals, or about 6 cwt. of useful load. Wheels are used both of malleable and cast iron, and vary in diameter from 8 to 12 inches, being sometimes fixed to the axle and at other times loose upon it.

In many places the drawing of coals, as well as the getting of them, is performed by the collier, and in such cases there is some difficulty in ascertaining the actual cost of conveyance; in others, the drawing of the coals is performed by men specially employed for that purpose, with horses to convey the trucks along the level roads and up inclines, where, from any unavoidable cause, these are necessary in the operations of the mine.

The following particulars are the result of inquiries made regarding the cost of conveyance in some of the collieries in the Monkland district, where drawers are employed, and no horses introduced:—

1. In pits where the metals are nearly horizontal, the distance travelled

per day, with the load of 6 cwt. is from 4000 to 6000 yards, and the cost per ton per mile, from 2s. to 3s. 2d.

2. In pits with the metals inclined upwards, with a rise of about 1 in 6, or an angle of 10°, the distance travelled, with the load of 6 cwt. per day, is from 3000 to 5500 yards, the cost per ton per mile varying from 2s. 4d. to 4s. The difference in this case may arise from the greater length of rise roads.

3. In pits where the drawing of the load is upwards, and where, from other local causes, the roads have to be laid off with bad gradients, the distance travelled with the usual load per day varies from 1250 to 3000 yards, and the cost per ton per mile is from 4s. to 7s.

The following particulars are from collieries on the Lesmahagow line of railway, established within the last few years, where the drawing is a combination of manual and horse labour:—

1. Distance travelled with the load on rise roads, 170 yards; distance travelled on level roads, 220; total, 290 yards. Average cost per ton per mile, 1s. 3¾d.

2. Distance travelled with the load on rise roads, 250 yards; distance travelled on level roads, 374; total, 624 yards. Average cost per ton per mile, 1s. 7d.

At Auchinheath and Craignethan gas coal works, in the parish of Lesmahagow, an attempt has been made to improve upon the system of underground transit as now at work in the west of Scotland. The carriages used (figs. 7 and 8) are 4 feet 9 inches long by 3 feet wide inside, and 8 inches deep, and weigh when new and dry, 4 cwt. 1 qr. 14 lbs., with 12-inch cast-iron wheels for edge rails. The average load of coals, taken from the weigher's book at the pit mouth, is 13 cwt. In drawing ironstone or refuse the average weight is about 17 cwt., although a load of 20 cwt. is sometimes put into the waggons and sent up the shaft.

Common malleable-iron bars are used for rails, 2 inches by ⅝ths on the rise roads, and 2 inches broad by ¾ths thick on the more permanent level roads, being notched into the intermediate sleepers, with cast-iron chairs at the joinings. The cost of a mile of railway is £300. In laying the bars, the joinings of opposite rails are never made on the same sleeper. Some time previous to the introduction of horse labour, about eighteen months ago, a careful account was taken of the work performed and the cost of it. The average length of the level roads was 376 yards, the shortest being 120 yards, and the longest 611. The average length of the rise roads was 118 yards, the shortest being 12 yards, and the longest 283. The greatest distance travelled by a "drawer" per day, taking the average of a fortnight's labour, was 9 miles 91 yards; the general average of travel was between 6 and 7 miles, this including going out with the load and returning with the empty waggon; but it must be noticed that the pushing of the empty waggons up the rise roads was the most severe portion of the labour performed.

At the time when the cost was calculated, the employment of a boy to assist the "drawers" up the rise roads had become almost universal, and the price paid for drawing was 4s. per day to a man and 2s. to a boy for one load. The writer is satisfied that in this case the distance was exceeded at which, under the circumstances, manual labour should have been employed—the number of "drawers" upon such a length of road causing much time to be lost in waiting upon each other, whilst on the level roads a boy was not required, although the labour had become too severe for one man to perform the usual and requisite number of journeys. The cost per ton per mile varied from 2s. to 3s. 8d. at 6s. per day for the drawing of one load, or at the rate of from 1s. 4d. to about 2s. 6d. per ton per mile when 4s. per day was paid. Horses are now introduced, whereby all the labour of drawing is performed, with the exception of taking the loaded waggon from the working face to the foot of the rise roads.

Previous to giving the details of cost, it may be noticed that the system is at work where the arrangements of the mine were not specially prepared for it, and it is already seen where several improvements to lessen cost can be introduced. Considering that remarks on a matter so local are unsuited for a paper such as this, the details of the system are given precisely as they are now in operation, with the labourers' wages at from 3s. 6d. to 4s. per day.

1. Labour performed by men—taking the loaded waggons from the working faces to the foot of rise roads, and walking back the distance the load is conveyed, is paid at the rate of 1·5d. per ton, or 16·6d. per ton per mile.

2. Labour performed by ponies, that is, taking the waggons up the rise roads and returning the same distance without any load, say with turnings 7 miles per day, now costs at the rate of 2·5d. per ton, or 23d. per ton per mile.

3. Incline work 1·6d. per ton, or 8·7d. per ton per mile.

4. Train horse, with driver, &c., travelling from 12 to 14 miles per day, ·8d. per ton, or 2·6d. per ton per mile.

The total cost per ton by *horse* labour is 6·4d. of a penny per ton, or at the rate of 1s. 1½d. per ton per mile, the average length of roads being taken at 836 yards. The average cost of *manual* labour previous to the change was 9·6d. per ton, or at the rate of 2s. 10¼d. per ton per mile; but at that time the distance conveyed was considerably less, being only an average one of 494 yards.

The following particulars are from the Coltness Iron Company's pits, Wishaw district:—

Pit, No. 1.—Output for 4 weeks, 4934 tons.

| | £ | s. | d. |
|---|---|---|---|
| Cost of Transit:—Horses (5 at 3s. each per day), 24 at 15s., = | £18 | 0 | 0 |
| Bottomers, . . . . | 6 | 14 | 4 |
| Roadsmen, . . . . | 8 | 8 | 0 |
| Ostler, . . . . | 3 | 12 | 0 |
| Drawers, . . . . | 55 | 5 | 10 |
| | £92 | 0 | 2 |

| | | | | | Per ton per mile. |
|---|---|---|---|---|---|
| 49 men draw 400 yards, 2912 tons, cost . | £54 | 6 | 2 | = | 12·64d. |
| 34 " 800 " 2022 " . | 37 | 14 | 0 | | 9 84d. |
| Average, . . . | | | | | 11·24d. |

Pit, No. 2.—Output for 4 weeks, 5687 tons.

| | £ | s. | d. |
|---|---|---|---|
| Cost of Transit:—Horses (5 at 3s. each per day), 24 at 15s., = | £18 | 0 | 0 |
| Bottomers, . . . . | 7 | 12 | 0 |
| Drawers, . . . . | 31 | 19 | 5 |
| Drivers, . . . . | 8 | 16 | 0 |
| Roadsmen, . . . . | 12 | 18 | 6 |
| | £79 | 5 | 11 |

| | | | | | Per ton per mile. |
|---|---|---|---|---|---|
| 45 men draw 300 yards, 2641 tons, cost . | £36 | 16 | 6 | = | 19·63d. |
| 52 " 650 " 3046 " . | 42 | 9 | 5 | | 9·06d. |
| Average, . . . | | | | | 14·34d. |

The following particulars are from the Staffordshire district where "skips" (fig. 13) are used, and are taken from a certain pit which is considered to present a fair example of the cost of haulage. The *datà* for the calculation are—7288 skips, weighing 345 tons 12 cwt., conveyed the distance of 645 yards; that is, the average distance of the working faces from the bottom of the pit, at the cost of—

| | £ | s. | d. |
|---|---|---|---|
| 18 Horses, at 6s. 6d., . . . = | £5 | 17 | 0 |
| 18 Drivers, at 2s, . . . . | 1 | 16 | 0 |
| Roadsmen, . . . . . | 0 | 4 | 0 |
| Horse-fettler or groom, &c., . . | 0 | 3 | 6 |
| Cager or hanger-on, . . . | 0 | 3 | 6 |
| | £8 | 4 | 0 |

This makes the cost per ton per mile 15·55d.

The writer has already alluded to the numerous and peculiar difficulties intimately connected with all kind of underground mineral transit; and to these may be attributed the slow progress of improvement, the light loads conveyed, and, generally, the high cost of conveyance per ton per mile, as compared with railway carriage above ground. One of the difficulties—perhaps the chief one—is the utter impossibility of maintaining uniformity of gradient; and the practical result of this want of uniformity is evident, the load having to be regulated by the steepest part of the road over which it has to be conveyed, and in most cases this difference being very considerable. We have said the load has to be regulated by the steepest part of the road; and this is the case, whether as regards the pushing of the load upwards or the lowering of it down, when the inclination is more than 1 in 6, and the load from 6 to 8½ cwt. gross.

When an arrangement can be made to concentrate a number of rise-roads into one, a self-acting incline, regulated by a brake, is a usual and approved mode of lowering coals, where the loaded hutches in descending on one line of rails take up the empty ones upon another line.

A similar arrangement of roads, with motive power at the top of the incline, may be used when the load has to be taken upwards. Where the gradient is such that the descending empty carriages "overhaul" the rope, one line of rails will be found sufficient for a very large output, if fitted up with the necessary motive power. Where the inclination is less and the empty hutches descending do not "overhaul" the rope, a double line of rails is again necessary, or some other application of a "tail-rope," to take the empty carriages and the drawing rope to the lowest part of the mine for a new load. Or the rope may be worked over pulleys at the top and bottom of the incline with a slow continuous motion, the ascending loaded carriages being upon one line of rails and the empty descending ones upon the other, arrangements being made for attaching and detaching at any place when necessary.

Where the natural mode of working a bed of coal will admit of the working faces being carried on parallel to the main level road, or nearly so, a self-acting incline, with an endless rope, to which the loaded carriages could be attached, and from which the empty ones could be taken at any place upon the incline, would be an economic and novel application (so far as the writer knows) of this mode of transit—this plan being suggested by the description of drawing loads upward in a similar manner.

For examples of what can be done under ground under favourable circumstances, as regards the extent and regularity of the coal-field, we can refer to vols. iii. and v. of the Transactions of the North of England Institution of Mining Engineers. It is there stated that engine planes have been worked of a length of 2519 yards, or nearly one and a half miles; that 106 tubs, each containing 8 cwt. 2 qrs. 8 lbs. of coals, and weighing 482 lbs., or a gross weight of nearly 13 cwt., were conveyed in one train at a rate of speed equal to nine miles per hour upon an incline of 1 in 5. In the same volumes will be found a paper by Nicholas Wood on a plan of working coal-fields entirely by a system of self-acting and engine-worked inclines.

Besides manual and horse power, steam power, compressed air, and water, have been and are used for driving winding machines under ground. At St. Helen's Auckland Colliery, Durham, steam is conveyed, first down a shaft of about 150 yards deep, and from the bottom of the shaft down an incline of 15° a distance of 1100 yards, making a total distance of 1250 yards.

From the result of this experiment it appears that a pressure of 40 lbs. per square inch is required to force steam at the rate of 64·5 feet per second through 1250 yards of 5-inch pipes, and that the loss by friction and condensation under such circumstances is 80 per cent., the pressure being reduced from 40 lbs, to 8 lbs. per square inch. Mr. Wood obtained no practical results from steam of 35 lbs. per square inch pressure, conveyed 1012 yards through 4-inch pipes.

Compressed air is used as a motive power at Govan Colliery, near Glasgow. The steam-engine used for compressing the air is at the pit bank; the compressed air is carried down the shaft 92 yards, and from thence to the place where it is used, a distance of 706 yards. A paper upon this engine by Mr. Charles Randolph, Glasgow, was read at the Glasgow meeting of the Institution of Mechanical Engineers in September, 1856.

Where there is surplus pumping power, water, with a high pressure, may be taken from the engine pump, conveyed along the passages of a mine, and used as a motive power for winding with any kind of suitable machine.

For working out a detached area of coal—where the cost of sinking a pit from the surface would be more than the profit on the quantity which it contains, and where, from any cause, the introduction of steam or any other motive power would also be too expensive—a wire-rope may be passed down a bore from the surface to the place where the lifting power is required, being worked by steam or any other available means.

The writer has introduced these observations on motive power to show that where the object in view is of sufficient importance to demand an effort from the inventive faculty of the engineer, the necessary mechanical appliances are not wanting. What we most require, however, is a simple, safe, and expeditious mode of working inclines at a high angle, say with a rise at the rate of 1 in 1½, or 1 in 2, and that with loads of from 15 to 20 cwt., under the control of one man.

Such a machine, to be really useful, should be of such a description that it could be applied to the working-roads as these were cut forward, and also to any place upon a road where, in consequence of "hitches," or any other cause, a steep gradient had been introduced. There are many ways, perhaps, in which this can be done, but none has yet been discovered sufficiently cheap and simple to warrant its universal adoption, from its merit being clearly seen and felt, as in the case of Mr. Curr's rails and wheeled carriages.

Self-acting inclines are the nearest things we have that are available, and might be used advantageously to a much greater extent than they now are, notwithstanding the cost of the drum, &c., or the still more simple arrangement of a single pulley—the fixed retarding force being a certain number of the wheels made fast, whilst the man going along with the loaded hutch holds back or pushes forward as may be required to keep up a uniform motion.

The writer has tried several modifications of the incline—1st. A double road worked by single length of chain, passing round a horizontal wheel, with friction-strap upon it, and a second strap to press upon the chain where more retarding power was required. 2nd. For short and very steep gradients such as an angle of 45°, where the nature of the roof precluded the idea of making any opening sufficiently wide to admit of a double road, a line of rails was laid for running a counter-weight upon, which assisted the friction brake on lowering the carriage when loaded, and was of sufficient weight to raise it when empty, as shown in fig. 19. 3rd. A single road and pulley, with the chain running under the descending waggon, until the two meet upon a platform midway. At this place the empty waggon is removed from its position below the loaded one, and put upon the rails above it, the chains being at the same time adjusted so as to run under the ascending empty waggon. This latter mode, shown in figs. 17 and 18, may be applied with advantage where the work to be done does not warrant the erection of a proper machine.

Where hitches in the *strata* are numerous, and the field unexplored, in drawing loads, such as from 12 to 15 cwt., it will be found the cheapest plan in many cases to go over these at a high angle—45°, or whatever is the angle of the rise, or slope of the dislocation. To work this a small crane can be used, whereby one man can lower the loaded waggon and take up the empty one with ease.

When it is kept in view that the present yearly output of coal in Scotland is upwards of 10,000,000 tons, and the output of limestone, ironstone, and other minerals, will be about 3,000,000 tons, an idea can be formed of the magnitude and importance of the matter to which attention has been directed. Viewed as a money matter, and taking 1s. per ton as the average sum paid for underground transit on all minerals raised, the total amount is £650,000, although from the statements here given perhaps £1,000,000 would be nearer the real amount.

Having already taken up so much space with the few facts collected, the writer refrains from making the comparative remarks which these naturally suggest, further than to notice the decided improvement which has taken place in the condition of the underground labourer. In making any comparisons, however, as to the amount of labour performed, the wages paid must be kept in view as well as the cost per ton per mile, and also that the value of plant employed has not been considered in any of the calculations.

In concluding, it may be stated that the writer would gladly have put additional matter, regarding some of the more extensive mining concerns, into a shape for comparison in this paper, had he not experienced a difficulty in procuring it—in such a form as to be of any value—notwithstanding the explanation that the details were wanted for a purely scientific object.

With a more extended range of facts it might be interesting to reduce the several kinds of labour performed into units of power, and thus ascertain without complicating the subject by the value of cash or labour, whether the daily toil of the workman has increased or diminished within the last fifty years.

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*Description of Plate X.*

Figs. 1 & 2.
" 3 & 4. } Side and end elevations of trucks used in the neighbourhood of Glasgow. Load, 6 cwt.

" 5 & 6. Side and end elevations of trucks used in Messrs. J. Ferguson & Co's. mines, Auchinheath and Craignethan, Lesmahago. Load, 15 cwt. Used for soft coal.

" 7 & 8. Ditto——Load, 15 cwt. Used for gas coal and ironstone.

" 9 & 10. Ditto——Load, 10½ cwt.

" 11 & 12. Side and end elevations of trucks used in the Duke of Hamilton's mines, Lesmahago. Load, 8 cwt.

" 13. Elevation of the skips used in Staffordshire. The iron hoops are added after the other, as the coals are built up. Load, 24 cwt.

" 14. Edge elevation of malleable-iron sleepers, recently introduced in underground railways in Staffordshire. These sleepers are used with a 21-lb rail, for a gross load of about 30 cwt., and the cost of a mile of way laid with them is £300.

" 15. Vertical section, showing early mode of "bearing" in a *thin* seam of coal.

Fig. 16. Vertical section, showing the "sledge" system in use at Auchinheath in 1832.

" 17 & 18. Vertical and horizontal sections, showing plan of self-acting incline, with one line of rails.

" 19. Vertical section of self-acting incline, with counterweight running beneath the main rails.

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In the discussion which followed—

Mr. SIMPSON was afraid cast-iron sleepers could not be successfully used underground where the roof was brittle, and he was of opinion that malleable iron ones would not serve much better; for though they did not break they would bend, whilst both applications would be more expensive than wood, and not so easily bedded. The Scotch collieries had scarcely all advanced so far as Mr. Ferguson had said, for at Teaze's Colliery in Fife the sledge mode of transit was still in operation. In regard to the cost of transit—was the difference between a thick seam and a thin one kept in view by Mr. Ferguson in his estimate of the quantity of coal conveyed? A thin seam might be double the distance, or more, from the shaft for the same quantity; but a mean distance between the shaft and the face would give a more correct idea of the cost of transit.

Mr. FERGUSON did not very well understand the question; but all his calculations were reduced to the cost per ton per mile, so that it made no difference whether the coal was brought long or short distances.

Mr. SIMPSON did not understand what Mr. Ferguson meant by the various inclinations or ups and downs in drawing roads that the miner had to contend with, as the general practice was to make the inclinations as uniform as possible, and self-acting inclines were now generally adopted for rise workings, and ponies were generally used for drawing from the inclines along the levels to the shaft.

In answer to a question, Mr. FERGUSON said his calculations of cost of transit included all the cost of keeping, but not the first cost.

Mr. R. BROWN remarked that he had read a letter in a newspaper the other day from a gentleman who had been down sulphur mines in Sicily; and he stated that instead of the sulphur being brought up by an engine, it was brought out on the backs of girls and boys, who cried all the way up, and as soon as they delivered their load they began to whistle, and continued until they got to the bottom again. Some of our pushing engineers might get orders out there, if they could show the benefits of the mode adopted in this country.

Mr. NEIL ROBSON said, that Mr. Ferguson's paper was so full and complete that it had left little to be said upon the subject. He had never heard so comprehensive a description of the different modes of underground transit. He agreed with Mr. Ferguson in almost all his conclusions; but he thought Mr. Ferguson need not have travelled to Newcastle to cite examples of drawing minerals underground by steam power; for at a colliery within seven miles of where they were sitting there was an incline nearly three quarters of a mile in length, with an inclination of one in five, worked very efficiently by an engine placed near the pit bottom, to which the steam was conveyed by a 4-inch pipe, carried down the shaft to a depth of about 40 fathoms. The coal was drawn up that incline at a cost considerably under any instance that Mr. Ferguson had given. He had at one time thought that the drawing of minerals from the dip could not be done as cheaply as from the rise or down-hill—by self-acting inclines, or by gravity alone—but he found in the instance referred to that it was really cheaper. It was obvious, however, that there was still a good deal to be done in cheapening underground transit. Supposing Mr. Ferguson to be correct, of which he had little doubt, 15d. seemed to be about the average cost per ton per mile from the working faces to the pit bottom, whilst carting was done in Glasgow at 6d. per ton per mile; and on railways on the surface, minerals were carried at rates varying from 1d. to 3d. per ton per mile. One good end to be served in bringing this paper before the society, would be to lead practical men to think of still further economy in this matter, and thus benefit them all, as they were all interested in cheapening the working of coal and ironstone.

The President was gratified with the manner in which Mr. Ferguson had responded to his request in bringing forward this paper. The complete and correct *data* therein recorded, would form a standard from which others might prosecute inquiries into the matter. They were also very much indebted to Mr. Ferguson for introducing a new subject for inquiry to them. It had been a matter of surprise to himself and others, that they had not had other papers on mining operations, especially considering that so large an amount of the capital of the country was engaged in them, and so much employment given in this neighbourhood by them. There were many other matters besides this one connected with mining, which had important influence on the profits and loss of large collieries, and which would form advantageous questions for discussion; and it was very much to be regretted that none of these matters had before engaged their attention; but he hoped that in future years subjects connected with mining would be brought before them. He concluded by proposing a vote of thanks to Mr. Ferguson for his paper, which was duly awarded.

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THE EIGHTH MEETING of the Session was held in the Philosophical Society's Hall, on Wednesday, 17th April, 1861—the PRESIDENT in the chair.

This was the Annual General Meeting for the election of office-bearers for the Fifth Session, 1861–62.

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The discussion was resumed

*On Surface Condensers.*

The SECRETARY read the following communications:—

*From* Mr. DAVID NAPIER.

"I have not the slightest doubt of the day not being far distant when surface condensation will be generally used, both on land and water. I have had nothing to do with a steam engine of any kind for upwards of thirty years, without a surface condenser. The engine I had for driving my lathes at Millwall, London, had one. It is true that I have sold steamers having surface condensers, which the purchasers immediately turned out. I may state an instance of that in the *Falcon*, about twenty-six years ago, on hearing which, I wrote the proprietors offering to buy the condenser if they had no other use for it. It consisted of a number of thin flat iron tubes made of sheet iron, contained in an iron box or case about four feet square. I ultimately did buy it back, and put it just as it was into a steamer called the *Chieftain* (which steamer I purchased from the same parties who bought the *Falcon* from me). After constructing the engines of the *Chieftain* so that they would consume every particle of steam the boilers could produce, and not allow any to blow off, I had the boilers filled with pure water from the hills of Kilmun, from which place I started and went by the Pentland Firth to London, from thence to Rotterdam and back, when I sold the *Chieftain*. But before parting with it I had some water drawn from the boilers, which were still hot, for the purpose of making toddy, when I found the water nearly as pure as when we left Kilmun."

*From* Dr. JOULE of Manchester.

"The numerous experiments I have made with a surface condenser, fitted to a two-horse engine, have led me to form a decided preference for it over the method by injection. In addition to these, I have made between one and two hundred experiments with a condensing apparatus not in connection with a steam engine, the results of which I have communicated to the Royal Society, and they will, I trust, be of some use in furnishing *data* for the guidance of practical men. Probably the best arrangement of a large condenser is that in which the refrigerating water is forced through pipes surrounded by the steam to be condensed, for then a small leakage only contributes to supply the loss of steam perpetually going on from a variety of causes. Pipes from ¾ths of an inch to 1 inch diameter, appear to be the most suitable. A considerable advantage is obtained by causing the water to circulate in the pipes with a spiral motion, which is easily effected by placing a loose spiral wire in each pipe, as patented by me some time ago. The conduction of heat through the pipes is principally retarded by a film of adhering water, and is not as much affected as might have been anticipated by the greasiness of the surfaces. The grease which passed from the cylinder of my engine did not seriously impair the working of the condenser, and I did not find that the presence of grease in the boiler occasioned corrosion or a tendency to prime. It appears to be almost immaterial in which direction the refrigerating water is transmitted, that is, whether or not the coldest water comes in contact with the steam which has been longest in the condenser; the reason evidently being that the temperature of the vacuum is nearly equal in every part. There is a limit to the advantageous diminution of the diameter of the pipes, which is soon reached on account of the increased force required to propel the water. The experiments I have made show, that the pressure of the water entering the condenser ought in no case to exceed 10 lbs. on the inch. I believe that a head of 10 feet, or 5 lbs. pressure on the square inch, is amply sufficient. The difficulties at first experienced in the application of surface condensers to steam engines are evidently fast disappearing before the intelligence and practical experience of the present day; and I think few engineers will doubt that in marine engines, at any rate, they will soon be universally employed."

*From* Mr. J. G. Lawrie.

"The contentions of the advocates of rival plans, exhibited on the last occasion when this subject was before the Institution, carried the discussion into matter somewhat irrelevant, and led to questions of less importance in surface condensation than to the competing interests of these several gentlemen themselves. It may therefore not be without advantage to review our position, and to see where we really are. With the intention of doing this, the following remarks will be of two kinds—one being addressed to the opinions of the rival advocates in the order in which they were expressed, and the other tracing a general outline of surface condensation.

"Mr. Davison in his paper stated the minimum economy derived from the use of fresh water in boilers to be 13·7 per cent., and explained his mode of making the calculation; but Mr. Spencer objected to receive that calculation as any estimate of the resulting economy, on the ground that when salt water was used, and, of course, blowing off resorted to, a quantity of steam was blown off together with the water. It is true that the actual economy derived from the use of fresh water in boilers must be, and is, greater than the minimum stated by Mr. Davison; but the explanation given by Mr. Spencer certainly does not account for the difference, which arises chiefly in the following way:—The water being blown off from one particular part of the boiler, causes a current of all the water, including the feed water, to that place; and, therefore, to maintain the salinometer, placed at another part of the boiler, uniformly at the same degree, a larger quantity obviously must be blown off than the minimum quantity, which, to have the effect assumed by Mr. Davison, must be withdrawn equally from every part of the boiler, a desideratum that cannot in practice be accomplished. The economy is thus greater than the minimum of 13·7 per cent., stated by Mr. Davison, to an extent different in different boilers. Mr. J. M. Rowan argued that for surface condensation the lubrication of the machinery must be effected by water, apparently for the double reason that the use of other lubricating material was incompatible with keeping the condenser clean, and because when tallow or oil was used it was decomposed at 250°, releasing glycerine in the case of tallow, and they were therefore, when steam was superheated, unfit for lubrication. Tallow suffers some decomposition at about 300°, and fish oil at about 500°; but whether they then become unfit for lubrication, is really of little moment; because no one supposes that even in those cases in which a cupful of tallow is occasionally injected into the cylinder, the rubbing surface is thereby kept coated with tallow. Mr. Rowan appears to imagine that the practicability of superheating depends solely on the applicability of tallow in lubrication to prevent the rubbing surfaces from being torn up, but in no case has a quantity of tallow been used to keep the rubbing surface of the piston coated with it, and there are other methods by which injurious effects arising from superheated steam can be palliated, and perhaps avoided. Until these other methods are exhausted, the use of superheated steam cannot be set aside as impracticable. The amount of economy to be derived from an extended expansion of the saturated and wet steam which all marine boilers produce, is by no means so apparent as that derived from the expansion of superheated steam, and no course of procedure inconsistent with its use can be received as satisfactory. Each of the advocates claims a superiority in the mode of securing the tubes, and also a superiority in the arrangement of the condenser for effecting condensation. In the writer's opinion the time stated by Mr. Davison as necessary to withdraw and replace the tubes when secured with india-rubber washers and nuts, at 2½ minutes for each end, is correct, or, at all events, not overstated. It is not, however, so simple a matter to decide which of the arrangements of condenser recommended is most effective for condensation. The advocates for the condenser of Mr. Rowan contend, that the effective vacuum obtained by it arises from a perfect circulation of the water due to the central fan, that each tube is equally effective, and that the temperature of the condensing water must be uniform; but an examination of the arrangement leads to the conclusion that the condenser is by no means entitled to all that is claimed for it. The cooling water enters the condenser at the centre, and is intended to be thrown out radially by the fan; but if it be so thrown, it follows, as a necessary consequence, that while all the water is brought into contact with the tubes nearest the centre, those nearer the circumference receive less and less in proportion to their distance from the centre. Besides, the passage from the condenser for the heated water being tortuous, and the outlet confined to one part of the condenser, the current which is stated to exist is inherently impossible. When it was urged that the use of this condenser on board the *Thetis*, through 17,000 miles in twelve months, proved its superiority, it was omitted to be stated that the greater part of that work, indeed all the successful part of it, was performed while the vessel was employed on a short station, on which at short intervals the condenser was scoured out with fresh water.

"To obtain a good vacuum does not appear difficult with various forms of surface condenser. In a ship called the *India*, with which the writer was somewhat connected many years ago, and which latterly became the property of the Peninsular and Oriental Steam Navigation Company, Hall's condensers were fitted. The engines of this ship had steam cylinders of 63 inches diameter, with 5 feet 6 inches stroke, and each of the condensers contained 5 miles of half-inch brass tubes. The engines were completely finished before Hall's condensers were attached, and in consequence the arrangements were such that the common condensers, or Hall's, could be used either alternately or in different engines at the same time. The experiment was repeatedly tried of working alternately with the different condensers, and invariably the vacuum in Hall's was from a pound to a pound and a quarter better than with the common condensers. The vacuum with Hall's was about 28 inches.

"Proceeding with the second object of these remarks, the writer would observe that the use of surface condensation is of old date. In 1699 Savery used surface condensation in the first steam engine ever constructed. James Watt, during his early pgroress, generally used the same plan of condensation, arranging his condensers in the form of large tubes or flues, and also in the form of flat boxes like books or chambers. Watt, in writing to Smeaton in 1788, thus explains his reasons for discontinuing the use of surface condensation :—'The idea of condensing the steam by injecting into the eduction pipe was as early as the other kinds of condensers, and was tried at large by me at Kinneal; but the other imperfections of that engine made me attribute a bad vacuum to the air which entered with the injection, and consequently I disused the injection until the size and expense of the tubulated condensers for large engines made me resolve to sacrifice part of the power to convenience, and to employ large air-pumps.' The first authentic record with which the writer is acquainted of a tubular condenser made with small tubes, is contained in a patent granted to the elder Brunel in 1822. Since that time tubular condensers have been twisted into various forms, but without any remarkable change until 1840, when Craddock contrived and patented the plan of constructing the condenser in the form of a revolving frame, consisting of small tubes, with the intention of giving that frame rotation in air or in water, as expressed in the patent. There is no question that Craddock's plan effects a most thorough circulation of the condensing water; but his condenser has been little used, arising probably from inconvenience in the structure of the rotating frame. Next in order of novelty is the plan of Messrs. Rowan and Horton, which is shown in fig. 9, Plate VIII., and which has already been commented on in these remarks.

"To condense steam by surface condensation involves no recondite principle. The object will be most effectively accomplished by the plan which passes the largest quantity of condensing water with the greatest uniformity over the condensing surface, and with the smallest expenditure of power. A considerable amount of surface is desirable; but the power or effectiveness of the condenser is measured quite as much, or perhaps more, by the quantity of water brought into contact with each square foot of surface, than by the number of square feet. With that definition of an effective condenser, and profiting by various suggestions that have been made, the writer submits the form shown in fig. 1, Plate XI., as that in which the conditions are most perfectly fulfilled. The area for the passage of the water into the condenser, and amongst the tubes, as well as that out of the condenser, is constructed to be in excess of the area of the pipe from the circulating pump by such an amount as appears in the particular case desirable, and also the area of the space among the tubes is regulated in the same way. With the channel for the cooling water constructed in this way, there must unavoidably be a tolerable approach to uniformity in the quantity of cooling water received by each tube. The kind of packing for the tubes is shown in fig. 2, and resembles somewhat that recommended by Mr. Davison. The box in the centre of the condenser, the primary object of which is to regulate or form the current of the water, is also not unsuited for the reception of impurities when the cooling water is foul. The cover of the condenser is made in several pieces, to permit of easy access to the tubes for the purpose of scouring them out, and also for the purpose of removing them. With this arrangement the whole power spent on the cooling water is employed to pass it through the condenser, and, with a judiciously-constructed circulating pump, much power is not necessary for that purpose. The effectiveness of a condenser is not only increased by an increase in the quantity of the cooling water, but in the same proportion is the tendency to a deposit of salt lessened.

"The difficulties of surface condensation which are met with in the boiler the writer would propose to obviate by three expedients:—

1st. By the use of tubes in the condenser, thickly coated with tin, or, what is probably better, made wholly of tin, to avoid the formation of verdigris.

2nd. By the use in the boiler of two of Armstrong's sediment collectors, one being placed at the bottom of the boiler, and the other at the surface of the water.

3rd. By the use of a small surface blow-off from the sediment collector placed at the surface of the water, into a tank constructed for the purpose, in which the surface impurities would be separated from the pure water."

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In the discussion which followed—

Mr. J. F. SPENCER said that he saw a copy of Mr. Davison's paper only a few hours before the last discussion; and although he read it carefully through, was somewhat unprepared at that time to speak decidedly on some of the calculations and statements in it. It was necessary to take the paper itself as his text in his remarks on the present occasion, and he could not therefore lose sight of the fact that, although the arrangement of condenser and mode of fitting in the tubes Mr. Davison advocated had only had one trial of a comparatively short duration in this country, whilst those he himself advocated had been working successfully for several years, yet Mr. Davison ignored the efficiency and success of any surface condenser but Sewell's, the one the paper supported. He considered the calculation in the paper for estimating the loss by blowing out was incorrect, and had a tendency to mislead, as it was, in fact, assuming that they were changing from fresh to salt water instead of the reverse; for engineers and ship-owners wanted to know what saving could be realized by adopting the fresh instead of the salt water system. That this difference was not an imaginary one could be readily seen, when it was considered that any saving must be a per centage on the gross consumption of fuel. By the calculation in the paper the amount of loss by blowing out at $\frac{2}{32}$ of sea water was estimated at 13·7 per cent., and at $\frac{1\cdot5}{32}$ of sea water, 27·4 per cent.; but, taking the *data* in the calculation as correct, he would consider the following as giving the most correct estimate of saving by using fresh instead of salt water in marine boilers.

*Assumed Data.*

Steam pressure, 20 lbs.; temperature, 261°; total heat, 1210°; temperature of hot well, 110°.

Case 1.—Hydrometer $\frac{2}{32}$, or, twice sea water.

| | |
|---|---|
| Evaporated 1 lb. × (1210° — 110°) . | = 1100 units. |
| Blown out 1 lb. × (261° — 110°) . | = 151 units. |
| Total heat expended, . . . | 1251 units. |

Ratio of heat blown out 151 to total heat 1251 = 12·07 per cent.

Case 2.—Hydrometer $\frac{1\cdot5}{32}$, or, one and a half sea water.

| | |
|---|---|
| Evaporated 1 lb. × (1210° — 110°) . | = 1100 units. |
| Blown out 2 lbs. × (261° — 110°) . | = 302 units. |
| Total heat expended, . . . | 1402 units. |

Ratio of heat blown out 302 to total heat 1402 = 21·5 per cent.

The total heat of 20-lb. steam being somewhat less than the above, would slightly increase the proportion of heat lost by blowing out, but the *data* assumed in the paper were sufficiently accurate for comparison. One of the chief objects of the paper being to show the saving that could be realized by the adoption of surface condensers, it was simply a question of how much fuel would be saved by using fresh instead of salt water. Thus, if an annual consumption on the salt water system, hydrometer $\frac{1\cdot5}{32}$, was 1000 tons of coal, and supposing the previous calculations to represent all the saving to be realized by using fresh water, this saving would actually amount to 215 tons, and not 274 tons as deduced by Mr.

Davison's calculations. He must, however, repeat that any calculation for ascertaining the heat expended in raising the temperature of the feed to be blown out from that of the hot well to that at which it was blown out, only indicated a *portion* of the heat lost, as in blowing out much steam (containing its proportion of latent heat) was discharged with the water. Thus, speaking generally, if, of the weight of steam and water blown out, $\frac{4}{5}$ths was actually water and $\frac{1}{5}$th steam, the loss was nearly doubled. To return to the previous calculations—supposing the saving by using fresh water instead of salt at $\frac{2}{32}$ was estimated at 12 per cent., there was evidently not this saving on the total fuel consumed, but only on that portion of the fuel utilized in heating and evaporating the water, and as not less (as an average) than one-half of the coal consumed was lost up the chimney and by radiation, the per centage of saving of the *fuel* was reduced one-half; and, notwithstanding every fair allowance for incidental advantages (such as clean boilers, less total heat in the steam, &c.), it was quite evident that such calculations as those in the paper were totally inadequate to represent the amount of saving actually realized in substituting fresh for salt water in marine boilers. He had never known the practical saving to be less than 20 per cent. by using a surface condenser instead of salt water at $\frac{2}{32}$ of the hydrometer. To quote two cases:—In engines of 50 H.P., with the injection condenser and ordinary saltness, the speed of the ship was $8\frac{3}{4}$ knots; under exactly similar circumstances, with a surface condenser (fitted by him in 1857), and the same consumption of coal, the speed was fully $9\frac{1}{2}$ knots, thus showing an increase of power of about 30 per cent. In the second case of the *Frankfort*, 100 H.P., referred to in the previous discussion—by substituting fresh for salt water, notwithstanding the additional friction of separate engines to work the air-pumps, the average saving of the last twelve months had been fully 21 per cent., the hourly consumption being reduced from $16\frac{1}{2}$ to 13 cwt. By referring to the diagrams, figs. 3 and 4, Plate XI., it would be seen that the power of the engines had been more than fully maintained and the vacuum improved. The full lines represented the power with the injection condenser, and the dotted lines, E E, the power with the surface condenser, and they were fair averages from a series of diagrams taken during the ordinary working of the ship between Gibraltar and Genoa. The next point he would refer to, was the reduction of power required to work the air-pump. With an injection condenser they had simply to do with an air-pump which delivered both condensed and condensing water; but with surface condensers there was an air-pump and also a circulating pump, and experience corroborated the statement of the paper, that less power was required to work the two surface condenser pumps than the one injection air-pump; but he did not agree with the statement, that the power to work the circulating pump was only that necessary to overcome the friction in the pipes. As stated at the last discussion, he had often found a pressure in the circulating pump equal to a head of forty feet of water; in support of which statement he must refer to some diagrams taken from the *Frankfort's* pumps (figs. 5 and 6, Plate XI.) The full line was the diagram from the injection air-pump; the dotted lines, WW, represented the diagram of the surface condenser circulating pump, the greatest pressure in which was equal to 23 lbs. per square inch; and the dotted lines, PP, represented the diagram of the surface condenser air-pump. If the capacity of the circulating pump could be so arranged as to insure the water always following the plunger or bucket, it might be possible to use the inlet pressure to balance the delivery pressure; but to provide for contingencies and variations of temperature of the sea water, the average supply from the pump was much less than its capacity, and hence much of the pressure shown in the diagram, the remainder being caused by friction through valves and pipes, the supposed back pressure on the plunger or bucket being in fact a vacuum. Still, with this fact allowed, the amount of power required to work the pumps was less with surface than with injection condensation, and the reduction in the case of the *Frankfort* was 13 per cent. There was another advantage not referred to in the paper, namely, the reduced capacity of air-pump necessary to obtain the same vacuum. To prove this, he gave the following relative capacity per minute of the air-pumps of three steamships fitted with his surface condensers:—

| Ship. | H.P. | Injection. | | Surface. | |
|---|---|---|---|---|---|
| | | Capacity. | Vacuum. | Capacity. | Vacuum. |
| | | Cubic feet. | Inches. | Cubic feet. | Inches. |
| *Alar*,.......... | 50 | 70 | 23 | 45 | 24·5 |
| *Frankfort*,.... | 100 | 350 | 23 | 200 | 24·5 |
| *Hibernian*,.... | 400 | 1100 | 25 | 500 | 27·5 |

This contrast was very striking, and showed how little air entered a surface condenser, compared with what entered with the injection water of an injection condenser. As another instance of a good vacuum in a surface condenser with a small air-pump, he would mention a rolling-mill engine of 100 horses power, indicating nearly 300, in which there was no expansion, and the steam entered the condenser at a pressure of nearly 30 lbs.

when full work was on. He lately attached to this engine one of his surface condensers, and a 14-inch single-acting air-pump, having a capacity per minute of 90 cubic feet; and with this small pump the vacuum ranged from 24 to 26 inches, with the feed upwards of 130°. Mr. Davison might also have stated the well-known fact, that whereas in injection condensers the vacuum disappeared in the condenser within ten or twelve minutes after the engine stopped, it would take from thirty to forty minutes to disappear in a surface condenser—a great advantage when handling engines in harbour, or among shipping. He considered that too much stress had been laid on a high vacuum, as deciding the efficiency of a marine engine, whilst it was well known there were hundreds of steamships with injection condensers that did not average 24 inches of vacuum. He could name six or seven of large power that never had an average vacuum of 9 lbs. in the cylinder, whereas in the *Hibernian* they had 10½ to 11¼ lbs. If a poor unfortunate surface condenser did not indicate 26 inches, it was pronounced a failure. It was by no means a decided point that a cold feed and a high vacuum were the most economical in working, but it was well known that many practical engineers found they got a better result by keeping the feed at a high temperature, and having a vacuum of 24 or 25 inches. During the voyage of the *Hibernian* to Liverpool the vacuum in the condenser frequently ranged from 28 to 28½ inches, and averaged 27¼.

He (Mr. Spencer) was the first to successfully introduce in this country that form of condenser in which the tubes were horizontal, the water circulating through the tubes, and the steam outside, with division plates at each end for causing a longer traverse of the condensing water. This class of condenser was familiar to him in 1853, and a vessel was fitted with it in 1854, and, as previously stated, between twenty and thirty were now being introduced. He believed that this arrangement of condenser, from its simplicity and practical advantages, would ultimately supersede all others. Mr. Davison stated there were certain conditions essential to the efficiency of a surface condenser; and whilst he agreed with this statement and the conditions named, he decidedly objected to the conclusion Mr. Davison arrived at, that none but Sewell's arrangements fulfilled those conditions; on the contrary, he had found by actual experience that he had himself successfully fulfilled all those conditions for some years past. Mr. Davison stated that he was able to bring his tubes within 5-16ths of each other, and thus save much occupied space. Now he much doubted if this close work could be carried into general practice, as 1-8th of an inch for the india-rubber, and 1-16th of metal for the guard plate was rather fine work. With the packing he used he could bring the tubes easily within 3-8ths of an inch of each other, and each one could be removed without having to remove any guard or other screwed metal—a great advantage over the condenser recommended in the paper. With reference to the time required to make the joints, Mr. Davison assumed that it would take five minutes—two and a half minutes at each end—to make the joints of one tube with any other plan than his own; and thus, with a condenser of the size he was having made, it would take seven weeks to make all the joints; but taking Mr. Davison's own assumed *data* of five minutes per tube, the whole of the joints in the condenser of the *Hibernian* of 400 horses power could be made by one man in five and a half days; and if it was a 700 horses power condenser, being, he believed, the size of the condenser Mr. Davison referred to, all the joints could be made in twelve days at the outside. He was therefore quite at a loss to understand Mr. Davison's arithmetic. It must also be remembered that at least four men could be employed at once, which would materially reduce the time named. But Mr. Davison also stated that, in the condenser taking seven weeks to have the tube-joints made with other plans, by his they could all be made in about four hours. He would appeal to all present whether that could be so—the tubes of a large condenser, say of from 500 to 700 horses power, jointed with india-rubber and a guard plate screwed on in about four hours; he believed it to be practically an impossibility. As to the tightness of the joints, his own plan, or that of Hall, Rowan, or Sewell, was each more or less efficient; but he repeated that a simple expansion joint, providing for the easy and independent removal of one or any number of tubes, was indispensable for an efficient surface condenser.

On the question of cost, Mr. Spencer believed he had the advantage of any plan extant.

Mr. D. More said he thought that they, as a society, had nothing to do with the rival claims of patentees. They were all agreed that surface condensation was a good thing, and superior to the system of injection; but he thought what they had mainly to consider was the best method of making the ends of the tubes tight, and how they could with the greatest facility put them in order at sea when required. He would not follow Mr. Spencer or Mr. Davison into the question—which was the best kind of condenser; and as he had no particular system to uphold, he would merely give his unprejudiced opinion as to the best system for packing a tube, and making it tight for use on board of a steamer. If they had 2000 or 3000 tubes in a condenser, and before they could get them out they had to pick out a ring for each, and that ring must be picked out with a very small point, as in Mr. Spencer's plan, it would take a long time, and it was plain that Mr. Davison's system was much easier and better, where a flat sheet of india-rubber was put on the ends merely. He believed both condensers were good; but it was for the meeting to consider the relative value of the two systems, and not the value of surface condensation, a point on which they were all at one.

Mr. Spencer said that the tube was taken out always before the washer. To show the perfectness of this manner of packing, he might state that by mistake the full pressure, 20 lbs., was left upon the condenser of the *Hibernian* on one occasion, yet none of the tubes were afterwards found faulty.

Mr. Davison, in reply, said that none of the gentlemen who had taken part in the discussion differed from him as to the conditions required for a good surface condenser, while much had been said to confirm his views on the subject; and no person had questioned the fact—that the condenser he recommended fulfilled all the required conditions, although much had been said endeavouring to prove that other plans were equally good. Mr. Scott had said that Mr. Rowan's even surpassed others, but he would endeavour to point out where Mr. Scott was in error. He would admit that the tubes in Mr. Rowan's condenser could be made tight, *provided* sufficient care was taken in packing both ends; but the accuracy of workmanship in making, and care required in packing, he thought were great objections to its use. The glands of a large number of tubes being held down by the same plate, if the rubber ring of one tube was larger than the others, that one would prevent the plate from bearing equally on the others; and if one chamber was less in diameter or not so deep as others, or if the glands were not all equal, or if there was any inequality in the surface of the plate, the same effect of unequal tightness would be produced. It was a mistake to suppose that the india-rubber would accommodate such inequalities, for rubber was not elastic in volume, but its elasticity was entirely confined to change of form. It was also very difficult to remove rubber from such a place when it had remained long, as it adhered firmly to the metal surface; and should any portion of the old rubber remain, new washers would not fit. Mr. Scott thought that difficulty of circulation was not experienced in all condensers with the circulating water outside the tubes, and referred to Mr. Rowan's as an example; but the fact—that an agitator with all its packings, shafting, bearings, couplings and other gear, together with an additional air-pump with all its appendages, was required in that condenser for no other purpose than to improve the circulation—was certainly sufficient proof that the difficulty did exist; whilst, as previously shown, notwithstanding all this machinery, the circulation was still imperfect. Mr. Scott also seemed to think that Mr. Rowan's condenser occupied less room than others, and stated that one for 400 indicated horses power occupied but 65 cubic feet. As the amount of surface—the quantity of steam it would condense—the pressure of steam

—or the grade of cut-off—were not named, they must be assumed to be the same as in others of Mr. Rowan's engines. Taking that basis he found that Sewell's condenser of the same power would occupy but 28 cubic feet instead of 65, which appeared quite likely upon looking at the plans of both condensers. Mr. Scott also stated that that condenser produced a higher average vacuum from a less amount of cooling surface than others; but this did not agree with Professor Rankine's experiments, showing that the condensation was but 4 lbs. per foot per hour in Rowan's—whilst in Sewell's condenser it was 6 to 9 lbs.

Professor Rankine begged to remind Mr. Davison that he had stated that the engine was at the time going below its maximum speed, and using very little steam.

Mr. Davison said if Professor Rankine's former statement was too low, no doubt Mr. Scott would have corrected it. He seemed to have an erroneous idea of the relative efficacy of surface condensers, as he stated that one "which, with a given amount of surface, could reduce a given amount of steam to a minimum temperature, was clearly the most efficient in working." It was quite evident that the higher the temperature of the feed-water, the greater was the economy; and in comparing condensers with the same surface, producing the same vacuum, and condensing the same steam, the one that would deliver the condensed steam at the highest temperature was the most efficient. Mr. Scott omitted to call attention to a very important point in Mr. Rowan's condenser, viz., the increased cost due to its complicated construction.

Mr. Davison thought that, on referring to the paper, Mr. Spencer would find that the amount of heat required for steam, and the additional amount required to heat the blow-water, were correctly and distinctly stated, and also that the percentages there given were calculated upon the amount required for steam; and he could not conceive how any person could misunderstand it, or suppose that the expression 13·7 per cent. *more*, could mean 13·7 per cent. *less*, as Mr. Spencer had put it in his calculation. Mr. Spencer thought that the percentage of saving as calculated did not apply to the total fuel consumed, but only to about one-half of it, owing to the heat from the other half being lost up the chimney, &c., and this error might account for his difficulty in reconciling the calculations with experiments. It was evident that, as the calculations were based upon the whole quantity of steam made in the boiler, they should be applied to the whole amount of fuel consumed for the purpose of producing that steam, of which amount the loss up the chimney was in every case a corresponding percentage. The only uniform loss was that by radiation (the pressure being the same), and that was too small practically to affect the result, and it was more than counterbalanced by the well-known increase in the efficacy of fuel in ordinary boilers, when the quantity burned per hour was decreased. Mr. Spencer's doubts as to the distance apart of the tubes in Sewell's condenser he might remove, by stating that one condenser of 500 horses power was about finished in Glasgow, with ¾-tubes 5-16ths apart, and others had been working for some years with ½-inch tubes 3-16ths apart, and the greatest distance that any have been placed apart was ⅜-inch. If Mr. Spencer had stated the number of tubes in the condenser of the *Hibernian*, they could have checked his calculation, and have seen whether he packed them in less than 2½ minutes each. He might state, that with Sewell's condenser the act of putting in the tubes packed one end, and he had seen the packing put on the other end at the rate of 2000 per hour by one man. Mr. Spencer's other remarks he did not think required notice.

Much, Mr. Davison continued, had been said on the subject of lubrication. Rubbing surfaces were found to move with much less friction, when oil or tallow was used, than with water. Referring to experiments made with cast-iron upon cast-iron, the co-efficient of friction with olive oil was ·064; with tallow ·100; with water ·314—showing the friction to be nearly five times as much with water as with oil. This was a loss of power not detected by the indicator, and might exist without being observed; but whatever might be the best practice, he would not recommend a condenser that would prevent the use of tallow in the cylinders. In the paper he had only called attention to two points—namely, the necessity for surface condensation, and the best apparatus for the purpose; but the discussion had led to other considerations which he would not at present follow, as he thought such questions as the proper proportions of condensers for different cases, and the best mode of using them as to temperature and other particulars, would alone furnish matter for a lengthy discussion, and might be a subject of future consideration.

The President thought that for the present they had now pretty well exhausted the subject, but would have liked to have made some remarks himself on several points brought forward, had it not been so late. In closing the discussion, he must say the Institution was very much indebted to Mr. Davison for bringing the paper before them, and for attending on so many successive occasions. They were also indebted to Mr. Spencer for the trouble he had put himself to in coming from Newcastle to attend the discussions, and for furnishing so much additional information. He therefore proposed that the thanks of the meeting be voted to Mr. Davison and Mr. Spencer.

The votes of thanks were unanimously awarded.

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In accordance with a Special Notice, the meeting considered the propriety of altering Regulations XL., XLI., and XLII.

The following alterations were proposed by Mr. Gilchrist, and seconded by Mr. Wilkie:—

In Regulation XL. to substitute the words, "Every Member shall contribute the sum of Two Pounds Ten Shillings the year he becomes a Member, and the sum of One Pound Ten Shillings every subsequent year."

In Regulation XLI. to substitute the words, "Every Associate shall contribute the sum of Two Pounds the year he joins the Institution, and One Pound every subsequent year."

In Regulation XLII., instead of the words, "One Pound One Shilling," to insert the words "Fifteen Shillings."

These alterations were unanimously agreed to.

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List of Works presented to the Institution during the Session 1860–61:—

"The Autobiography of a Seaman," Vol. II. From the Author, the Earl of Dundonald.

"Proceedings of the Institution of Mechanical Engineers" for 2d November, 1859; 25th January, 25th April, and 8th and 9th August, 1860; Parts I., II., and III.

"Proceedings of the Scottish Shipbuilders' Association" for October, November, and December, 1860, and January, February, and March, 1861.

"Transactions of the Royal Scottish Society of Arts," Vol. V., Part 4.

The thanks of the Institution were voted for these donations.

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The **Treasurer** presented his accounts and statements in accordance with Rule XV.; and Messrs. **Russell** and **Kirkaldy** were appointed Auditors in accordance with Rule XVII., to examine the same.

## Abstract of Treasurer's Accounts—Session 1860–61.

*Dr.*

| | | | | | | |
|---|---|---|---|---|---|---|
| April 11, 1860. | | | | | | |
| To Balance from Session 1859-60. | | | | | | |
| Cash in Union Bank, | £393 | 12 | 0 | | | |
| Cash in Treasurer's hands, | 6 | 8 | 3 | | | |
| | | | | 400 | 0 | 3 |
| April, 17, 1861. | | | | | | |
| To Subscriptions— | | | | | | |
| 116 Members, at £2 2s, | 243 | 12 | 0 | | | |
| 20 New Members, at £3 3s., | 63 | 0 | 0 | | | |
| 3 Associates, at £1 11s. 6d. | 4 | 14 | 6 | | | |
| 1 New Associate, | 2 | 12 | 6 | | | |
| 8 Graduates, at £1 1s., | 8 | 8 | 0 | | | |
| | | | | 322 | 7 | 0 |
| To Cash for copies of the Transactions, 4 Vol. I., 3 Vol. II., and 5 Vol. III., | | | | 5 | 14 | 6 |
| To Interest from Union Bank, | | | | 10 | 18 | 10 |
| | | | | £739 | 0 | 7 |

*Cr.*

| | | | | | | |
|---|---|---|---|---|---|---|
| April 17, 1861. | | | | | | |
| By Secretary's Salary, 1 quarter, Session 1859–60, and 3 quarters, Session 1860–61, | | | | £100 | 0 | 0 |
| By fees to Officer and Janitor, 1859–60, | | | | 6 | 0 | 0 |
| By rent of hall, 1859–60, | | | | 15 | 0 | 0 |
| By cost of 300 copies of the Transactions, Vol. III., and of Circulars, Stationery, &c., 1859–60, | | | | 60 | 4 | 0 |
| By Postage, Porterage, &c., | | | | 5 | 10 | 6 |
| By Reporter, 1859–60 | | | | 8 | 8 | 0 |
| Balance— | | | | | | |
| Cash in Union Bank, as per pass-book, | £540 | 18 | 10 | | | |
| Cash in Treasurer's hands, | 2 | 19 | 3 | | | |
| | | | | 543 | 18 | 1 |
| | | | | £739 | 0 | 7 |

After their examination, the Auditors presented the following Report:—

"Glasgow, 17*th April*, 1861.—We have examined the foregoing statement, and compared it with the vouchers, bank book, &c., and find it correct, there being in Bank Five hundred and forty pounds eighteen shillings and tenpence; and in the Treasurer's hands, Two pounds nineteen shillings and threepence: in all, carried to the credit of the Institution, Five hundred and forty-three pounds eighteen shillings and one penny."

(Signed) James Russell, David Kirkaldy, } *Auditors.*

The thanks of the meeting were voted to the Auditors.

The following gentlemen were duly elected Office-Bearers for the Fifth Session (1861–62) of the Institution, in accordance with Regulations XXIV., XXXV., XXXVI., XXXVII., and XXXVIII., which were read:—

*President.*

NEIL ROBSON, Esq.

*Vice-Presidents.*

W. J. MACQUORN RANKINE, Esq., LL.D.
JAMES R. NAPIER, Esq.
WILLIAM ALEXANDER, Esq.

*Councillors.*

WALTER M. NEILSON, Esq.
WILLIAM JOHNSTONE, Esq.
ANDREW M'ONIE, Esq.
R. BRUCE BELL, Esq.
BENJAMIN CONNER, Esq.
JAMES MILNE, Esq.
WILLIAM TAIT, Esq.
HUGH BARTHOLOMEW, Esq.
WILLIAM SIMONS, Esq.
JAMES BROWNLEE, Esq.

*Treasurer.*

DAVID MORE, Esq.

The election of Secretary was postponed to an adjourned meeting to be held on 1st May.

AN ADJOURNED MEETING (being the Ninth Meeting of the Session), was held in the Philosophical Society's Hall, on Wednesday, 1st May, 1861—the PRESIDENT in the chair.

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The election of a Secretary for the Fifth Session, 1861–62, was considered, when—

Mr. A. GILCHRIST moved that the salary of the Secretary be reduced to £80 per annum.

Mr. W. JOHNSTONE seconded the motion.

Mr. A. M'ONIE moved that it be continued at £100 per annum.

Mr. MILNE seconded the amendment.

On a division, the amendment was carried by a majority of 19 to 5.

Mr. A. M'ONIE moved—"That the election of a Secretary be delayed, and that it be remitted to the present Council (1860–61) to take steps, by advertising or otherwise, to obtain suitable candidates, and to report at a general meeting of the Institution."

The motion being seconded by Mr. WILKIE, was agreed to.

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It being announced that no reports had been received from sundry committees appointed during previous Sessions, it was unanimously agreed to relieve them of their duties.

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The following paper was read:—

## *On the Operation of Air-Engines.* By Mr. J. G. LAWRIE.

Air-engines have received from time to time no inconsiderable share of the attention of engineers. In the year 1845 a paper was read to the Institution of Civil Engineers by Mr. James Stirling, *On Stirling's Improved Air-Engine.* In 1853 a paper, by Mr. Benjamin Cheverton, *On the Use of Heated Air as a Motive Power*, was read to the same Institution, and the reading of this paper, together with the discussion of it, extended over three evenings. Later in the same Session three papers, of which the authors were Mr. Manby, Mr. Leslie, and Mr. Siemens, were read and discussed for the elucidation of the same subject; and recently this Institution has had an opportunity of discussing the subject of air-engines, on the occasion of a contribution by Mr. Patrick Stirling being read.*

These several papers and discussions, though written and conducted by men eminently fitted to remove the difficulties of such a subject, do not appear to have exhausted it. They do not appear to have satisfactorily elicited the elementary principles of air-engines, nor to have established the grounds upon which their action depends.

The respirator or regenerator, a prominent part of Stirling's air-engine, has been the occasion of considerable diversity of opinion among engineers. Mr. James Stirling asserted, that without a respirator or regenerator an air-engine would be more expensive in fuel than a steam-engine, and that the use of some means of removing the heat from the air at one part of the stroke, and of imparting the same heat at another, is indispensable to the success of such an engine. On the other hand, Dr. Faraday, Mr. Bidder, Mr. Brunel, Mr. Hawksley, Mr. Manby, and indeed the whole influential weight of the Institution of Civil Engineers, declared against the respirator. These gentlemen admitted the ingenuity of the apparatus—admitted that it was admirably adapted to cool the air when passing through it in one direction, and to heat it when passing in the other. They assumed that it could be constructed so as to deprive the air passing in one direction of all the heat necessary for the action of the engine, and that it would deliver it up again to the air when passing in the other; yet they contended that it afforded the means of no mechanical utility. No advantage, it was asserted, was obtained from its use. It was pronounced to be a fallacy.

These opinions are very extreme, and the authors are very distinguished; yet it does appear, by tracing the engine to its elements, that the respirator is the true source of the economy of air-engines.

Figs. 1 and 2, Plate XII., show an elementary form of Stirling's air-engine, comprising the heater or vessel, A B D C, in which the air is heated; the plunger, G H F E, of the heater; the cylinder, J K L M, of the engine in which the pressure of the air imparts motion to the piston; the respirator or regenerator, P S R T, formed of wire-gauze, diaphragm plates, or otherwise.

The fire or other source of heat is applied to the heater in a manner such that all the air under the bottom, E F, of the heater plunger, and the bottom, T R, of the respirator, is heated to the required temperature.

* The writer regrets that he has not had an opportunity of reading the paper by Dr. Rankine, read to the British Association in 1854.

The respirator is supposed to be constructed so that all the air above the line, P S, is cooled to the degree intended.

Suppose that the piston-rod, V, is fastened to the bottom of the cylinder, or is without motion, and that the plunger-rod, U, is moved by hand alternately up and down. When the plunger, H E, is at the bottom of the heater, all the air is reduced to its lowest temperature and least pressure; and when at the top, all the air is raised to the highest temperature and greatest pressure—the difference of these pressures depending on the difference of the temperatures of the air when above and below the respirator. There is thus a time in each revolution of the engine when the air is of a high pressure, and a time when it is of a low pressure, and yet no consumption of heat; the heat being only at one time removed from the respirator, and at another imparted to it. During the period when the air is increasing in pressure, plainly it can be made to operate in giving motion to a piston by acting like steam on the steam side; and during the period when the air is diminishing in pressure, its action on the piston will be analogous to that of the vapour in the condenser on the vacuum side. If, however, there be no respirator, there will be no difference in the pressure of the air at one time and at another, unless the heat be removed from the air at one time by a refrigeratory process, such as the use of water, and imparted at another by the application of new heat. When the plunger is at the top of the heater all the air is hot, and without a respirator it will continue to be so when the plunger is at the bottom, unless the heat be removed from the air by the use of a refrigeratory process. But the difference of pressure obtained in this way by the use of a refrigeratory process, such as the application of water, involves a loss of heat to the extent of the action of this cooling process, while it has been seen that a difference of pressure obtained by means of a respirator constructed to act in the manner intended, in a manner similar to that in which it did act in Stirling's engine, involves no loss or consumption of heat. If the difference of pressure obtained by the use of a respirator acting in the manner explained be considerable, and sufficient to actuate an engine effectively, the power or dynamic effect so obtained involves no loss or consumption of heat, due to the increase of pressure obtained by means of the respirator, beyond that which is utilized or converted into dynamic effect.

In the discussions already referred to, opinions were expressed acknowledging that, in all probability, the respirator could be constructed to remove from the air as much heat as was necessary for the action of the engine—to maintain in fact the air at a constant maximum and minimum temperature when below and above the respirator, or rather to maintain the air when below and above the respirator at temperatures which were constant in consecutive revolutions of the engine. There are no means by which to calculate the extent to which this effect will take place, but it appears certain that it will, to a large extent, if the respirator be sufficiently large. To what extent, however, it can be made to take place, trial only will determine;* and trial only will ascertain whether the dimensions of respirator necessary will entail effects due to the friction of the air in the passages, or other obvious causes, of an amount to damage materially the action of the engine.

It thus appears that in the engine shown in figs. 1 and 2, Plate XII., there is, on the assumption of the efficiency of the respirator, no considerable consumption of heat beyond the amount utilized in dynamic effect, irrespective of course of loss from radiation, &c.; and if it be assumed that

* Two elements, in the operation of air-engines of the kind considered in this paper—the change in the temperature of the air due to the change in the pressure, and the change in the temperature due to the heat required for the development of dynamic effect—are material to the action of the respirator; and to understand the ultimate extent of that action, it is necessary to trace these elements.

If the air passing through a respirator, whether used for an air-engine or for any other purpose, be maintained at a constant pressure, there is a continuous current of heat passing through the material of the respirator towards the cold end, which must be removed by a subsidiary cooling process, and which on that account involves a loss of heat; because, with the condition of constant pressure, the air passing through the respirator upwards will necessarily leave the line, P S, fig. 1, at a higher temperature than that of the line, P S, and will therefore heat the line, P S, when returning downwards through the respirator. Hence, at the next stroke of the heater plunger, the air will not be cooled to so low a temperature, and so on in each successive stroke. An analogous effect will take place at the other end of the respirator, and therefore there is a constant current of heat passing through the material of the respirator from the hot to the cold end, which must be removed by the application of a refrigeratory process.

But if the pressure of the air, instead of being constant, varies in the manner in which it actually does vary in the operation of the engine, the action of the respirator is as follows:—In diagram, No. 8, the heater plunger ascends during the part of the diagram from A to E, descends through E B C F, and ascends through F D. The temperature of the air in A B H G, fig. 1, the upper part of the heater, is dependent on the pressure, increasing when the pressure is increased, and diminishing when the pressure is decreased, in accordance with the law that the temperature rises or falls proportionally to the dynamic effect employed to increase the pressure, or given out when the pressure is diminished. During the part of the diagram, E B C F, a greater quantity of heat is passed through the respirator than is returned during F D A E, the difference being utilized in dynamic effect. Thus the air in A B H G varies not only in quantity, but also in temperature, from two causes, and there are no means by which to calculate with precision the effect of these variations in the temperature of the air upon the action of the respirator. Any such calculation would be valueless, even if there were the means to perform it, owing to the operation of conduction, radiation, &c. But, plainly, there is not essentially any considerable current of heat passing through the material of the respirator towards the cold end, if the effect of radiation and conduction be omitted.

this heat which is utilized can be imparted to the air in the heater in a manner to meet the requirements of the engine, the means are pointed out, in a note at the end of this paper, by which to calculate the result of engines of this description.

The power or dynamic effect depends on the following elements:—

1. The quantity and pressure of the air in the engine.

2. The temperature to which the air is raised when in the heater, and the temperature to which it is lowered by the respirator.

3. The volume of the cylinder in relation to the volume of the heater.

4. The position of the heater plunger in relation to that of the cylinder piston in the stroke or revolution of the engine.

In Plate XII. there are eight diagrams calculated in the manner explained in the note referred to at the end of this paper, showing the results due to variations in these elements, and the substance of these diagrams* is embodied in the following table:—

| Diagrams. | Temperature of the air when in the heater. | Temperature of the air when cooled by the respirator. | Volume of the cylinder. | Advance of the heater plunger before cylinder piston. | Actual H.P. of each engine at 33,000 foot pounds. |
|---|---|---|---|---|---|
| I. | 600° | 150° | ½ of heater. | 90° | 904 H.P. |
| II. | " | " | " | 60° | 753 " |
| III. | " | " | " | 120° | 823 " |
| IV. | " | " | ⅓ of heater. | 90° | 1050 " |
| V. | " | " | 1 of heater. | " | 630 " |
| VI. | 400° | 100° | " | " | 484 " |
| VII. | " | " | ⅓ of heater. | " | 683 " |
| VIII. | " | " | ¼ of heater. | " | 854 " |

Quantity of air in engine = heater full, with a pressure of ten atmospheres, and constant temperature.

Diameter of cylinder, 50 inches.

Speed of piston, 300 feet per minute.

In all these diagrams the pressure of the air is taken at ten atmospheres; and by examining the investigation in the note at the end, it

* These diagrams are drawn in the same way as the indicator would form them; but it must be remembered that no diagrams made by the indicator give the acting pressure at the different parts of the stroke. The line A B, in diagram No. 1, should be reversed into the position A′ B′, to show the acting pressure correctly. In steam-engine diagrams the bottom line is usually nearly parallel to the atmospheric line, and therefore to reverse it does not make any considerable change, but it is different with air-engine diagrams. For example, in diagram No. 1 the acting pressure at the end of the stroke is negative.

appears that the power of the engine is in exact proportion to the pressure of the air. In engines therefore worked like Ericsson's, in which the air used was of atmospheric pressure, the power would be only one-tenth of the amounts stated in the table.

On the assumption that one pound of coal would impart the same heat to the heater of this engine as to the boiler of a steam-engine, the consumption of coal with this engine, on the conditions of this paper, would be $\frac{1}{3 \cdot 4}$* lbs. per horse power per hour, irrespective of course of loss from any current of heat through the material of the respirator, or from radiation and other sources, with which all engineers are familiar.

In the foregoing table the speed of the piston is put at 300 feet per minute; but with so high a speed the respirator, and also the heater, may be of inconvenient magnitude, and it may be better to use a lower speed with a reduced amount of effect from a cylinder of given size. Or it may be desirable to use a refrigeratory process, to facilitate the adoption of a high speed of piston; but to reduce the size of the respirator by using a refrigeratory process, involves an increased size of heater, and, as has been already stated, a loss of fuel to the extent of heat dissipated in the refrigeratory process.

There are difficulties to be encountered in perfecting an engine of this kind by no means unimportant. There is the high pressure of the air, the difficulty of imparting heat to the air, the construction of the respirator; but the engine possesses features of great promise. The performance of the Dundee engine, as described by Messrs. James and Patrick Stirling, was exceedingly satisfactory. In those days, when this engine was in operation, the science upon which questions such as are involved in air-engines was less advanced, and now it is known that there were obvious defects in that engine. But it is the scheme of a perfect instrument, while the steam-engine, after all that can be done for it, is the scheme of an imperfect machine. There is no part of a steam-engine, there is scarcely a part of any machine in the whole range of mechanics, possessed of the extreme elegance of the contrivance by which the Messrs. Stirling sought to impart to the air, and to remove from it, the heat constituting the working element of their engines.

Experiments with machinery of all kinds, and perhaps especially with an apparatus such as this air-engine, are most costly and harassing, as

* 1 lb. of coal evaporates $7\frac{1}{2}$ lbs. of water, and therefore the water receives $1150° \times 7\frac{1}{2}$ of heat $= 8625°$. One horse power per hour $= 33{,}000 \times 60 = 1{,}980{,}000$ foot pounds $= 2538°$ at 780 foot pounds for one degree; therefore the horse power due to 1 lb. of coal $= \frac{8625}{2538} = 3 \cdot 4$ and one horse power $= \frac{1}{3 \cdot 4}$ lbs. of coal per hour.

human foresight cannot predicate the experience of practice; but there are grounds to believe that an intelligent resuscitation and prosecution of Stirling's air-engine would be rewarded with a success and renown scarcely, if at all inferior, to that of James Watt with the steam-engine.

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*Note.—Calculation of the effect of Stirling's Air-Engine.*

Temperature of air when cooled by respirator . $= t$
Do. of air when in heater . . $= t'$
Volume of air in engine when the temperature is $t$ $= v$
Pressure of air when the volume is $v$ and the temperature $t = p$ atmospheres.
Volume of heater . . . . . $= v'$
Do. of cylinder . . . . $= c$
Stroke of cylinder = stroke of heater . . $= 2s$
Area of cylinder . . . . . $= a$ square ins.
Distance L N travelled by piston of cylinder $= s\,(1 - \cos.\,\theta')$
Do. C E travelled by plunger of heater $= s\,[1 - \cos.\,(\theta + \theta')]$.
Do. G A to be travelled by do. $= s\,[1 + \cos.\,(\theta + \theta')]$.

Volume of air of temperature $t$ and pressure $p'$ in cylinder $= \dfrac{1 - \cos.\,\theta'}{2} \times c$

Volume of air of temp. $t$ and pressure $p'$ in heater $= \dfrac{1 + \cos.\,(\theta + \theta')}{2} \times v'$

∴ Total volume of air of temperature $t$ and pressure $p'$ in engine,

$$= \frac{1 - \cos.\,\theta'}{2} \times c + \frac{1 + \cos.\,(\theta + \theta')}{2} \times v'$$

∴ Total volume of air of temperature $t$ and pressure $p$ in engine,

$$= \left[\frac{1 - \cos.\,\theta'}{2} \times c + \frac{1 + \cos.\,(\theta + \theta')}{2} \times v'\right] \times \frac{p'}{p}$$

∴ Volume of air of temperature $t$ and pressure $p$, which is exposed to heat,

$$= v - \left[\frac{1 - \cos.\,\theta'}{2} \times c + \frac{1 + \cos.\,(\theta + \theta')}{2} \times v'\right] \times \frac{p'}{p};$$

And volume of this air when heated to temperature $t'$,

$$= \left\{v - \left[\frac{1 - \cos.\,\theta'}{2} \times c + \frac{1 + \cos.\,(\theta + \theta')}{2} \times v'\right] \times \frac{p'}{p}\right\} + \frac{460 + t'}{460 + t},$$

the pressure being $p$. Hence,

$$\frac{\left[\frac{1 - \cos.\,\theta'}{2} \times c + \frac{1 + \cos.\,(\theta + \theta')}{2} \times v'\right] \times \frac{p'}{p} + \frac{460 + t'}{460 + t}\left\{v - \left[\frac{1 - \cos.\,\theta'}{2} \times c + \frac{1 + \cos.\,(\theta + \theta')}{2}\ v'\right] \times \frac{p'}{p}\right\}}{v' + \frac{1 - \cos.\,\theta'}{2} \times c} = \frac{p'}{p}$$

Resolving that equation for $p'$, and putting $m = \frac{460 + t'}{460 + t} \times v$,

$n = \frac{t' - t}{460 + t}\left(\frac{c}{2} + \frac{v'}{2}\right) + v' + \frac{c}{2}$, $r = \frac{t' - t}{460 + t}\left(\frac{v'}{2}\cos.\,\theta - \frac{c}{2}\right) - \frac{c}{2}$, and

$d = \frac{t' - t}{460 + t} \times \frac{v'}{2}\sin.\,\theta$, there is obtained $p' = p\,\frac{m}{n + r\cos.\,\theta' - d\sin.\,\theta'}$

Put $\theta' = 180^\circ + \theta'$, and $p' = p \times \frac{m}{n - r\cos.\,\theta' + d\sin.\,\theta'}$. Therefore,

Effective pressure $= p \times \frac{m}{n + r\cos.\,\theta' - d\sin.\,\theta'} - p \times \frac{m}{n - r\cos.\,\theta' + d\sin.\,\theta'}$.

Distance travelled by cylinder piston $= s\,(1 - \cos.\,\theta')$;

and $ds(1 - \cos.\,\theta') = s \times \sin.\,\theta'\,d\,\theta'$.

$\therefore\ d\,\text{work} = a\,p\,m\,s \times \left(\frac{\sin.\,\theta'\,d\,\theta'}{n + r\cos.\,\theta' - d\sin.\,\theta'} - \frac{\sin.\,\theta'\,d\,\theta'}{n - r\cos.\,\theta' + d\sin.\,\theta'}\right)$.

The integral of this differential is obtained in series which are of a character somewhat elaborate, and the discussion of which exceeds the limits of this paper.

In the foregoing investigation the effect due to the air contained in the passages of the engine has not been taken into account, and the total volume of temperature $t$ and pressure $p$ in engine, should in strictness contain the factor $\left(\frac{p'}{p}\right)^{\frac{1}{\gamma}}$ instead of the factor $\frac{p'}{p}$, which has been taken for ease of calculation.

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In the discussion which followed—

In reply to the President, Mr. Lawrie said that he did not recollect of anything to add to the paper, except, perhaps, he might mention that he did not know any other investigation of air-engines in which the advantage had been shown of placing the heater plunger in advance of the cylinder piston. In all investigations with which he was acquainted, the heater plunger and the cylinder piston had been assumed to perform the stroke simultaneously.

Professor Macquorn Rankine feared that anything he could say on this subject would be a mere repetition of what he had already published; but he might say that it was very satisfactory to him to hear Mr. Lawrie's results; for although he could not judge of the details of such calculations until he saw them in print, and had an opportunity of going through them carefully, yet he had no doubt they were, in the main, correct. He thought there were one or two points, however, in which Mr. Lawrie was in error. Mr. Lawrie stated that in all the investigations of which he knew, the plunger and piston were supposed to begin to work together, that being a wrong mode of working. Mr. Lawrie was right in considering it to be a wrong mode of working; but he erred in supposing it to be the case considered in all previous investigations. Among the earlier investigations on engines driven by heat, as distinguished from the steam-engine, were those Carnot published in 1828, in which he showed he was cognisant of the important principle, that in the working of an engine driven by the mechanical power of heat there were four processes, and that the action of that engine would be the most efficient when the four processes took place the one after the other. The first was the raising of the temperature of the fluid; the second, the expansion of the fluid at the high temperature; the third, the lowering of the temperature of the working fluid back again, so as at the same time to lower its pressure; and fourth, the compressing of it at the low temperature into its orginal volume. Now, Carnot showed that it was by the performance of those four processes, at distinct intervals of time, that the best effect was to be produced; and though he did not know the mechanical convertibility of heat, still he was right so far; and by following out Carnot's principle, it would indicate the particular instants at which the strokes of the piston and plunger should commence so as to work to the best advantage. It was impossible in practice to carry out that mode of working with mathematical precision, as it would lead to a motion of jerks; still there must be an action as nearly as possible, such as required by that theory. Mr. Lawrie further said that if the regenerator worked with theoretical perfection, there would be no heat expended except what disappeared in producing mechanical work. He (Professor Rankine) agreed in that so far. There would be no heat expended except what disappeared in producing mechanical work in the act of driving forward the piston, and so far there was no difference between Mr. Lawrie and himself; but it seemed to him that Mr. Lawrie had not stated this—that when the piston made the back-stroke, the performance of which caused the compression of the fluid, it must generate heat, and that heat must be thrown away, and could not be saved by any contrivance whatever; for when the engine worked best the generation of that heat took place at the lowest limit of temperature. Heat could only be communicated from a body to one colder than itself. The temperature of the fluid must be kept down to the lowest limit while the compression was going on, and the heat generated must be abstracted by means of some refrigerating process. There was an important general law which connected the quantity of heat thus necessarily thrown away with the total expenditure of heat. In the first place, the temperature was reckoned—not from the zero of an ordinary thermometer, but from a point called the absolute zero; a temperature at which a perfectly gaseous substance would exert no pressure, namely, 461° below zero of Fahrenheit's thermometer. This being defined, the law was as follows:—As the absolute temperature at which the heat is received during the forward stroke, is to the absolute temperature at which the waste heat is rejected during the back stroke; so is the whole heat necessarily expended to perform the work, to the heat which is necessarily lost. It was the difference between those two quantities of heat which produced mechanical work, and was proportional to the difference between those two limits of temperature. Now, that was the absolute law which applied to all substances whatever, and which had been confirmed by all experiments and contradicted by none. He might say, in regard to the experimental confirmation, that he had applied the law, and drawn up practical *formulæ* on that law, which agreed both with Dr. Stirling's and Mr. Ericsson's experiments. It was in 1852 that he had first done so in an approximate manner, when he sent a paper to the British Association at Liverpool, "On the means of realizing the advantages of the air-engine." In 1849 Professor Clausius and he, the one in Switzerland and the other in this country, had come to the same result by very different methods of investigation—different in detail, though the same in principle. In the paper of 1852 he had applied the law in a rough way, that paper having been clear of algebra, as it was intended to give a popular view of the subject; consequently, the calculations were not made with very great precision, but still they gave a very good approximation to the results of the well-known experiments upon Stirling's and Ericsson's engines. Of course those experiments fell short of the maximum theoretical results, because they involved losses which no rough calculation could take into account. In 1853, when Mr. James R. Napier and himself were engaged in designing an air-engine, it was found necessary to employ exact *formulæ* for their own guidance; and then he had to take into account the fact that there was always in every air-engine a certain amount of air which did not undergo an alternate heating and cooling, but which acted as a kind of cushion, and did not waste air or heat, but which rendered it necessary to have a larger cylinder. He had treated at length of this cushion and other matters of detail in his latest work, published about a year ago, "On Prime Movers." There was a waste of heat in the regenerator of from 5 to 10 per cent. When that was taken into account, the theoretical law which he stated before brought out results agreeing very precisely with Stirling's and Ericsson's experiments. It was quite true, as Mr. Lawrie had said, that if in such an engine as that of Dr. Stirling the respirator was done away with, there would be a far greater waste of heat than the necessary waste; because, instead of the heat being alternately taken from and restored to the air during the changes of temperature, there would be thrown away the whole heat necessary to produce those changes at every stroke, and the waste of heat would be enormous. But there was a method of avoiding that waste without the use of a respirator —by causing the changes of temperature to be obtained by additional compression and expansion. It was true that this system had its disadvantages, as a much larger cylinder was required to do the same work, so that the effective pressure was smaller, and the friction bore a larger proportion to it. What he meant to show in these latter remarks was, that the respirator was not absolutely necessary to produce the greatest economy of heat upon theoretical grounds; but the advantage it secured was that of obtaining the greatest compactness consistent with realizing the greatest practical effect from a given amount of heat.

Mr. LAWRIE said that the efficiency of the elementary engine described in the work "On Prime Movers," is measured by the law referred to; but the conditions of that elementary engine are not the same as those of Dr. Stirling's. In all the engines in that work it is supposed either that the strokes of the cylinder and heater begin simultaneously, or that the air is heated before the stroke begins. In every engine described in that work it is necessary to use a refrigerator of large power.

Professor MACQUORN RANKINE said that the law applied to a fluid working under certain prescribed conditions, and if these conditions were deviated from, according to the theory he supported, there would be a less proportion of heat converted into mechanical power. The proportions of the engine must be suited to the circumstances under which it was worked, or they would not get the best possible result under the circumstances. He so far agreed with Mr. Lawrie; but he maintained, notwithstanding his arguments, that in every air-engine some heat must be lost. No doubt he made that assertion without having had the opportunity of looking over Mr. Lawrie's calculations; but when he had considered them he would be in a position to search through the investigations and figures for error, if it existed, in this the only point in which he differed from Mr. Lawrie, and be able to point out whence it arose.

Mr. BROWNLEE remarked that if the plunger and piston started at the same time, the engine would not move at all.

Mr. LAWRIE remarked that if a refrigerator were used they might both start and end at the same time—a fly-wheel being used to turn the centre, as in every engine that has a point of no action.

Mr. BROWNLEE said that in the paper referred to by Mr. Lawrie as having been read by Mr. Stirling in 1845 before the Institution of Civil Engineers, Mr. Stirling mentioned that the average power required to drive the works at Dundee, had been ascertained to equal about 700,000 lbs. raised one foot per minute, or about 21 horses power. The quantity of coal consumed was 50 lbs. per hour, or five-sixths of a lb. per minute; and 250 lbs of water was passed through the refrigerator per minute, which was raised in temperature from 16 to 18 degrees. Assuming 16 degrees as the elevation of temperature communicated per minute to 250 lbs of water, and 772,000 foot lbs. per minute as the work of the engine, there was for each five-sixths of a lb. of coal consumed, $16 \times 250 = 4000$ units of heat transferred to the refrigerating water; whilst the work of the engine, if expended in friction, would have been capable of raising the temperature of $\frac{772,000}{772} = 1000$ lbs. of water, one degree. The coals were stated to have been of an inferior quality; but if they assumed each five-sixths of a lb. to have generated 8000 units of heat, then 1000 of those units were converted into work, 4000 were transferred to the refrigerator, and 3000 escaped by the chimney, or were otherwise lost by radiation; one-eighth of the whole generated, or one-fifth of that communicated to the air within the heaters having been rendered efficient. The lower temperature was stated by Mr. Stirling to have been 150° and the higher about 650°; and with these pair of temperatures, the theoretical

$$\text{Maximum efficiency} = \frac{650 - 150}{650 + 461} = \frac{500}{1111} = \quad . \quad . \quad \cdot 45$$

$$\text{Minimum heat rejected} = \frac{150 + 461}{650 + 461} = \frac{611}{1111} = \quad . \quad . \quad \cdot 55$$

$$1 \cdot 00$$

With these temperatures it was not possible to utilize more than 45 per cent. of the heat communicated to the heaters, and unless the whole of the heat required to elevate the temperature of the air from the lower to the higher temperature was alternately stored and restored by the respirator, this efficiency could not be realized. In actual practice it appeared that the efficiency was only $\frac{1}{5} = \cdot 2$, being less than half of ·45, the maximum. In an engine of this kind with a perfect regenerator, the work per unit of heat did not depend upon the pressure, but upon the ratio of the absolute temperatures only, and the maximum efficiency for the given pair of temperatures could not be realized unless the heated air was maintained at a constant temperature whilst expanding, and was likewise prevented from rising above the lower temperature when being compressed. With a perfect engine, the heat requisite to maintain the hot air at a constant temperature whilst expanding was all which it is absolutely necessary to expend; and that produced whilst compressing the same air at the lower temperature, it was no less necessary to reject as rapidly as it was generated, as otherwise this heat would go on accumulating, and heat the cold end of the containing vessels and respirator until the temperature was equalized throughout, when the engine would come to rest. The heat generated and rejected whilst compressing the air in its cold state was to that expended in maintaining a constant temperature whilst expanding, as the lower absolute temperature was to the higher. The heat so expended corresponded to the gross expansive effort and the space through which that effort was exerted by the air whilst expanding; but with the temperatures named, 650° and 150°, $\frac{150 + 461}{650 + 461} = \frac{55}{100}$ of that effort must be spent in reducing the air to its primitive volume. When an air-engine had no respirator, the maximum efficiency did not depend directly upon the ratio of the temperatures, but chiefly upon the ratio of compression and expansion, or upon the number of times which the lower pressure was contained in the higher. With the higher pressure, for example, double that of the lower, it was not possible to utilize more than 18¼ per cent. of the heat expended with any pair of temperatures whatever. The maximum efficiency with any pair of pressures which were as

| | | | | | | |
|---|---|---|---|---|---|---|
| 2⅔ | to | 1 | was | 25 | per | cent. |
| 4 | " | 1 | " | 33 | | " |
| 6 | " | 1 | " | 40½ | | " |
| 10·94 | " | 1 | " | 50 | | " |

Instead of preventing the air from rising in temperature when compressed, the efficiency here stated was (without the respirator) impossible, unless the heat so generated was retained by the air itself; and after the temperature had been further elevated by the application of heat whilst at the higher pressure, it was also essential that no further supply be added to the air whilst expanding from the higher to the lower pressure. Under such conditions, for each unit of heat supplied to the air, the quantity rejected $= \left(\frac{P_2}{P_1}\right)^{\cdot 29}$; and the maximum efficiency, $E = 1 - \left(\frac{P_2}{P_1}\right)^{\cdot 29}$

When a perfect gas was prevented from rising in temperature, if

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| compressed from | 1 to | $\frac{3}{4}$ | $\frac{1}{2}$ | $\frac{3}{8}$ | $\frac{1}{4}$ | $\frac{3}{16}$ | of its volume, the pres- |
| sure would rise from | 1 to | $\frac{4}{3}$ | 2 | $\frac{8}{3}$ | 4 | $\frac{16}{3}$ | and the product of |
| | — | — | — | — | — | — | |
| these numbers, | 1 | 1 | 1 | 1 | 1 | 1 | was constant. But |

when the heat generated by that compression was entirely retained by the gas itself whilst being compressed

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| from | V | = | 1 to $\frac{3}{4}$ | $\frac{1}{2}$ | $\frac{3}{8}$ | $\frac{1}{4}$ | $\frac{3}{16}$ | the pressure rose |
| from | P | = | 1 to $\frac{3}{2}$ | $\frac{8}{3}$ | $\frac{4}{1}$ | $\frac{64}{9}$ | $\frac{32}{3}$ | and the product |
| | | | — — | — | — | — | — | |
| (PV = T) rose from | | | 1 to $\frac{9}{8}$ | $\frac{4}{3}$ | $\frac{3}{2}$ | $\frac{16}{9}$ | 2. | |

Thus, in compressing to half the volume, they had $\frac{8}{3}$ of the pressure, and $\frac{3}{4}$ of the absolute temperature or product, P V. And conversely when, without being supplied with heat, a perfect gas expanded under pressure,

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| from V | = | 1 to $\frac{4}{3}$ | 2 | $\frac{8}{3}$ | 4 | $\frac{16}{3}$ | the pressure fell |
| from P | = | 1 to $\frac{2}{3}$ | $\frac{3}{8}$ | $\frac{1}{4}$ | $\frac{9}{64}$ | $\frac{3}{32}$ | and the absolute |
| temp. T. was | | 1 to $\frac{8}{9}$ | $\frac{3}{4}$ | $\frac{2}{3}$ | $\frac{9}{16}$ | $\frac{1}{2}$. | |

In taking, for example, 12 cubic inches of a perfect gas, say at a temperature of 307° Fahr., and at a pressure of 64 lbs. per inch, and assuming it possible to prevent the gas from drawing heat from the sides of the envelope, in expanding under pressure,

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| from | 12 to | 16 | 24 | 32 | 48 | 64 | cubic inches, |
| P. fell from | 64 to | $42\frac{2}{3}$ | 24 | 16 | 9 | 6 | lbs. per inch. |
| PV. = T = | 768 | $682\frac{2}{3}$ | 576 | 512 | 432 | 384 | |
| | 461 | 461 | 461 | 461 | 461 | 461 | |
| $t$ = | 307° | $221\frac{2}{3}$° | 115° | 51° | — 29° | — 77° | Fahr. |

If the air was compressed at a constant temperature, and at the higher pressure, $P_1$, was heated to such extent only, that, when expanded to the primitive pressure, $P_2$, it should also fall to the primitive temperature; then, with such an engine, neglecting friction, &c., the theoretical maximum efficiency,

$$E = 1 - \frac{\text{hyp. log. } \frac{P_1}{P_2}}{3{\cdot}451 \left\{ \left(\frac{P_1}{P_2}\right)^{\cdot 29} - 1 \right\}}$$

Under the above conditions it was not possible to utilize more of the heat expended with any pair of pressures, such as—

| | | | | |
|---|---|---|---|---|
| | | | C. | |
| 2 | to 1 | than 9·8 per cent. | 2·6 | 176° |
| $2\frac{2}{3}$ | " 1 | " $13\frac{1}{2}$ " | 1·9 | 233° |
| 4 | " 1 | " 18·8 " | 1·4 | $318\frac{1}{2}$° |
| 6 | " 1 | " 23·8 " | 1·08 | 415° |
| 10·94 | " 1 | " 30·7 " | ·84 | 581° |

Assuming each pound of coal to yield to the air as much heat as would raise the temperature of 42,000 lbs. of air, or 10,000 lbs. of water, one degree Fahr., the minimum coal per horse power per hour would equal C = 1,980,000 ÷ 7,720,000 E.

Assuming the lower temperature to be 60° Fahr., the numbers entered in the last column indicated the temperatures to which the air would require to be heated so as to prevent its falling below 60, whilst expanding from the higher to the lower pressures.

Professor Rankine said, with respect to the heat that was taken away by the refrigerator, it not only comprehended the heat necessarily wasted, but it also included the heat that the regenerator failed to take up, amounting to 5 or 10 per cent. of the heat required to produce the change of temperature.

The President regretted that from the lateness of the hour they must bring this very important subject to a close—a subject upon which they might get a great deal of information from Dr. Rankine, Mr. Lawrie, and Mr. Brownlee, who had all deeply studied it. He trusted on its being reopened next Session; and in the meantime he was sure they would unite with him in a hearty vote of thanks to Mr. Lawrie for his paper.

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*Note by Mr. Lawrie.*—Dr. Rankine in his remarks alleges that the writer has fallen into two errors:—

1st. He states that the writer is in error in supposing that hitherto in investigations of this kind of air-engine, the plunger of the heater and the piston of the cylinder have been assumed to perform the stroke simultaneously.

2nd. He states that the writer is in error in supposing, that if the action of the respirator be perfect there is no loss of heat beyond what disappears in dynamic effect; or in other words, that in air-engines, or rather in all engines, there is, in addition to the heat utilized in dynamic effect, a necessary and unavoidable loss of the heat indicated by the increase of temperature due to compression in the return or back stroke, which heat must be removed by a refrigeratory process, and, so far as the action of an engine to perform work is concerned, be lost; that the equation, $\frac{\text{Heat utilized}}{\text{Heat employed or used}} = \frac{\tau_1 - \tau_2}{\tau_1}$, expresses the best possible performance of every possible thermo-dynamic engine.

Dr. Rankine, in explanation of his views, refers to the investigations of Carnot, and states that an engine constructed to act in the manner contemplated by Carnot, by the performance of the four processes described at distinct intervals of time, is that in which the highest efficiency is obtained. These four processes are the following:—

In the diagram, fig. 3, Plate XII., of an air-engine acting in the manner explained by Carnot, A is the commencement of the stroke; and—

1st. During the part of the stroke from A to B, the air is maintained at a constant temperature by the application of heat.

2nd. From B to C the air expands without the addition of heat, and consequently falls in temperature.

3rd. In the return stroke from C to D, the air is compressed and maintained at a constant temperature by a refrigeratory process.

4th. From D to A the air is compressed without the removal of heat, and the temperature rises to be equal to that at the commencement of the stroke of the engine.

These are the four processes described by Carnot, and constitute the action of the engine, the efficiency of which is alleged to be the highest possible, and is measured by the law which Dr. Rankine states in his remarks.

In an engine of which the operation is as described by Carnot, and as is shown in the foregoing diagram, a refrigeratory process is essential to maintain the temperature of the air constant, or at a low degree, during C D; because if no refrigeratory process be applied, the pressure of the air during the return stroke would be the same as during the forward stroke, and no dynamic effect would be obtained; that is, if the acting pressure in the forward stroke be represented by the line A B C, the resisting pressure in the return stroke will, if no refrigeratory process be applied, be represented by the line C B A, and therefore no dynamic effect produced.

If a respirator be used, and if the plunger and piston perform the stroke simultaneously, a refrigeratory process is still necessary, because without it the return stroke would, as before, be precisely the reverse of the forward stroke, and still no dynamic effect would be produced. If, however, both a respirator and a refrigerator be used, dynamic effect will be obtained; but no mechanical advantage whatever will be derived from the use of the respirator. For an engine so arranged, with the heater, plunger, and cylinder piston performing the stroke simultaneously, the opinions respecting the respirator expressed at the Institution of Civil Engineers are correct. It affords in such a construction no advantage.

But if the action be as follows:—1st, If the air expands during the forward stroke, A B, fig. 4, Plate XII.; 2nd, is then passed through a respirator, and reduced in pressure and temperature to C; 3rd, is then compressed during the return stroke, C D; 4th, and repassed through the respirator, so as to receive the heat imparted to the respirator at the termination of the forward stroke—a refrigeratory process is not necessary for the production of dynamic effect.

In an engine so constructed, the expression $\frac{\text{Heat utilized}}{\text{Heat employed or used}}$ has a very different value from what it has in the engine of Carnot. In this engine there is a continuous current of heat through the respirator from the hot to the cold end, because the air, after it has passed through the respirator, being increased in temperature in consequence of the compression of the air in the return stroke, imparts heat to the cold end of the respirator, which, for the continued action of the engine, must be removed by a cooling process, and in consequence of the use of this cooling process, more heat is employed than is utilized, to an extent depending on the *data* of the engine; but the law stated by Dr. Rankine, the law $\frac{\tau_1 - \tau_2}{\tau_1}$, is no measure of the efficiency of this engine. The efficiency is much greater than is expressed by that law, and is greater to an extent depending principally upon the quantity of heat imparted to and received from the respirator.

The action of the respirator in the kind of engine considered in this paper is not thus confined to the two ends of the stroke, and is more advantageous. In this engine the respirator is continually in operation, and the heat to be removed by a cooling process, irrespective, of course, of that due to radiation, conduction, &c., is not more than that due to the compressing of the air during the latter part of the return stroke, during the part F D of the stroke in diagram No. 8.

The writer is not acquainted with any investigation of air-engines in which the advantage of placing the heater plunger in advance of the cylinder piston has been taken into account, although Stirling's engine, the only successful air-engine ever constructed, was arranged in that way. It has not been done in any of the investigations by Dr. Rankine in his work *On Prime Movers.* In the investigation in paragraph 266, page 343 of that work, Dr. Rankine loses sight of the important difference obtained by the advance of the heater plunger, and reduces an engine so constructed to the level of a machine composed of a series of engines in which the heater plunger and cylinder piston perform the stroke simultaneously.

These are the reasons why the writer continues to think that Dr. Rankine will find it necessary to reconsider the conclusions expressed in his remarks on this paper.

*Note by Professor Rankine.*—The preceding note by Mr. Lawrie has been shown to Professor Rankine in proof. With respect to the general question of the action of the "regenerator" or "economizer," he considers it best to defer any discussion of the subject until it shall again come before a meeting of the Institution. With respect to his statement that Mr. Lawrie was in error in believing that in all previous investigations the heater plunger and the piston were supposed to begin to work together, he has to refer to the work *On Prime Movers*, already cited, article 275, pages 362 to 371, in which not only is the heater plunger supposed to begin to work before the piston, but it is also supposed to have completed the operation of transferring the air through the economizer before the piston begins its forward stroke. He has also to refer to a paper in the *Philosophical Transactions* for 1854, pages 140 to 145, in which the effect of an economizer in an air-engine is investigated generally for any arrangement whatsoever of its motions. That general investigation was not introduced into the before-mentioned work *On Prime Movers;* because in that work the author thought it desirable to confine his attention to those problems which appeared to him to be of practical utility.

W. J. M. R.

*18th August*, 1861.

## *On the Removal of the Junction Lock at Grangemouth Harbour, and its Replacement by an Enlarged Lock.* By Mr. James Milne.

The prior works of a scheme for increasing the harbour accommodation at Grangemouth, formed the subject of the paper read before the society last Session—*On the Enlargement of the Junction Basin, and the Deepening of the Communication between the Junction Basin and the Entrance Lock.* As the removal and replacement of the junction lock completes the works of the scheme, and forms the subject of the present supplementary paper, the writer trusts that such may be deemed some excuse for so soon again submitting to the society a paper on so commonplace a subject, and in which there is so much of the former paper repeated.

A general plan of the harbour of Grangemouth, showing the locks, docks, basins, and canal, fig. 1, Plate II., of Vol. III., and also illustrates the present paper.

By the substitution of a cast-iron invert in lieu of the original ashlar invert, removed from the entrance to the junction basin, under the junction bridge, an additional depth of 3½ feet was obtained at the entrance and throughout the junction basin. It was resolved to take further advantage of this increased depth by deepening and extending the junction lock, so as to carry the available depth through to the timber basin, by a lock of suitable dimensions in length and width for passing ships of 15 feet draught of water to the timber basin.

The area of the timber basin is now 12¾ acres; it lies contiguous to a basin of 4¾ acres in which only bonded timber was kept, until by the recent alteration in the timber duties the bonding of timber was discontinued;* and this basin, with several acres of contiguous ground, may all be made into one basin, having an area of fully 20 acres, for timber and shipping, on the same level as the canal reach, to which the basin forms the communication from the junction lock.

Previously to completing the drawings for the enlarged lock, several bores were put down through the building of the former lock for the purpose of testing the depth to a *stratum* of till and boulders, which lies under the alluvial deposit at Grangemouth. This *stratum* under the lock varies in thickness from 7 inches to 13 inches, and it was found to lie at the depth of from 20 feet 10 inches, to 21 feet 2 inches under the level of the surface of the coping at the junction bridge, which is assumed as

* Vol. III., page 28.

the *datum* level herein referred to, and answers to 2 feet 6 inches above high water of spring tides. It was also found by the bores that the foundation of the walls of the former lock were not built in such manner, and to such depth, that any portion of the former wall, which was in the same line as the new wall, could be retained as a portion of the wall of the new lock.

The former lock was built in 1842; it measured 91 feet in length from point to point of gates, and 21 feet in width, with a depth of 12 feet water on the sill of the upper gates, and 13 feet 2 inches depth of water in the lock at high water of spring-tides. These dimensions were found to be insufficient for passsing any considerable proportion of the vessels arriving at the port, and too large to navigate the canal; whilst the capacity of the lock being fully one-fourth greater than the capacity of the canal locks, wasted this proportion of water in locking through the canal craft.

With the view of removing and rebuilding the lock, the lower entrance from the wall of the junction basin to the centre of the draw-bridge over the lock was widened and deepened in 1859. Preparatory to removing the lock, a temporary bridge was constructed over this portion of the entrance. The communication between the timber basin and the canal was shut up by a cofferdam piled in across the entrance; and the junction basin was shut off by the iron cofferdam, formerly described, being set on a sill log and placed against the return walls.

The site of the old lock was found to have been dug out to the average depth of about 4 inches above the surface of the till bed, and the whole of the bottom of the lock and foundations was found to be built on two thicknesses of yellow pine planks—the lower planking in breadths of about 18 inches, laid at about 18 inches apart longitudinally to the lock, and all bedded on concrete about 12 inches in depth, under these planks; whilst the upper planking was in breadths of about 13 inches, and laid at about 13 inches apart transversely on the lower planking. All the spaces between the edges of the planks were filled in with concrete, and on this floor of planks and concrete an invert of dressed ashlar, 2 feet 6 inches in depth, was built for the bottom of the lock, and the side walls abutted on the invert bottom. The whole building of the lock was of most substantial masonry, and stood quite firm and unaltered.

Before deciding on the dimensions of the enlarged lock, all the sailing vessels which arrived at the port for upwards of a year were measured in length, breadth of beam, and draught of water, and it was found that a lock 25 feet in width, 15 feet draught of water, and of sufficient length to hold two canal vessels, would pass the proportion of about five-sixths of the sailing vessels arriving at the port.

It was deemed most important to preserve the till bed unbroken under the site of the lock; and in order to get the requisite depth of lock with this restriction, it was absolutely necessary to make the depth occupied by the bottoming of the lock as limited as practicable with sufficient strength for safety; and this led to the application of cast-iron for the platforms of the bottom recesses of the intermediate and lower lock gates, and to the use of timber logs and planking for the lock bottom and foundations.

Fig. 1, Plate XIII., is a longitudinal elevation of the lock-side and bridge-wall inside the lock, with the lock-bottoming, the forebay, and recess for the upper gates, in section; and fig. 2 is a plan of the lock and the building for the draw-bridge, which spans over the lower entrance to the lock. Figs. 3, 4, and 5 are three cross sections of the lock. Fig. 3 represents it as at C D in fig. 2, showing the planking and logs under the lock-bottom and the foundations, half the stone invert bottoming, and half the filling of timber on the logs between the stone inverts, with the side walls and counterforts of the lock, and a sectional outline of the former lock. Fig. 4 represents the lock as at A — B in fig. 2, showing the excavations, the cast-iron bottoming of the recesses, and the walls and counterforts over the transverse girders. Fig. 5 shows the section through the upper recess, as at E — F in fig. 2.

The enlarged lock now built, as shown by the Plate, has three pairs of lock gates, and measures 145 feet from point to point of extreme gates, being 25½ feet in width, with a depth of 15 feet water on the sill of the upper gates, and 16 feet 4 inches depth of water in the lock at high water of spring tides. The intermediate gates are placed at 70 feet from the lower gates, and 75 feet from the upper gates; the five feet of greater length in the upper compartment being equal to the shortening of that compartment by the forebay for the sill of the upper gates, and making each of the compartments the necessary length for the largest vessels which can pass through the canal locks. The compartment next the upper gates only is used for locking through canal craft singly; but when two canal vessels arrive at the lock together for being passed up or down, the extreme gates only are used, and the two vessels are passed through by one locking; and if a third boat of the dimensions for the Union Canal arrives at the same time, as sometimes occurs, the three vessels are passed through the lock together. It may be observed that by locking the canal craft through the lock singly, and using both compartments of the lock for lowering or lifting the rise of the lock at twice, nearly half the water may be saved. Say, that in locking down, the vessel is brought into the upper compartment of the lock, and the three pairs of gates shut, the water then in the upper compartment when levelled into the two compartments will give both the compartments half full; by then passing the vessel into the lower compartment, and again shutting the intermediate gates, the vessel may be passed out of the lock, leaving the upper compartment half full, which will save a half lock of water if the next vessel arriving has to be passed down the lock. Should the next vessel arriving require to be passed up, by locking this vessel into the lower compartment of the lock, the half lock of water in the upper compartment will raise the vessel only one-fourth the lift, leaving three-fourths of the upper compartment to be filled, and saving only one-fourth of a lock of water. But if the next vessel in turn has to be locked down, the quarter of a lock of water left in the lower compartment would give one-eighth in the two compartments; and, consequently, this vessel would, by using the two compartments, be passed down on three-eighths of a lockful of water, and leave five eighths of a lock of water in the upper compartment. This system of locking would be resorted to only during the time of actual or apprehended scarcity of water, as it would be productive of delay, and give double the labour in locking vessels through.

Figs. 6, 7, 8, and 9 represent sectional elevation, plan, and cross sections of the cast-iron platform for the bottom recesses of the lower and intermediate gates, and the supplementary girders for the foundations of the walls. Fig. 10 is an enlarged cross-section of the girders. Figs. 11 and 12 are a section and plan of the cast-iron shoes for the turn-posts of the lock gates.

Each of the two cast-iron platforms measures 32 feet in length, and is made to the breadth of 17 feet, by nine box girders of equal breadth, and 13 inches in depth throughout the length; but the section of the girders is stronger at the middle than at the ends. Brackets or ribs 8 inches deep are cast on four girders of each set, and form the triangle for the timber splay pieces, against which the lock gates shut; and seats are cast in the girders at the hollow quoins for keying in the pivots for the gates, and oval holes are cored out of the girders for the purpose of bolting them together and filling them under after being laid to their places. The girders were cast with fitting strips, and fitted together by chipping and filing; they were cramped together for drilling the bolt holes, and these holes all broached out to the diameter of 1⅛ inch, and the bolts turned to fit. Transverse angle girders are fitted and bolted to the girders of the platform, the upright faces of these transverse girders corresponding to the faces of the walls at the side recesses. On the transverse girders, and on the ends of the platform girders, supplementary girders are fitted for carrying the side walls of the lock, and transmitting the weight of these walls to the platform.

On the site for the lock being cleaned out to the till bed, the girders of the platform were laid, and levelled, and bolted together to their places as low as the till bed would permit; and after the rows of sheeting piles were planted and bolted to the girders, and the transverse girders also bolted to their places, the boxes in the girders were wholly filled up with stones and iron-slag, all broken to the size of 2½ inch road metal; and after being so filled, all under the girders was run up with Roman cement, and the oval holes all filled flush with hard brick made for the purpose, and cemented in. The spaces formed by the brackets raised on the girders behind the splay pieces are all filled flush by stones dressed to fit, and run up with Roman cement.

The depth of the cast-iron girders being 13 inches under the surface of the recess for gates, and 8 inches for the sills of the gates, gave about 21 inches in depth for the bottoming along the middle of the lock. The site for the foundations and bottoming was wholly cleaned out to the till bed, and all under the foundations of the walls was levelled up with a layer of concrete about 2 inches in depth. On this levelling platforms of 3-inch planking are laid, at ½ inch apart, on the concrete under the foundation of the side walls and counterforts, and between these plankings the bottom of the lock was made up with concrete to the surfaces of the planking. On this concrete and planking logs of Memel and yellow pine timber are laid, at about 3 feet 6 inches apart. The logs measure about 14 inches square, and are of such lengths as pass through to the backs of the walls and counterforts. The logs when laid to their places were spiked to the planking, and loaded on the ends. The form of the bottom of the lock is an invert of 71 feet radius, and built with large dressed ashlar, fitted between the logs; the stones at the bottom of the invert are 12 inches deep, and set to about two inches above the timber logs; and the invert stones increase in depth to 18 inches at the side walls, where they stand about 11 inches above the timber logs. All these stones are set in Arden lime mortar, and run in with cement. The spaces over the logs are filled in to the form of the invert by two pieces of black birch meeting near the middle of the lock and spiked to the logs. On the invert being built in, all the half-inch spaces between the planking were grouted up, and the spaces between the logs built in with flat rubble.

The height of the lock walls from the till bed to the surface of the cope is 24 feet 2 inches, and the height of the walls at the head of the lock, 24 feet 8 inches. The faces of the walls, to 15 feet 6 inches below the surface of the cope, is built to a batter of 1 inch to 7 feet, and under this 15 feet 6 inches, to a hollow profile of 12 feet 8 inches radius.

There are two courses of found-stones, each course 12 inches in thickness, throughout the whole foundations of the walls and counterforts, the lower course abutting on the invert; and the two courses are so sized and bonded as to transmit the whole weight of the lock walls to the logs, the planking, and the invert. All the founds, invert, and bottoming of the lock are laid and built in Arden lime mortar.

Above the found-courses the walls are built with ashlar in front, and rubble backing, in courses of from 12 to 16 inches thick. The forebay wall is built to a radius of 15 feet, and to such height as gives 15 feet depth of water over the sill for the upper gates. The bottom recess for these gates is built with ashlar 18 inches deep, dressed and set to the radial lines of 71 feet radius, on found-stones 9 inches thick, and laid on a bed of concrete raised from the gravel bed. The concrete is all made with ground Arden lime. The walls above the founds are built with mortar made of ground Charleston lime; and the ashlar in the chamber of the lock is lipped with red-lead putty 2½ inches in from the face, and the end joints of the ashlar run up with Roman cement.

At the backs of the side walls of the lock, all between the counterforts at the upper gates and the counterforts at the lower gates, and back from the walls to 12 inches behind the counterforts, is made up from the till bed to the height of the counterforts with concrete, re-made from the old concrete, mortar, and chips, arising from the removal of the lock. All the concrete removed from the old lock was made of Charleston lime, and was on being removed found to be most firmly set and cemented together. The concrete again used behind the walls was broken up and mixed with about 1 ton of quick lime and 1 ton of mine dust, to 10 cubic yards of the concrete remade.

A wall of clay puddle was made on the till bed, and raised to 3 feet 6 inches in height all along the bottom of the concrete behind the walls. And from the tops of counterforts and concrete there is a puddle wall to 6 inches above the bed for the cope, with a covering of puddle over the tops of the counterforts and concrete. From the counterforts at the upper gates, all round the backs of the return walls at the head of the lock, and from the counterforts at the lower lock gates round the bridge cisterns and to the walls at the lock entrance, the walls are puddled at the back from the till bed to 6 inches up on the cope.

It may be stated that the concrete behind the walls is applied chiefly as a substitute for clay puddle; it is expected that it will adhere to and strengthen the walls, whilst the proper beating and making of a puddle wall behind such lengths of straight walls would have tended to press the walls towards the lock. The excavations behind the walls, concrete, and puddle, were all again made up with the earth arising from the excavations, all beaten in layers sloping from the lock walls.

The lock gates are made of timber, and are similar in appearance to the gates of the canal locks; but the enlarged sizes of gates, scantlings of the timber, and fastenings of iron work, make them about three times the weight of the canal gates. The lower gates, complete, weigh about 8 tons each gate. The hollow quoins for the gate posts are all faced from the sills to the cope with cast-iron quoin plates fitted and fastened to the building, and plumb throughout the length. With the view of making such heavy gates the more easily worked, and of lessening the wear of the gate posts, the sockets in the cast-iron shoes of the gate posts for the pivots are cored out ¼ inch eccentric to the circle of the posts, and eccentric straps of wrought-iron corresponding to the eccentric of the shoes are fitted to the gate posts for the neck straps of the gates, and the centres of the eccentrics of the shoes and straps are so placed as to bring the gate posts to bear on the quoin plates when the gates are shut; but so soon as the gates begin to open, the posts leave the quoins and bear only on the pivots and straps. As the gates are carefully balanced by the swing bars of the upper and middle gates, and by cast-iron back weights on the swing bars of the lower gates—where the swing bars are shortened for the drawbridge—there is but little strain or friction at the neck straps. Three wrought-iron plates, case-hardened, are fitted on the top of each of the bottom pivots for shoes, with a pin through the plates into each pivot for keeping the plates to their places when the gates are being shipped to or unshipped off the pivots. These plates are intended to lessen the friction and the wearing of the pivots, and also by increasing or lessening the number of plates, the gates may be raised or lowered to suit any subsidence or any inaccuracy in the depths of the pots cored in the shoes.

Throughout the building of the lock there was not any perceptible subsidence of the lock bottom or lock walls. The building of the lock walls has now been raised to the height of the cope for two months, and for the last month the lock has been open to the trade; and by trying a gauge rod between the walls of the lock, it is found that the walls stand unaltered.

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In the discussion which followed—

Professor Macquorn Rankine asked what was the slope of the earth that was rammed in layers against the walls?

Mr. Milne answered, about one in five from the walls.

The President said the novelty was in removing the old lock, and building a deeper one, without going under the till bed. That led to the introduction of a cast-iron floor, which had been so far quite successful.

In answer to the President and Mr. Lawrie, who asked how would cast-iron sides do also? Mr. Milne said, it was all a matter of cost. He had not worked out what tonnage would pass through the lock now, but he was sure craft of more than 400 tons would, whereas formerly a vessel of 150 tons could scarcely pass. It would be less expensive, but he did not know how much. The cast-iron platform cost about double the stone removed; and the new timber invert bottoming cost about one-half that removed.

The PRESIDENT said it seemed to him that cast-iron floors would give greater stability to the structure than if they had been of timber and stone.

Professor RANKINE said it seemed to have the properties of timber and stone combined, having the stiffness of the timber and the solidity of masonry.

A unanimous vote of thanks was then passed to Mr. Milne, on the motion of the President.

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The following paper was then read:—

## *On Canal Locks.* By Mr. George Simpson.

The first introduction of canal locks seems merged in oblivion—the rise and fall of the tide may have suggested the idea; at all events, any floating body on the sea, when elevated by the rise of the tide, or lowered by the fall thereof, would show clearly enough the power obtainable by water in this respect. The necessary chamber, gates, and sluices forming a canal lock for the raising or lowering of boats or other floating bodies, are too familiar to every one to require description. Of course canal locks are only called into requisition where uniformity of water level, practically speaking, is not to be had. The supply of water for a canal through a country requiring canal locks is of first importance. And the storage of water being attended with such great expense, the reservoirs in a mineral district being by nature so precarious, it is singular that such a wasteful mode of raising and lowering boats as that of canal locks should have been persevered in in modern times. The Chinese appear to have adhered to inclined planes on canals for upwards of two thousand years, evidently steering clear of the expense of reservoirs and the waste of water. The merit of a canal lock consists in the simplicity of the arrangements for deriving mechanical power from the water, but certainly not in the economical use of that power, as in any application of a canal lock which has come under the writer's observation, whether by the adoption of side ponds or low lifts, a very great waste of power follows. By way of example, the writer may refer to the Blackhill locks on the Monkland Canal, where there are eight locks in operation (four double locks) to accomplish a lift of 96 feet, the dimensions of each being:—length, 75 feet; width, 14 feet; depth, 12 feet; and they are each capable of containing 350 tons of water, whilst the largest boat and cargo that can be passed through is one of 80 tons; so that, for the elevation or lowering of a boat and cargo, 350 tons of water, less the displacement of the boat, are expended; or, irrespective of leakage, fully three-quarters of the power is unavailable, and even fully this loss follows in the raising or lowering of an empty boat. In other words, an empty boat in being raised or lowered requires more water than a full one. Besides the great waste of water, canal locks are very objectionable on account of the time occupied in passing a boat through them, and are most expensive to work and keep in repair. They limit the size of the boat and cargo to the working capacity of the lock chamber, whilst, not to speak of the large outlay involved in their construction, the cost of their maintenance and working is an important item in canal expenditure. The cost and maintenance of the reservoirs are directly chargeable against the lock, hence the rate per ton per mile of transit in passing locks is four times the amount on any other parts of the canal.

In order to overcome some of the defects arising from the use of the locks, and which invariably accompany all canal locks, there was constructed at Blackhill, eleven years ago, at a cost of little under £20,000, a double inclined plane. Two caissons of the form of the boat are used here, each placed on a carriage on rails, arranged so that one so far balances the other. The friction and also the loss of weight on the descending caisson entering the water in the lower reach, is overcome by a stationary steam-engine. A very complete description of this inclined plane is given in the Transactions of the Royal Scottish Society of Arts for 1852. Although this inclined plane is a decided improvement over canal locks, and would have been still more so had it been generally used, and not merely for the raising of empty boats; yet the raising of an empty boat thereby occupies fully ten minutes, compared with half an hour by the locks; and without taking into view the great first cost, tear and wear, and working expenses, the time of transit of a boat by it seems not quite to obviate the objection of the lock. It is a fact worthy of note, that in the face of existing and competing railways and stoppage by frost, the traffic on this canal, which at one time was so little as to induce the parties interested to shut it, is still increasing, and there is little doubt could the locks referred to be conveniently and economically superseded, the capacity of the boats considerably enlarged, and horse haulage generally supplanted by steam power, a greater traffic would follow. From 4000 to 5000 tons of material are passed daily at Blackhill. A much greater quantity might be passed were the boats to arrive at the locks at regular times, but this cannot be so arranged, so that a part of the present traffic is already diverted from the legitimate portion of the working day, pointing to a more expeditious mode of transit as likely soon to be required.

Many schemes besides the modern application of steam to inclined planes have been projected as substitutes for canal locks, such as vertical balance lifts, some of which have been put in practice. The object of course aimed at in all such lifts, is to store the power generated by the descent of the material, to be afterwards utilized; but in any of the lifts of this description which the writer has noticed, the storing of the power is accompanied by unnecessary friction, arising from the use of intermediate machinery and unnecessary weight thrown on the supporting parts of the lift, especially where two cradles or caissons, or one cradle and counterweight are suspended over pulleys. The writer sometime ago proposed as a substitute for canal locks what he calls a hydro-pneumatic lift, in which a buoyant vessel is made subservient to this end, and which he considers the best means for storing the power with the least friction. One application is shown by the model (exhibited at the meeting), and another in Plate XIV., fig. 1 being a sectional elevation, and fig. 2 a plan. In the model the buoyant vessel is placed under the cradle, and in the other arrangement, two buoyant vessels A, are placed, one on each side of the cradle, C, keeping the working parts entirely above ground. The model shows the mode of raising and lowering a boat by the lift. The buoyant air vessels, A, are made of malleable iron, and are capable of supporting the tubes, B, and cradle, C, with its contents. The tubes, B, act as regulators for the ascent or descent of the buoyant vessels, by means of the outlet of water at D, and the inlet of air at E. The junction with the upper and lower reaches of the canal is effected and cut off by means of sliding doors, F, such as are used at Blackhill. In ascending the buoyant power is in excess, but at the top the weight of the cradle is rendered in excess by a small extra quantity of water received from the upper reach. The descent is regulated by adjusting the air outlets, E, and the consequent entrance of the water at D. At the bottom the small extra quantity of water received at the top flows into the lower reach, which renders the buoyant power in excess, and causes the cradle to rise. The cradle is retained at either top or bottom by catches or stops. The cradle is guided in its ascent and descent by pillars, G, which the writer prefers to construct according to a plan proposed by him for chimney shafts. Each pillar consists of a central cylindrical shaft of the same diameter throughout, such shaft being formed with four external wings or abutments, such abutments in the case of chimneys all tapering from a wide base to the diameter of the shaft at the top. In the present case one abutment of each shaft is built with an outer vertical edge, in which is formed the groove for guiding the cradle. To insure the cradle being kept horizontal, racks may be fixed in the guiding grooves, the cradle being fitted with pinions gearing into the racks, and connected to each other by shafting and bevil gearing, so as to act simultaneously. For a lift of this kind, applicable at Blackhill, and calculated to raise and lower boats containing 100 tons cargo, the cost would be about £7000, exclusive of excavations and building, to bring the eastern extremity of the lower reach vertically under the western extremity of the upper reach. Two lifts placed alongside would not range so high in cost. As at Blackhill the heavy traffic is entirely in a downward direction, the improved lift would be the means of actual transferring water from the lower to the upper reach, as the loaded boats would displace more water out of the cradle into the upper reach than the empty boats would displace out of the cradle into the lower reach. In conclusion, it may be mentioned, that if it is inconvenient to apply a directly vertical lift, the hydro-pneumatic lift can be modified to carry the cradle up and down an inclined plane, and its application in this way would probably be the least expensive at Blackhill or similar localities.

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In consequence of the lateness of the hour, the discussion of this paper was postponed.

The PRESIDENT proposed a vote of thanks to Mr. Simpson, which was unanimously accorded.

Mr. D. MORE said he had much pleasure in proposing a cordial vote of thanks to Mr. Neilson for his conduct in the chair, and for his great attention to the interests of the Institution during his term of office as President. He must further move a special vote of thanks to Mr. Neilson for his originating the scheme of Prize Medals, and for his great exertions in collecting funds to enable the Institution to give such medals. He might state that he had already paid into the bank, to the credit of the medal fund, the sum of £180, and he had no doubt the remainder of the sum wanted would soon be collected.

The votes of thanks were unanimously accorded by the meeting.

The PRESIDENT said that Mr. Robson and Mr. Johnstone were equally worthy of praise with himself for their exertions in carrying out the medal scheme. They wanted to complete the fund to £750, and he hoped the balance would be obtained before the commencement of next Session.

A SPECIAL GENERAL MEETING (being the TENTH MEETING of the Session) was held in the Philosophical Society's Hall, on Wednesday, 4th September, 1861—W. M. NEILSON, Esq., President, in the chair.

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Mr. NEIL ROBSON having intimated that he could not undertake the office of President for the Fifth Session, to which he had been elected in his absence, on 17th April, 1861, the meeting proceeded to elect a President in his place, when

Mr. WILLIAM JOHNSTONE was duly elected President for the Fifth Session, 1861–62.

Mr. DAVID M'CALL was elected a Councillor in place of Mr. William Johnstone.

Mr. EDMUND HUNT was elected Secretary for the Fifth Session.

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The Members present were gratified with a view of Mr. DAVID KIRKALDY's magnificent picture of the steamer *Persia*, and a cordial vote of thanks was passed to him for exhibiting it.

This completed the proceedings of the Fourth Session, 1860-61.

# REGULATIONS

OF THE

# INSTITUTION OF ENGINEERS IN SCOTLAND.

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## SECTION I.—OBJECT.

1. 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.

## SECTION II.—CONSTITUTION.

2. The Institution of Engineers in Scotland shall consist of Members, Associates, Graduates, and Honorary Members.

3. MEMBERS shall be Mechanical Engineers, Civil Engineers, Mining Engineers, Military Engineers, Shipbuilders, and Founders.

4. ASSOCIATES shall be such persons, not included in the classes enumerated in the preceding regulation, as the Council and Institution shall consider qualified by knowledge bearing on Engineering Science or Practice.

5. GRADUATES shall be persons engaged in study or employment to qualify themselves for the profession of Engineers.

6. HONORARY MEMBERS shall be such distinguished persons as the Council and Institution shall appoint.

7. The number of Honorary Members shall be limited to twelve.

## SECTION III.—MANAGEMENT AND OFFICE-BEARERS.

8. The direction and management of the affairs of the Institution shall be confided to a Council, subject to the control of the General Meetings.

9. The Council shall consist of a President, three Vice-Presidents, ten Councillors, and a Treasurer; all of whom shall be Members, but not Associates, Graduates, nor Honorary Members. Five Members of Council shall constitute a quorum.

10. There shall be a Secretary under the control of the Council, who shall receive such salary as the Institution shall fix.

## Section IV.—DUTIES OF OFFICE-BEARERS.

11. The Office-bearers shall assume office immediately after the Meeting at which they are elected; they shall hold Meetings and make arrangements respecting papers and other matters for carrying on the business of the Session for which they are elected; and they shall, any or all of them, give their services as long after such Session as may be necessary to complete matters connected therewith.

12. The President shall take the chair at all meetings at which he is present; he shall conduct and keep order in the proceedings of the Institution; state and put questions, and, if necessary, ascertain the sense of the Meetings upon matters before them; he may sum up, at the termination of discussions, the opinions given, and declare what appears to be the sense of the speakers, to which he may add his own opinion; and he shall carry into effect the regulations of the Institution.

13. The Vice-Presidents shall take part in the Council proceedings; and they shall in rotation take the chair in the absence of the President, and perform the duties enumerated in the preceding regulation.

14. The Councillors shall take part in the Council proceedings, and aid the other Members thereof with their co-operation and advice.

15. The Treasurer shall take part in the Council proceedings; he shall take charge of the property of the Institution; receive all payments due to the Institution, and pay into one of the Glasgow Banks, in the joint names of the President, one of the Vice-Presidents, and himself, the cash in his hands whenever it amounts to Ten Pounds; he shall pay all sums due by the Institution, but not without an order signed by two Members of a Committee of the Council nominated to examine the accounts; he shall keep an account of all his intromissions in the General Cash Book of the Institution, which shall upon all occasions be open to inspection by the Council, and which shall be balanced annually, up to the last Meeting of each Session; and he shall produce at such meetings the Cash Book and Annual Balance Sheet, or financial statement, together with an Inventory of all the Property possessed by the Institution, and a Register of the names of the Members, Associates, and Graduates of the Institution, such Register being arranged so as to distinguish all persons whose contributions are in arrear.

16. The Secretary shall take minutes of the proceedings at all the meetings of the Institution and Council, and enter them in proper books provided for the purpose; he shall write the correspondence of the Institution and Council; prepare and revise papers for reading and publication; read minutes and notices at the meetings, and also papers and communi-

cations if the authors wish it, report discussions, and perform whatever other duties are indicated in the regulations of the Institution as appertaining to his department.

## Section V.—AUDITORS.

17. Two Auditors, who shall be Members of the Institution, but not Office-bearers, shall be chosen, at the last meeting of each Session, to examine the accounts and statements produced by the Treasurer.

## Section VI.—MEETINGS AND PROCEEDINGS.

18. The Institution shall hold Ordinary Meetings for reading papers and for discussing matters connected with the objects of the Institution; and such Meetings shall take place regularly, at least once in every four weeks during each Session; the Sessions to commence in each month of October, and continue until the month of April next following.

19. At every Ordinary Meeting of the Institution the Secretary shall first read the minutes of the preceding Meeting, which, on approval, shall then be signed by the Chairman. The Secretary shall next read any notices which may have to be brought before the Meeting; after which any Candidates for admission shall be balloted for, and any new Members shall be admitted. Any business of the Institution shall then be disposed of, and the paper or papers for the evening be read. The business of every Ordinary Meeting of the Institution shall commence as soon after Eight o'clock in the Evening as Ten Members are present.

20. Any of the Ordinary Meetings of the Institution may be adjourned by a vote of the Members present.

21. Extraordinary or Special Meetings may be called by the Council when they consider it proper or necessary, and must be called by them on receipt of a requisition from any five Members, specifying the business to be brought before such Meeting.

22. The Secretary shall issue notices of Meetings to all the Members, Associates, Graduates, and Honorary Members of the Institution, at least four days' before each Ordinary or Adjourned Meeting of the Institution; such notices mentioning the papers to be read and business to be brought forward at the Meeting. Similar notices shall be issued of the Annual General Meeting, and of all Extraordinary or Special Meetings of the Institution, at least seven days before they are to take place.

23. The Council shall meet one hour before each Meeting of the Institution, and on other occasions when the President shall deem it necessary, being summoned by special circulars in the latter case only.

24. Any question of a personal nature before a Meeting of the Institution or Council shall be decided by ballot; all other questions shall be decided by a show of hands, or by any convenient system of open voting; the Chairman to have a second or casting vote when necessary. None but Members or Associates shall take part in any voting or balloting.

25. Each Member, Associate, Graduate, and Honorary Member, shall have power to admit one stranger to each Meeting of the Institution, who shall sign his name in a book kept for the purpose; but who shall not take any part in the discussions, unless requested to do so by the Chairman of the Meeting.

26. All papers read at the meetings of the Institution must relate to Engineering, Science, or Practice, and must be approved of by the Council before being read.

27. The papers read, and the discussions held during each Session, or such portion of them as the Council shall select, shall be printed and published as soon as possible, and shall be edited by the Secretary and a Committee of the Council.

28. The copyright of any paper read at a Meeting of the Institution shall be the exclusive property of the Institution, unless the publication thereof by the Institution is delayed beyond the commencement of the Session immediately following that during which it is read; in which case the copyright shall revert to the author of the paper. The Council shall have power, however, to make any arrangement they think proper with an author on first accepting his paper.

29. Drawings and Models accompanying any paper read at a Meeting of the Institution shall thenceforward be the property of the Institution, unless a special arrangement is made by the Council respecting them when the paper is first accepted.

30. The printed Transactions of each Session of the Institution shall be distributed gratuitously as soon as ready to those who shall have been Members, Associates, Graduates, or Honorary Members of the Institution during such Session, and to the authors of the papers printed, and they shall be sold to the public at such prices as the Council shall fix.

## Section VII.—ELECTION OF NEW MEMBERS AND OFFICE-BEARERS.

31. Every Candidate for admission as a Member, Associate, or Graduate of the Institution shall sign an application for admission, and obtain the recommendation of at least three Members; such application and

recommendation being according to a prescribed form contained in the Council Minutes. If the Council approve of the application and recommendation, the Secretary shall give notice of it at the first ensuing Ordinary Meeting of the Institution, and the Candidate shall be balloted for at the following Meeting of the Institution, and shall be admitted if three-fifths of the votes are favourable.

32. The granting of Honorary Membership to any person shall be proposed by the Council, and notice thereof shall be given by the Secretary at a Meeting of the Institution. The person shall be balloted for at the following Meeting of the Institution, and shall be admitted if four-fifths of the votes are favourable.

33. New Members, Associates, Graduates, and Honorary Members, shall be formally admitted by the President at the first Meeting at which they are present after being elected, when they shall sign their names in the Roll Book of the Institution, and receive a copy of the Regulations.

34. If any person proposed for admission into the Institution is rejected on being balloted for, no notice shall be taken of the proposal in the minutes; and it shall be ascertained from any person proposed to be made an Honorary Member before he is balloted for, whether he will accept the honour, no notice being taken of the proposal in the minutes unless he is elected. No Candidate for admission shall be balloted for a second time within twelve months.

35. The Office-bearers shall be severally elected by ballot for one year at an Annual General Meeting, to be held in each month of April, such Meeting being the last of the Session.

36. A Member holding the office of President or Vice-President one year, shall be re-eligible to the same office the next year; but he shall not subsequently be eligible thereto without being at least a year out of the office.

37. A Member holding the office of Treasurer or Secretary may be re-elected to such office any number of times.

38. Three of the Members holding the office of Councillor for one year shall be ineligible to such office for the ensuing year. Such three ineligible Members shall be those who have been in the office the longest; and in case one or more of the three have to be selected from two or more who are equal in this respect, then the selection of such one or more shall fall on the lowest on the list when originally elected to the office.

39. A vacancy occurring during any Session in consequence of the retirement or death of any Office-bearer, shall be filled up by the Council, until the next Annual General Meeting for electing Office-bearers.

## Section VIII.—CONTRIBUTIONS OF MEMBERS TO THE INSTITUTION.

40. Every Member shall contribute the sum of Two Pounds Ten Shillings the year he becomes a Member, and the sum of One Pound Ten Shillings every subsequent year.

41. Every Associate shall contribute the sum of Two Pounds the year he joins the Institution, and the sum of One Pound Ten Shillings every subsequent year.

42. Every Graduate shall contribute the sum of Fifteen Shillings every year.

43. The Annual Contributions shall be payable in advance, at or before the first Meeting of each Session.

44. The first contributions of New Members, Associates, and Graduates, balloted for after two-thirds of the Meetings of any Session have been held, shall not be due until the first Meeting of the following Session.

45. Honorary Members shall pay no contributions.

46. No Member nor Associate whose contribution is in arrear shall be entitled to vote.

47. Any Member, Associate, or Graduate, whose contribution is more than one year in arrear, may be removed by a vote at a Meeting of the Institution.

48. Any Member, Associate, or Graduate retiring from the Institution, shall continue to be liable for annual contributions until he shall have given formal notice of his retirement to the Secretary at or before the first meeting of a Session.

## Section IX.—REGULATIONS AND BYE-LAWS.

49. Any proposition for adding to or altering the Regulations may be laid before the Council, who may bring it before the Institution if they think fit, being bound to do so should it be accompanied by a requisition from any five Members of the Institution.

50. No alteration of, or addition to the Regulations shall be made except at a Special General Meeting of the Institution, called for the purpose by the Council, by a circular, giving at least seven days' notice, and detailing the alteration or addition proposed to be made.

51. The Council shall have power to make or alter Bye-Laws and minor ordinances, in accordance with the spirit, intention, and meaning of the Regulations of the Institution, whenever it shall, in their opinion, appear to be necessary for the good order and government of the Institution.

*List of Honorary Members, Members, Associates, and Graduates of the* INSTITUTION OF ENGINEERS IN SCOTLAND, *at the Termination of the Fourth Session*, 1860–61.

## HONORARY MEMBERS.

**JAMES WALKER, C.E., LL.D., F.R.SS.L. & E., Past President of the Inst. of Civil Engineers.**
**JAMES PRESCOTT JOULE, LL.D., F.R.S.**
**CHARLES PIAZZI SMYTH, F.R.SS.L. & E., Astronomer-Royal for Scotland.**
**WILLIAM FAIRBAIRN, C.E., F.R.S., F.G.S.**
**WILLIAM THOMSON, A.M., LL.D., F.R.SS.L. & E., Professor of Natural Philosophy in the University of Glasgow.**
**Professor R. CLAUSIUS of Zurich.**

## MEMBERS.

| | | |
|---|---|---|
| James | Aiken, jun., | Cranstonhill Foundry, Glasgow. |
| William | Aiton, | Partick. |
| William | Alexander, | Government Inspector of Mines. |
| Alexander | Allan, | Scottish Central Railway, Perth. |
| Robert | Angus, | Blair Works, Dalry. |
| David | Auld. | 80 Canning Street, Calton, Glasgow. |
| | | |
| Andrew | Barclay, | Kilmarnock. |
| Hugh | Bartholomew, | Engineer to the Glasgow City and Suburban Gas Works. |
| John | Bawden, | 24 St. Vincent Crescent, Glasgow. |
| R. Bruce | Bell, | 4 Bothwell Street, Glasgow. |
| Robert | Blackwood, | Kilmarnock. |
| James | Blair, | 61 M'Alpine Street, Glasgow. |
| Benjamin H. | Blyth, | 135 George Street, Edinburgh. |
| Charles T. | Bright, | Kt., F.R.A.S., F.R.G.S., 12 Upper Hyde Park Gardens, London. |
| James | Broom, | Blochairn House, Glasgow. |
| Andrew | Brown, | London Works, Renfrew. |
| Richard | Brown, | Shotts Iron Company, Glasgow. |
| James | Brownlee, | City Saw Mills, Port-Dundas. |
| James C. | Bunten, | Anderston Foundry, Glasgow. |
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| James T. | Caird, | Greenock. |
| Duncan | Cameron, | Springfield Iron Works, M'Neil Street, Glasgow. |
| James | Campbell, | Elliot Works, Finnieston, Glasgow. |

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| Peter | Carmichael, | Dens Works, Dundee. |
| Robert | Cassels, | 23 St. Enoch Square, Glasgow. |
| Alexander | Chaplin, | Cranstonhill Engine Works, Glasgow. |
| Daniel K. | Clark, | 11 Adam Street, Adelphi, London. |
| James | Clinkskill, | 56 Rose Street, Glasgow. |
| Benjamin | Connor, | Caledonian Railway. |
| Robert | Cook, | 100 Commerce Street, Glasgow. |
| Archibald | Craig, | Gateside, Paisley. |
| George | Crawhall, | Elliot Works, Finnieston, Glasgow. |
| James | Denny, | Dumbarton. |
| William S. | Dixon, | 1 Dixon Street, Glasgow. |
| John | Donald, | 21 Robertson Street, Glasgow. |
| John | Downie, | 100 Woodlands Road, Glasgow. |
| John | Duff, | Oakbank Engine Works, Garscube Road, Glasgow. |
| George B. | Edington, | Victoria Foundry, Glasgow. |
| John | Elder, | 12 Centre Street, Glasgow. |
| Robert | Faulds, | 6 Parson Street, Glasgow. |
| James | Ferguson, | Auchinheath, Lesmahagow. |
| John | Finlay, | 46 Buchanan Street, Glasgow. |
| Archibald | Finnie, | Kilmarnock. |
| William | Forrest, | 9 Canal Street, Glasgow. |
| J. R. | Forman, | 133 West Regent Street, Glasgow. |
| John B. | Fyfe, | Canal House, Ardrishaig. |
| James M. | Gale, | Engineer to the Glasgow Corporation Water Works. |
| John | Galloway, | Kilmarnock. |
| Archibald | Gilchrist, | Clydeholm Works, Whiteinch. |
| David C, | Glen, | Greenhead Works, Glasgow. |
| Matthew | Gray, | Dalmonach, Bonhill. |
| Henry | Gourlay, | Dundee Foundry, Dundee. |
| George | Graham, | Caledonian Railway. |
| John | Hamilton, | 11 Buchanan Street, Glasgow. |
| George | Harvey, | Albion Engine Works, 40 M'Neil Street, Glasgow. |
| James | Henderson, | 7 Exchange Place, Glasgow. |
| James M'L. | Henderson, | Renfrew. |
| James | Hendry, | 8 Dixon Street, Glasgow. |
| Charles | Howatson, | Muirkirk. |
| James | Howden, | 25 Robertson Street, Glasgow. |

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| Edmund | Hunt, | 28 St. Enoch Square, Glasgow, *Secretary*. |
| James | Hunter, | Newmains, near Motherwell. |
| John | Hunter, | Dalmellington Iron Works, near Ayr. |
| | | |
| Anthony | Inglis, | 60 Warroch Street, Glasgow. |
| John | Inglis, | 60 Warroch Street, Glasgow. |
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| William | Jack, | Carnbroe Iron Works, Coatbridge. |
| William | Johnson, | 166 Buchanan Street, Glasgow. |
| Ronald | Johnstone, | 204 West George Street, Glasgow. |
| William | Johnstone, | Glasgow and South Western Railway. |
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| David | Kirkaldy, | Lancefield Foundry, Glasgow. |
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| David | Laidlaw, | Alliance Foundry, Glasgow. |
| William | Lancaster, | Portland Iron Works, near Kilmarnock. |
| James G. | Lawrie, | Whiteinch. |
| John | Lawson, | Mountain-Blue Works, Camlachie. |
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| David | M'Call, | 133 West Regent Street, Glasgow. |
| Thomas | M'Culloch, | Vulcan Foundry, Kilmarnock. |
| James I. | M'Dermont, | Winton Buildings, Ayr. |
| Walter | M'Farlane, | Saracen Foundry, Glasgow. |
| James | M'Gregor, | Partick. |
| James | M'Ilwham, | Anderston Foundry, Glasgow. |
| John | Mackenzie, | Dundyvan, Coatbridge. |
| Robert | Maclaren, | Eglinton Foundry, Glasgow. |
| Walter | MacLellan. | 127 Trongate, Glasgow. |
| John | M'Nab, | Dumbreck Priory, Glasgow. |
| William | Macnab, | Greenock. |
| Andrew | M'Onie, | 1 Scotland Street, Tradeston, Glasgow. |
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| James | Milne, | 16 Windsor Terrace, St. George's Road, Glasgow. |
| James B. | Mirrlees, | 128 West Street, Tradeston, Glasgow. |
| John | Moffat, | Ardrossan. |
| David | More, | 33 Montrose Street, Glasgow, *Treasurer*. |
| Matthew A. | Muir, | Anderston Foundry, Glasgow. |
| James | Murdoch, | Lancefield Forge, Glasgow. |
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| James R. | Napier, | 26 Newton place, Glasgow. |
| John | Napier, | Lancefield Foundry, Glasgow. |
| Robert | Napier, | West Shandon. |

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| Walter M. | Neilson, | Hyde-Park Foundry, Glasgow, *President.* |
| Walter | Neilson, | Summerlee Iron Works, Coatbridge. |
| William | Neilson, | Mossend Iron Works, Bellshill. |
| Charles | O'Neil, | 40 Abbotsford Place, Glasgow. |
| John W. | Ormiston, | Shotts Iron Works, Motherwell. |
| William | Paton, | Edinburgh and Glasgow Railway, Cowlairs. |
| John | Paton, | 1 Dixon Street, Glasgow. |
| William | Ramsay, | 37 West George Street, Glasgow. |
| Charles | Randolph, | 12 Centre Street, Glasgow. |
| W. J. Macquorn | Rankine, *Past President,* | 59 St. Vincent Street, Glasgow. |
| James | Robertson, | Alliance Foundry, Glasgow. |
| Hazelton R. | Robson, | 2 Avondale Place, Glasgow. |
| Neil | Robson, | 127 St. Vincent Street, Glasgow. |
| Robert C. | Ross, | Springvale. |
| John M. | Rowan, | Atlas Works, Glasgow. |
| David | Rowan, | Cranstonhill Foundry, Glasgow. |
| James | Russell, | 25 Robertson Street, Glasgow. |
| Thomas | Russell, | 204 Dumbarton Road, Glasgow. |
| John | Scott, jun , | Greenock. |
| Thomas B. | Seath, | 42 Broomielaw, Glasgow. |
| Thomas | Shanks, | Johnstone. |
| Thomas | Sheriff, | 12 Monteith Row, Glasgow. |
| William | Simons, | Whiteinch. |
| George | Simpson, | 172 West George Street, Glasgow. |
| Alexander | Smith, | Eglinton Engine Works, Cook Street, Glasgow. |
| David | Smith, | 37 West George Street, Glasgow. |
| David | Smith, | St. James' Foundry, Anderston Quay, Glasgow. |
| George | Smith, | Sun Foundry, Port-Dundas, Glasgow. |
| William | Smith, | Eglinton Engine Works, Cook Street, Glasgow. |
| Robert | Steel, jun., | Greenock. |
| Andrew M. | Stewart, | Irvine. |
| David Y. | Stewart, | St. Rollox, Glasgow. |
| Patrick | Stirling, | Glasgow and South-Western Railway, Kilmarnock. |
| Peter | Sturrock, | Kilmarnock. |
| William | Tait, | Scotland Street Iron-Works, Tradeston, Glasgow. |
| George | Thomson, | Clyde Bank Foundry, Glasgow. |
| John | Thomson, | East Indian Railway, Mirzapore, India. |

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| John M. | Thomson, | Calder Iron Works, Coatbridge. |
| Thomas | Thorburn, | Borough Surveyor, Derby. |
| David | Tod, | Partick. |
| William | Tod, | Clyde Foundry, Anderston Quay, Glasgow. |
| John | Tulloch, | Dumbarton. |
| George | Urie, | 101 Commerce Street, Glasgow. |
| Matthew | Waddell, | Creetown, Kirkcudbrightshire. |
| William | Weir, | Eglinton Iron Works, Kilwinning. |
| Alexander | Whitelaw, | Gartsherrie House, Coatbridge. |
| Isaac | Whitesmith, | 29 Govan Street, Glasgow. |
| John | Wilkie, | 33 Renfield Street, Glasgow. |
| Peter | Wilson, | Edinburgh and Glasgow Railway. |
| Thomas | Wingate, jun , | Whiteinch. |
| Thomas R. | Yarrow, | Arbroath. |
| John | Young, | 1 Eldon Place, Glasgow. |
| R. | Young, | Caledonian and Dumbarton Railway, Bowling. |

## ASSOCIATES.

| | | |
|---|---|---|
| Archibald O. | Ewing, | 2 West Regent Street, Glasgow. |
| William | Hall, | Bellevue, Irvine. |
| George T. | Hendry, | 8 Dixon Street, Glasgow. |
| James | Young, | Limefield, West Calder. |

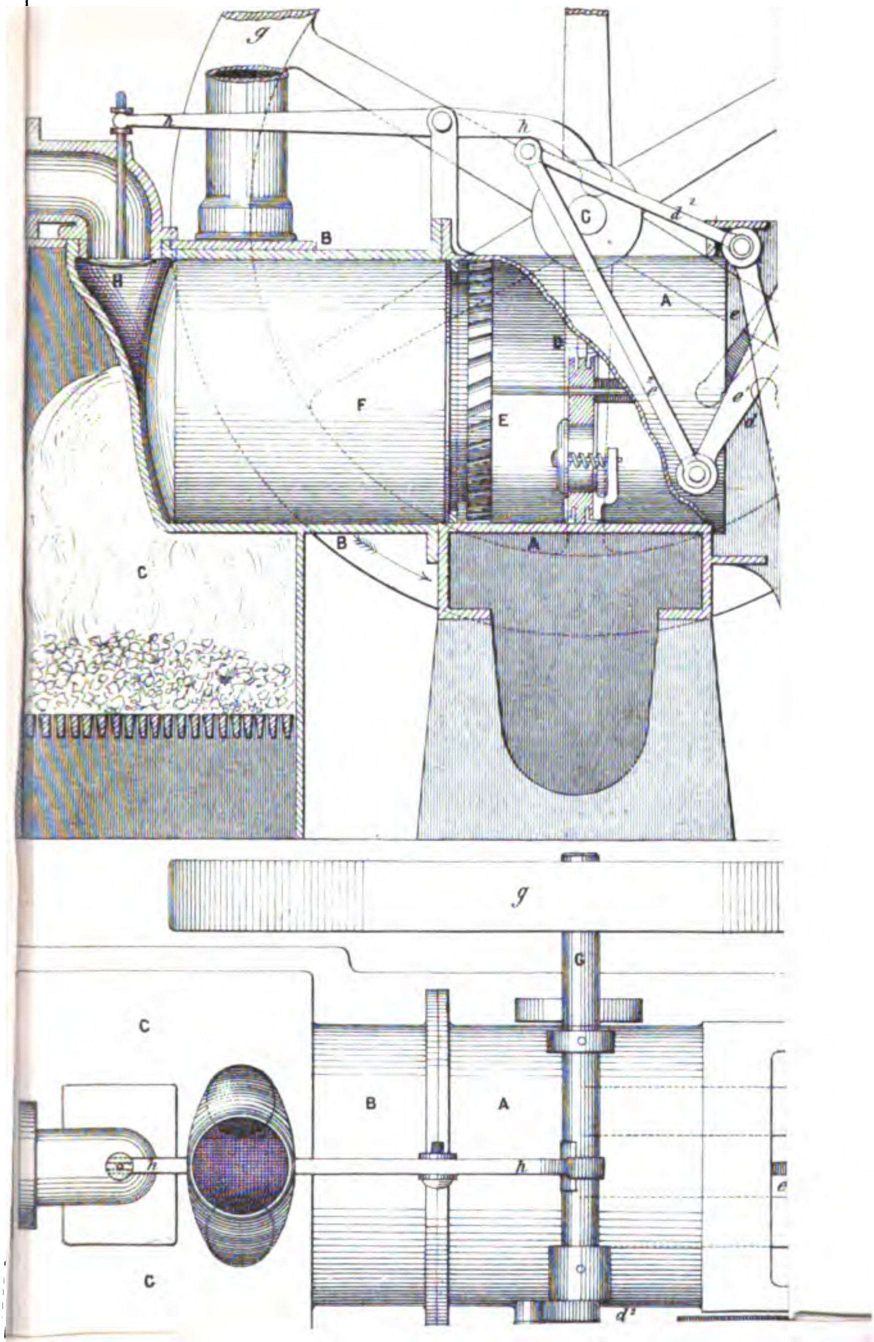
## GRADUATES.

| | |
|---|---|
| Thomas | Aitken. |
| Donald | Anderson. |
| Thomas | Black. |
| John | Hall. |
| William | Inglis. |
| Charles B. | King. |
| John | M'Donald. |
| David N. | Melvin. |
| G. James | Morrison. |
| Thomas | Roberts. |
| George | Russell. |
| Alexander M. | Strathern. |

# INDEX.

WILLIAM MACKENZIE,
PRINTER,
45 AND 47 HOWARD STREET, GLASGOW.

# AMERICAN AIR ENGINE.



## APPLICATION OF TRANSVERSALS TO RAILWAY LINES.

*Fig. 1.*

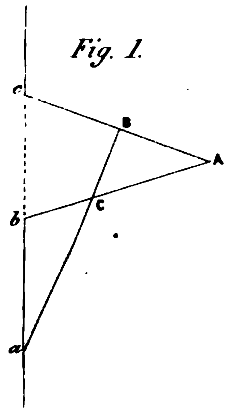
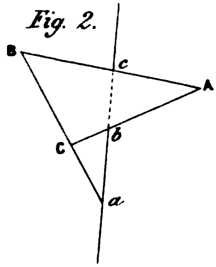



*Fig. 2.*



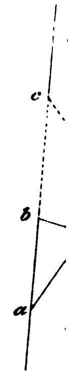




*Fig. 4.*

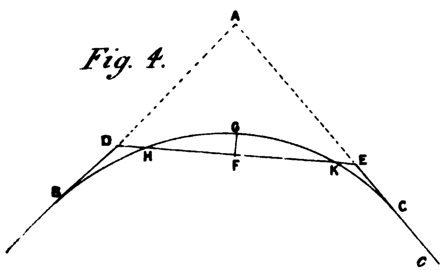
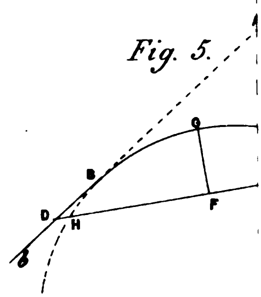



*Fig. 5.*




## RAILWAY CURVES.

*Fig. 6*

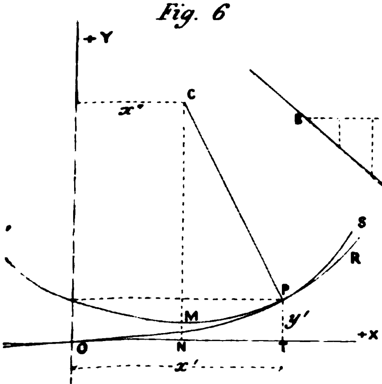
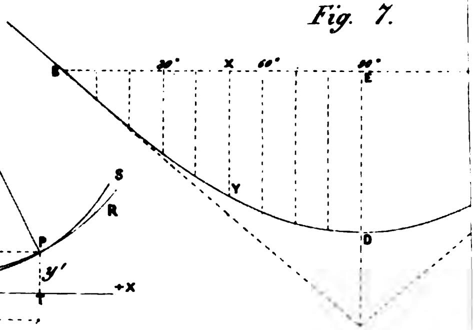
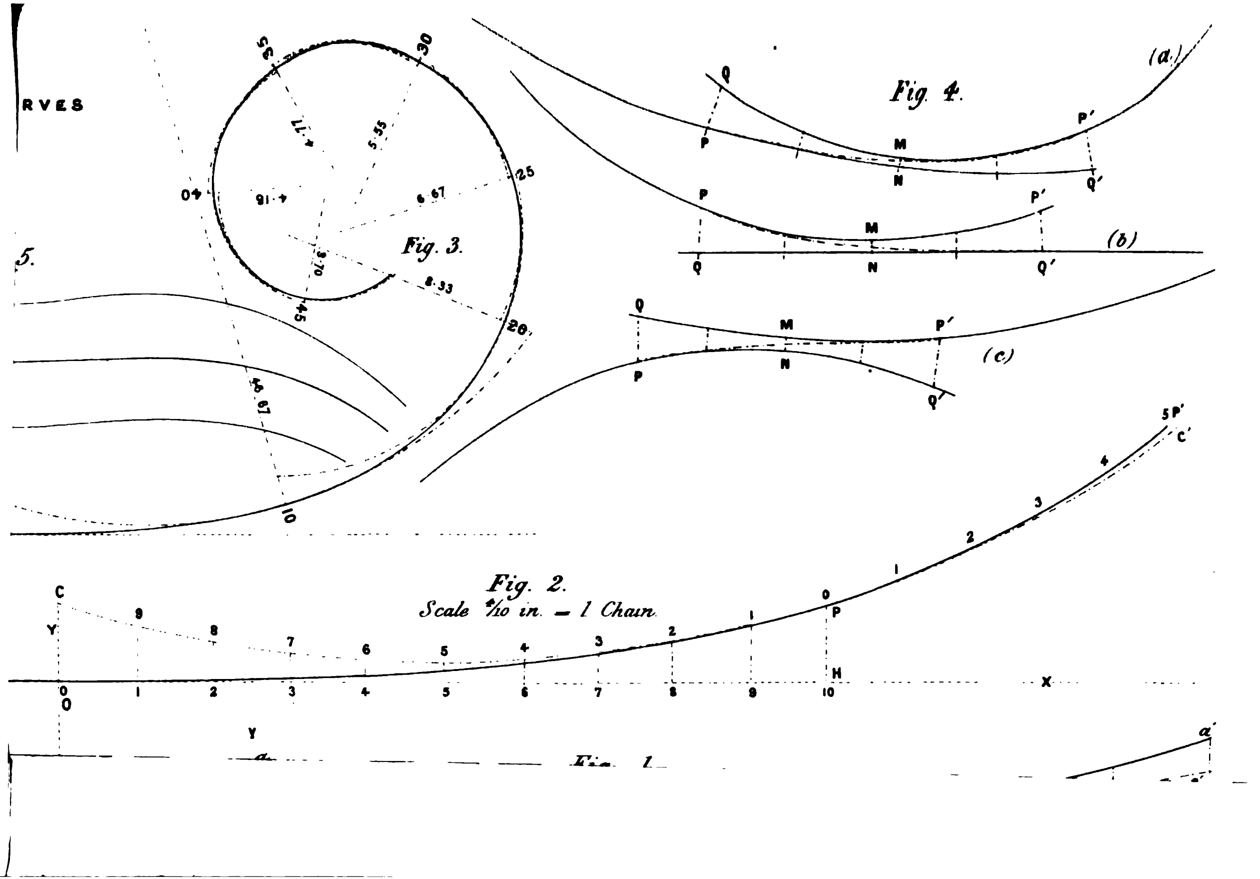



*Fig. 7.*




*(Proceedings Inst E.S. Vol. IV, pages 16, 23, 36.)*

RVES



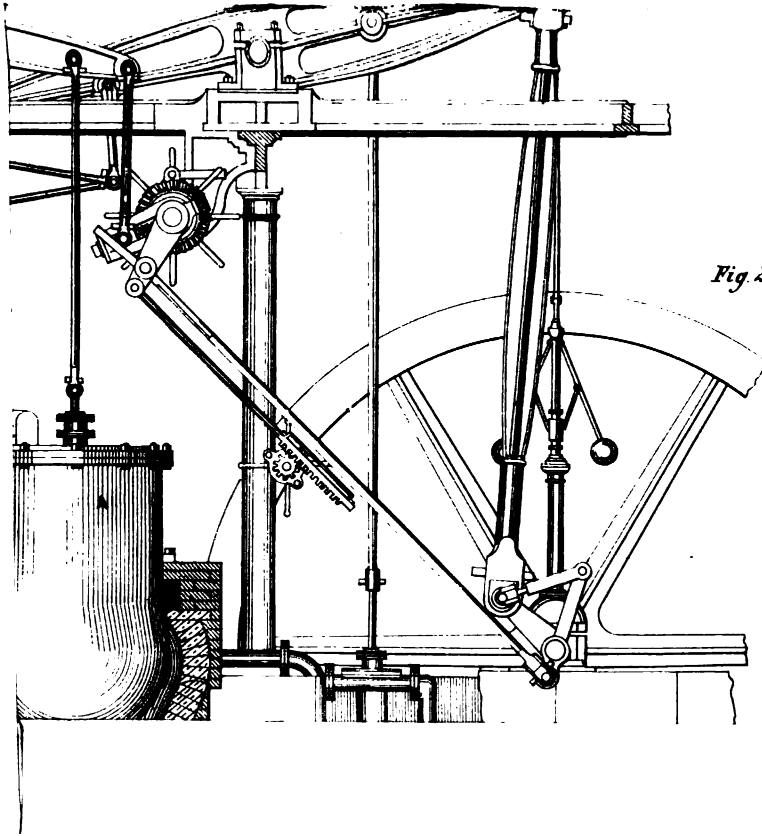



Fig. 2

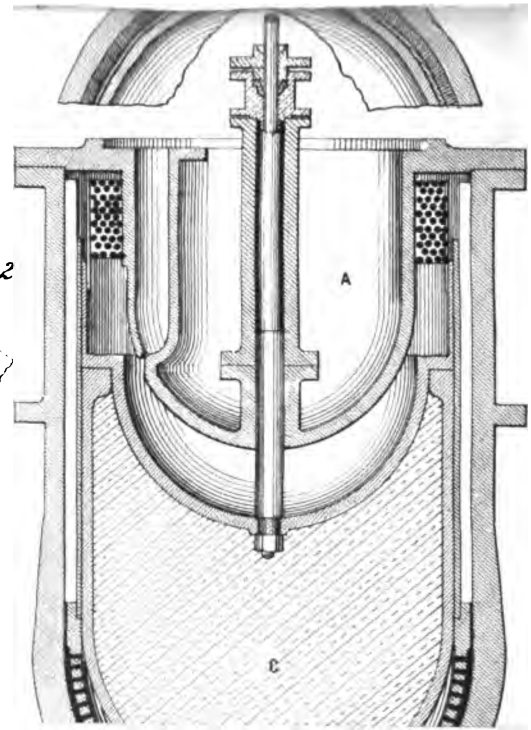
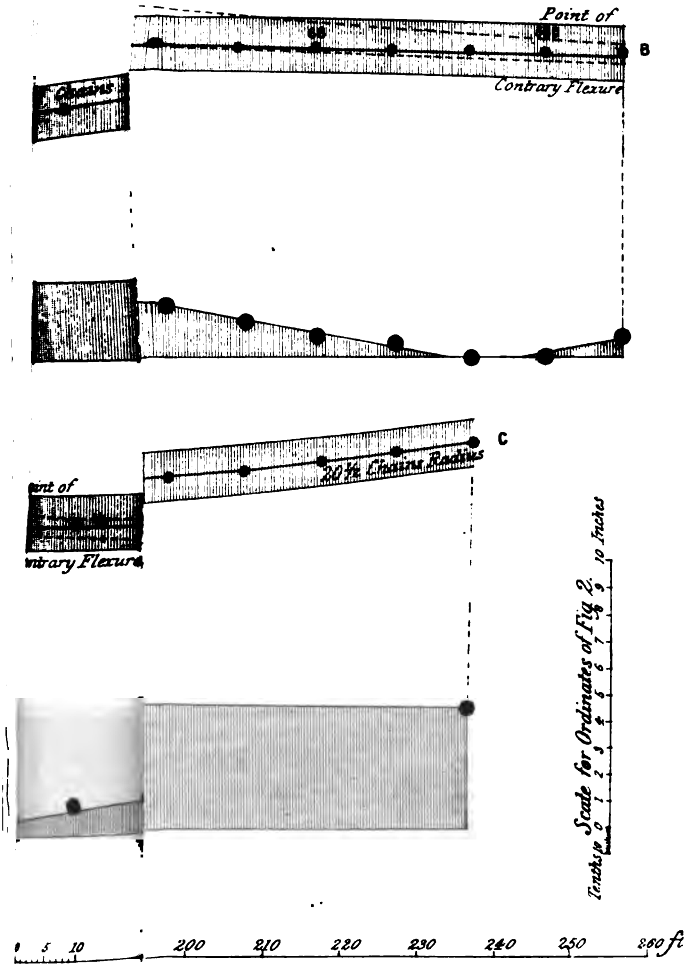
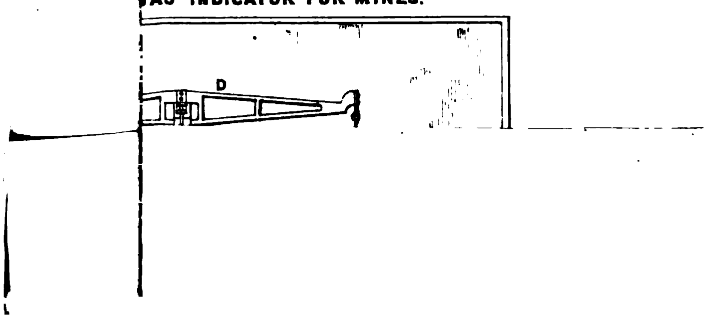


PLATE V




GAS INDICATOR FOR MINES.



SIMPSON'S PUMPS

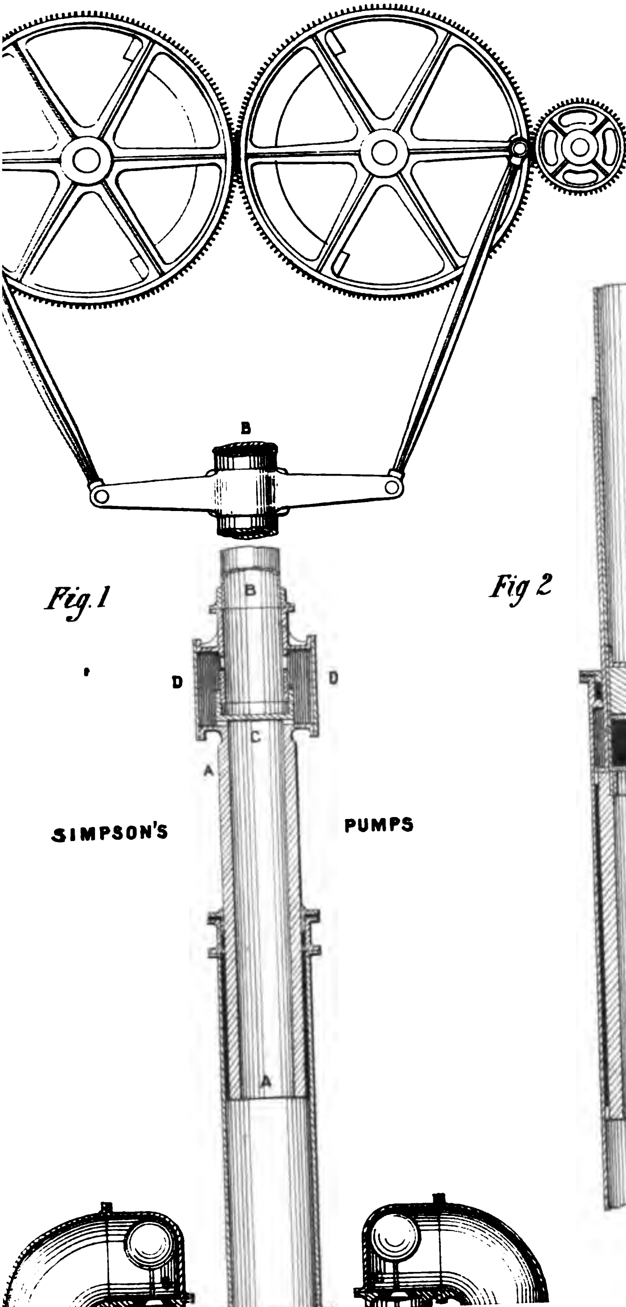



Fig. 1

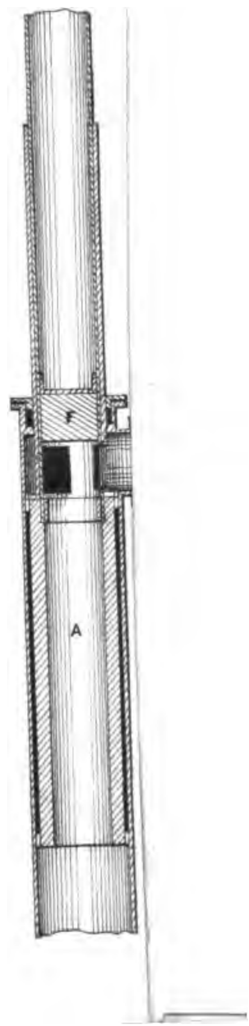



Fig 2

*Fig. 3. Pirsson.*

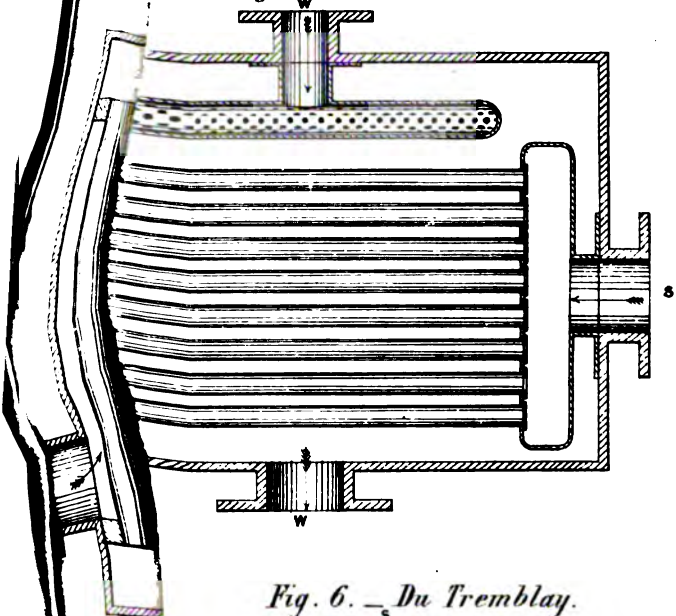



*Fig. 6. — Du Tremblay.*

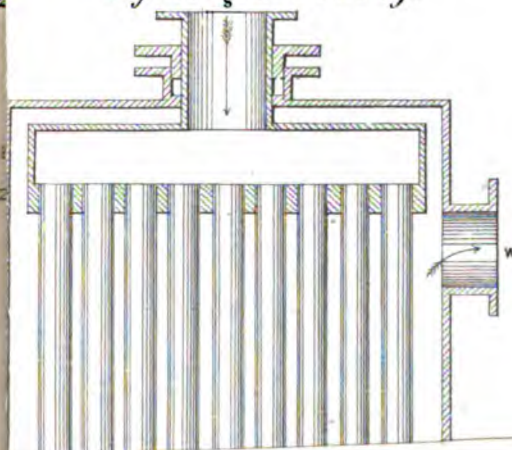


**PLATE VIII.**

Fig. 2 a.

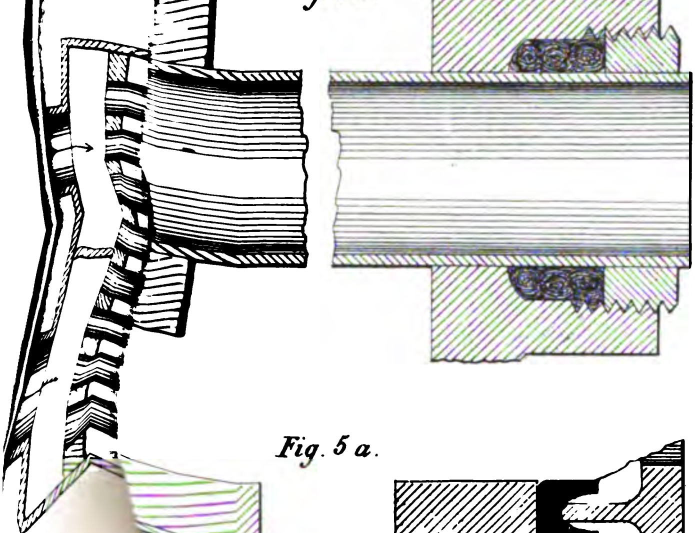


Fig. 5 a.

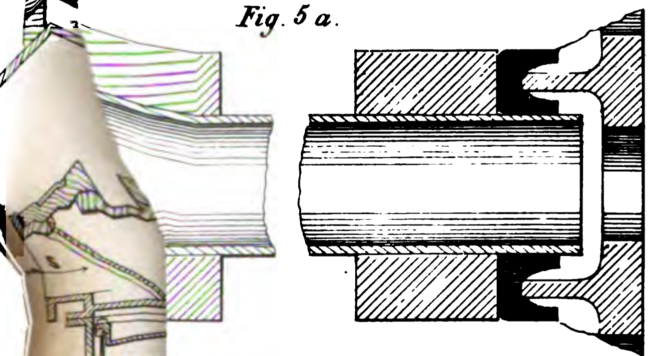
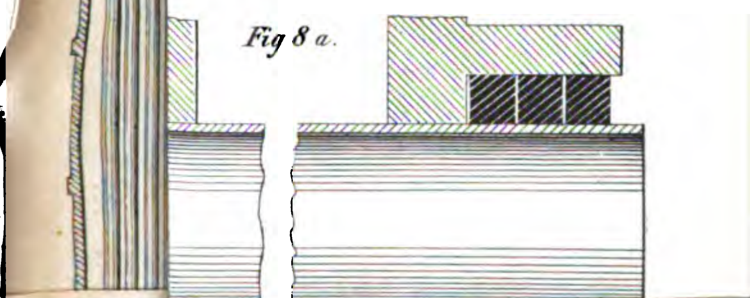
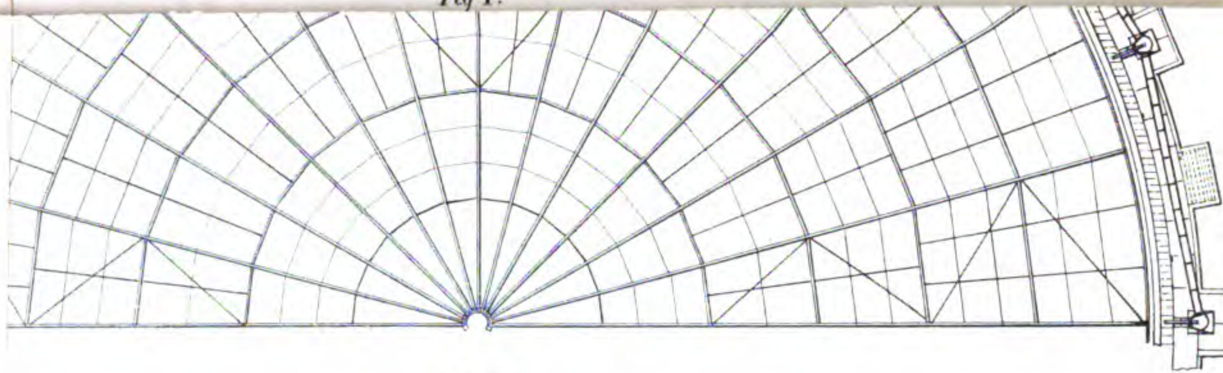


Fig 8 a.

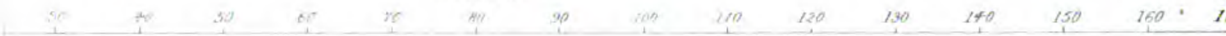


ERECTED 1860.

Fig 1.



Scale.




(. IV page 87.)

PLATE X

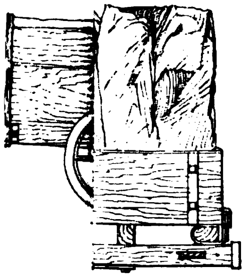
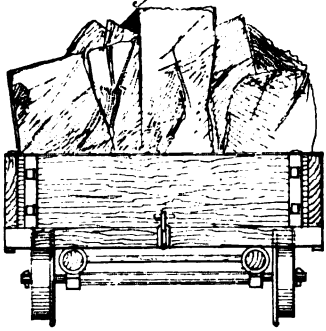
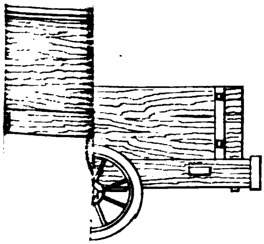


Fig. 8.





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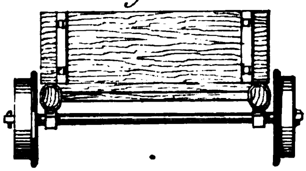

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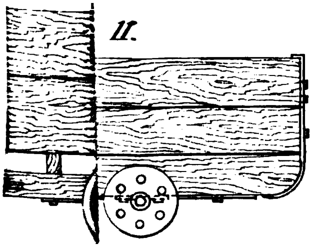
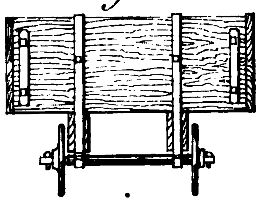
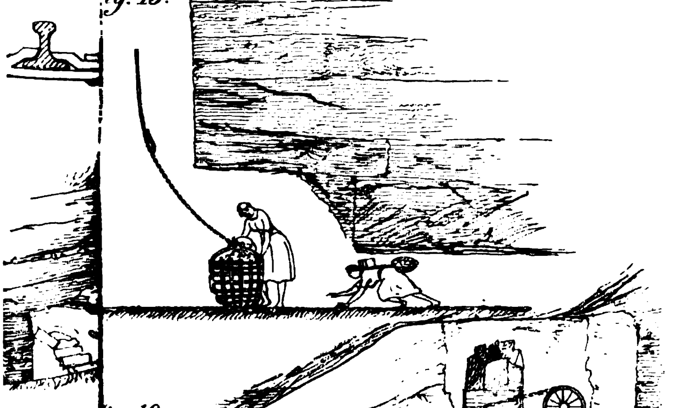


Fig. 12.



ig. 15.



ig. 19.

LAWRIE.

Fig. 1

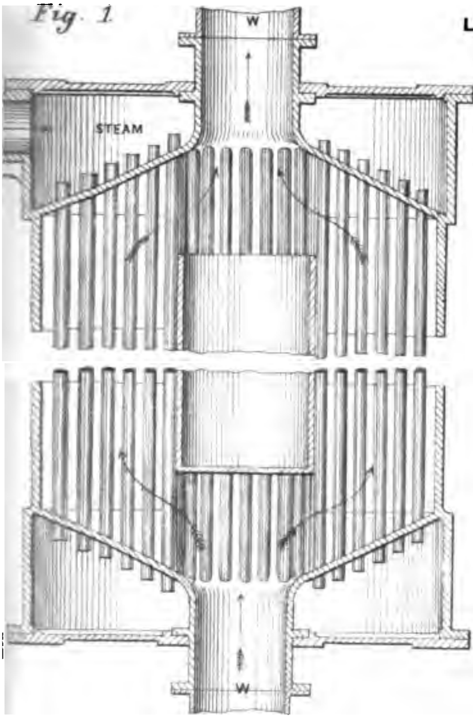



Fig. 2

Fig. 3

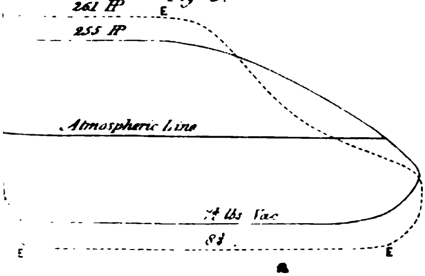



Fig. 4

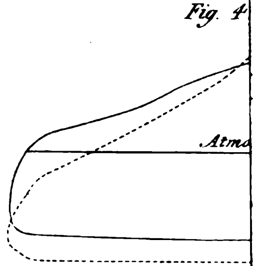



Fig. 5

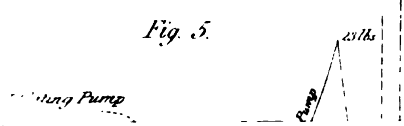
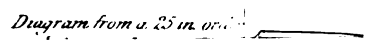


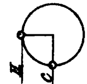

Fig. 6

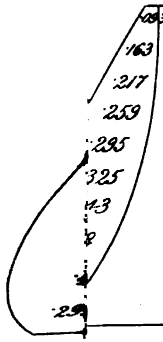


## Diagram VII

θ = 90° v = [illegible] c = ½ t = 100° t' = 400°

∴ m = [illegible] 1·652 r = – ·384 d = – ·266





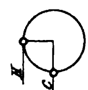
| Steam Side | Vac. Side | Effec. Pres. |
|---|---|---|
| ·821 | ·728 | ·093 |
| ·892 | ·729 | ·163 |
| ·958 | ·741 | ·217 |
| 1·020 | ·761 | ·259 |
| 1·082 | ·787 | ·295 |
| 1·143 | ·818 | ·325 |
| 1·201 | ·858 | ·343 |
| 1·255 | ·907 | ·348 |
| 1·289 | ·975 | ·314 |
| 1·293 | 1·077 | ·216 |

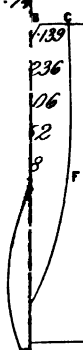
10 / 2·573
683 IP ·257

## Diagram VIII

θ = 60° v = [illegible] c = ¼ t = 100° t' = 400°

∴ m = [illegible] 1·461 r = – ·192 d = – ·266





| Steam Side | Vac. Side | Effec. Pres. |
|---|---|---|
| 1·018 | ·879 | ·139 |
| 1·098 | ·862 | ·236 |
| 1·165 | ·859 | ·306 |
| 1·220 | ·868 | ·352 |
| 1·269 | ·881 | ·388 |
| 1·310 | ·901 | ·409 |
| 1·341 | ·927 | ·414 |
| 1·361 | ·961 | ·400 |
| 1·355 | 1·013 | ·342 |
| 1·315 | 1·093 | ·222 |

10 / 3·208
854 IP ·321

θ = 120°
∴ m = [illegible]

Fig. 1.

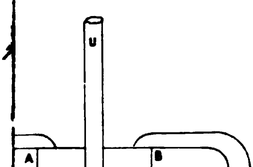



Fig. 2.

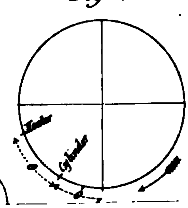


*Fig.* 6

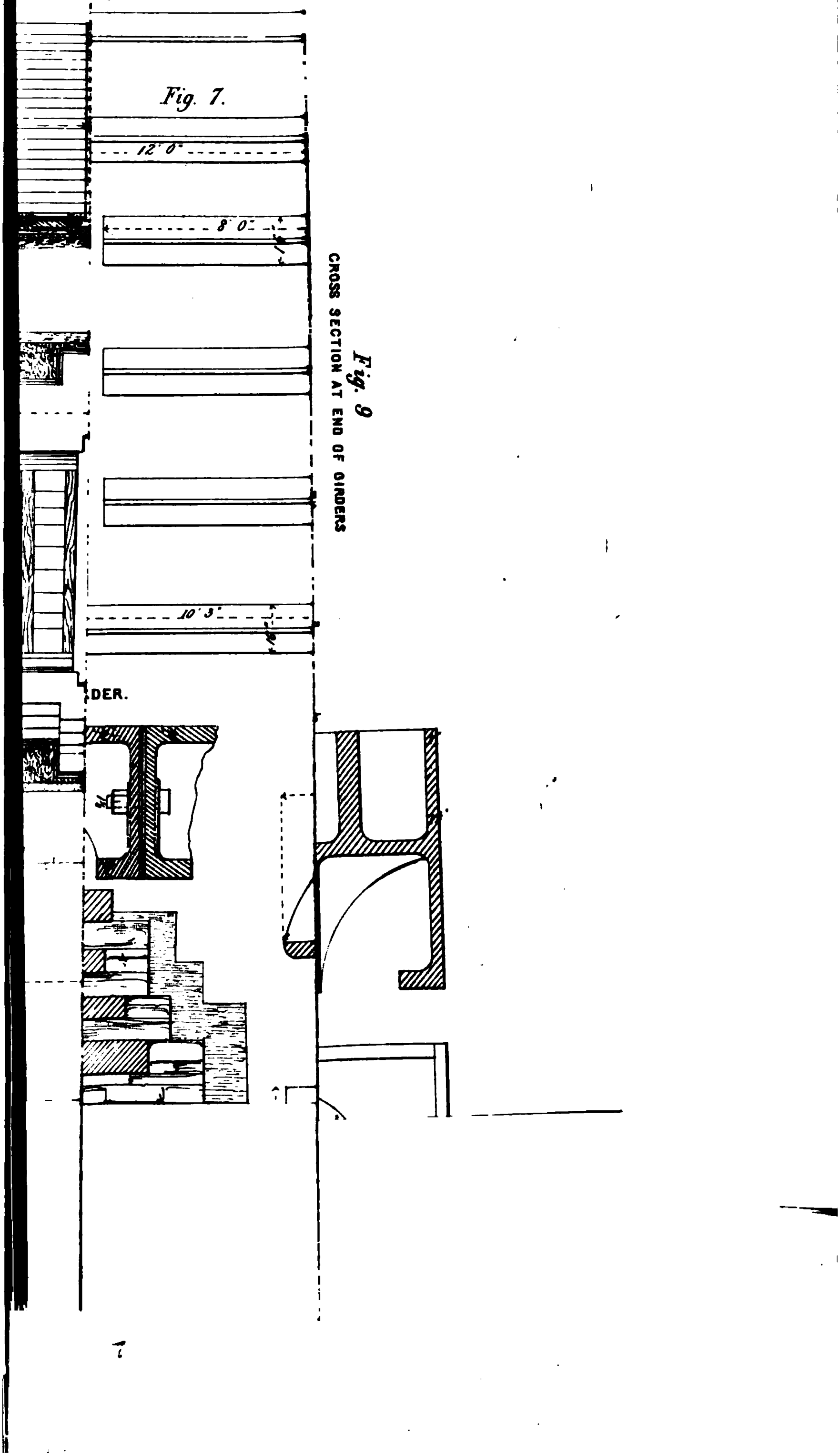



*Fig.* 9
CROSS SECTION AT END OF GIRDERS

SIMPSON'S CANAL LIFT.

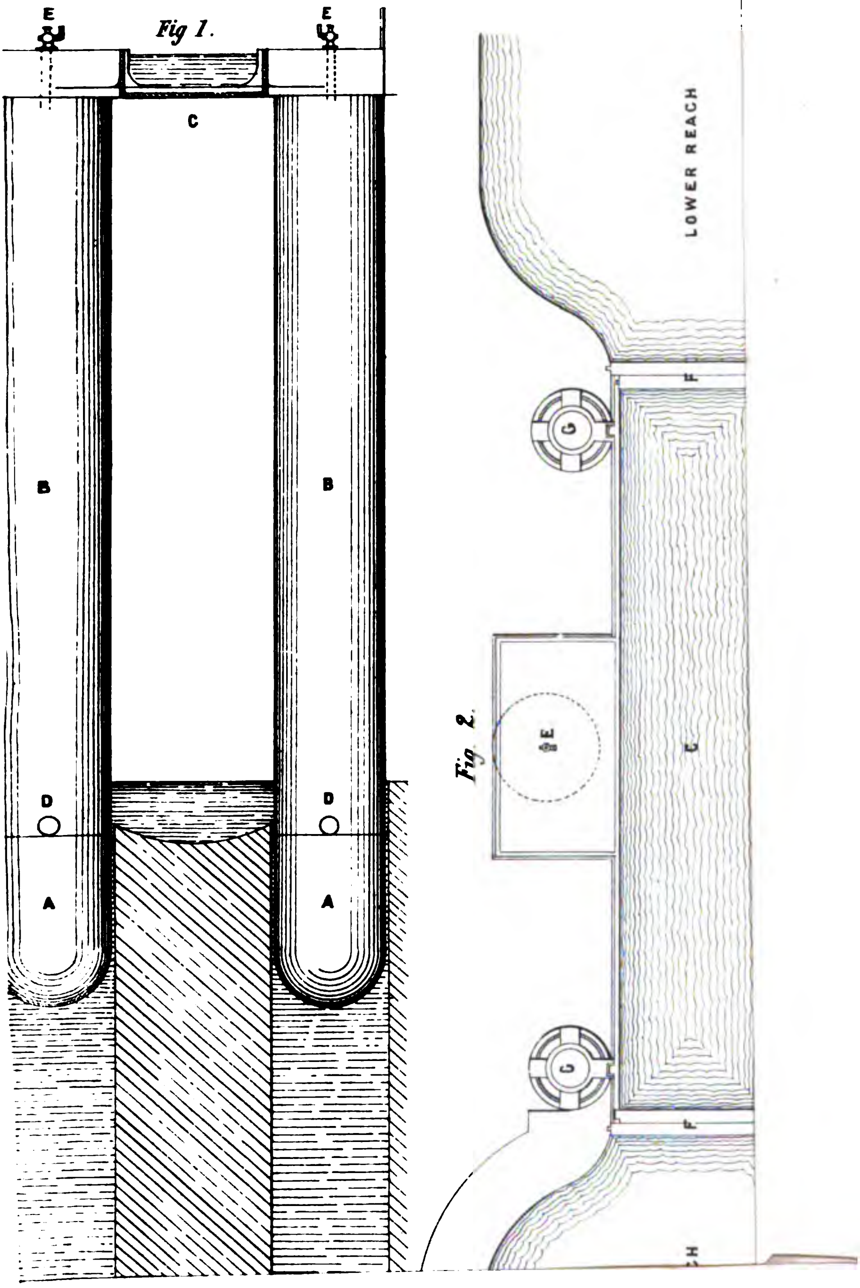



Fig 1.

Fig. 2.