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SEVENTH SESSION, 1863-64.

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INSTITUTION

OF

ENGINEERS IN SCOTLAND.

SESSION 1863-64.

Introductory Address. By Mr JAMES R. NAPIER, President.

Read 28th October, 1863.

GENTLEMEN,—It has been the custom for your President to give a history of all that was doing in the Engineering profession. But I shall confine myself to a few remarks on subjects which have interested me most in my own profession. And, *first*, as to Shipbuilding.

The numerous failures which have been made in the attempt to make vessels that would fulfil given conditions as to speed, carrying capacity, power, &c., show how little the subject has been understood. It was found that the French formula, which made the power required for the attainment of a given speed to vary as the mid-ship section by the cube of the velocity, could only be applied with any certainty to similar vessels of nearly equal size, or to vessels of nearly the same form and dimensions. The recent investigations of Dr Macquorn Rankine, which show that the friction of the water along the vessel's skin forms the greatest part of the resistance, if not the whole of it, has given, on the contrary, the most satisfactory results for all kinds and dimensions of vessels. I was so satisfied of the correctness of a theory which could determine the speed of vessels so dissimilar as the river steamer *Vulcan*, having 2,400 square feet of surface; the screw steamer *London*, having 6,000; and the screw steamer *Black Swan*, having 10,000; that, in order to increase the speed of a vessel I was about to build, I took fourteen feet from the length and added four feet to the breadth. The results of the trial showed the correctness of the principle. The adoption of Dr Rankine's theory leads at once to the construction of much stronger, safer, and more handy vessels, cheaper for the builders, and more economical for the owners, than the long, narrow parallel-sided vessels which have so often disappointed both.

The paper which Dr Rankine read at the Newcastle meeting of the British Association on "Plane Water Lines" will soon, I hope, be practically illustrated. A simple formula, whereby all the lines of a vessel could be calculated without the labour and expense of making full-sized drawings, and houses in which to make the drawings, would certainly be a great benefit to the shipbuilder. I have reason to believe that Mr Sang's formula is of this economical nature. He must either publish it, however, or sell himself to work the formula to a capitalist who has the courage to guarantee the fulfilment of all stipulated conditions.

The subject of the rolling of vessels at sea is discussed in several papers by Messrs Froude and Rankine, and others, in the *Transactions of the Institution of Naval Architects.* I have hitherto failed in making ships roll according to my views of the matter. They have rolled according to their own pleasure, and often in ways quite contrary to my wishes. Professor Smyth describes, in his voyage to Teneriffe, how he made nearly an entire revolution every minute. It requires such an instrument as he used, to measure accurately the amount of roll, as the ordinary incline meters have motions of their own which are independent of the ship's.

I wish to draw your attention to the important subject of collisions at sea. In order to prevent such collisions, especially at night, the Board of Trade has published laws and regulations, but until these regulations are complied with by all vessels, the chances of collisions will not be greatly reduced. The number of vessels sailing without lights may be judged of from the following abstracts from the log of a steamer every night at sea between Ardrossan and Belfast, which shows how many dark vessels they observed on the nights undernoted:—Oct. 19, 1863, two schooners and one brig at anchor at Carrickfergus, and one smack under weigh; Oct. 21, five vessels at anchor in Belfast Lough; Oct. 22, at three A.M., three vessels at anchor, and one under weigh; Oct. 24, one schooner under weigh; Oct. 27, one schooner and one smack sailing. It is clear that if masters or owners of sailing vessels care so little for their own lives as not to adopt the means approved of by all for their own safety, they have no right to jeopardize the lives of others by neglecting to do what the law has provided for the safety of all. A few police steamers cruising in the more frequented parts of the channel, and apprehending the dark ships, would soon make the law more respected, and collisions and loss less frequent. Again, the signal lights, which should be clearly seen at a considerable distance, are often very dim and insufficient. I have lately used paraffin oil for the red and green lights, and get a brilliant light at little cost and less labour. The light is apt to be blown out in the common lantern; but to prevent this, and, as much as possible, currents from blowing either up or down the lantern, I admit the fresh air by a pipe leading to the bottom, from the same level at which the heated air or gas escapes at the top. Now, in two vessels, whose lights I examined lately, the green was the most powerful. In the one vessel I believe it gave about six times the light, and in the other about twice the light of the red lamp, judging by reading a printed paper. Indeed, I had difficulty in discovering the red light in one of the vessels in a dark clear night, although passing it apparently at about half a mile's distance. The screens, also, are often improperly placed, and cause great uncertainty and annoyance to the passing vessel, from both the red and green lights being seen together through a great angle, instead of through a very small angle, or only in one position right ahead, as is required by law. Concentric lenses, economizing the light, and almost dispensing with the need of screens, have been used in some steamers, and are very effective.

I am glad to say that the compass deviations of iron ships, which was so long a source of trouble and uncertainty, is now better understood. The *Admiralty Manual*, edited by Mr Evans and Mr Archibald Smith, contains both the theory and the practice of the corrections or adjustments which are now made. An error in the *Great Eastern* compass, after having been carefully corrected by magnets and soft iron, according to Mr Airy's method, led Mr Evans to an interesting discovery, that two compasses placed near each other corrected the quadrantal error of each. This error had become very large in the iron-clad ships with iron decks and iron beams, and difficult to correct with iron, having no known or ungovernable magnetic properties. Mr Archibald Smith proposed to reduce the amount of these errors in ships with iron beams or decks, by placing the compass over a part of the deck from which the iron beams or deck had been removed for a certain distance, varying according to the height of the compass from the deck. Mr Smith has the art of putting intricate algebraic formulæ into geometric and graphic forms. The last edition of the *Manual* contains some useful additions to these. One of the most simple is his straight line method, published by the Board of Trade, but little known in this part of the kingdom.

It is still matter of regret that the power required to steer ships of given dimensions and speeds has not yet, so far as I know, been determined with any accuracy. A few years ago, I found the pressure on the rudder of the screw steamer *Messina*, by means of a spiral spring applied to the end of the tiller. The results were used for determining, by means of a rough rude formula, the dimensions of rudder head and steering chains; and a short paper on the subject was communicated two years ago to the Institution of Naval Architects, as a note to a long paper on the same subject by Admiral Halstead; but neither have yet been published. The more quickly ships can be turned when at their greatest velocity, the less will be the chances of accident from collisions. If it were possible for them to turn like hares, collisions would be almost impossible. Large rudders would certainly turn them faster; but it has hitherto been considered that men alone should steer a ship, and therefore the rudders and all their gear have been made suitable to the strength of the number fixed upon beforehand for the purpose. Mr Sickles, an ingenious American, contrived a very simple apparatus, whereby a boy might do all the steering which the biggest conceivable rudder on the biggest ship might require. He had only to move the valves, and the steam engine to which they were attached performed the work. A roughly made apparatus of this sort was exhibited in 1862. In order that the river steamer *Vulcan*, already referred to, might be turned quickly, and so perhaps be sooner at her destination than faster competitors, the keel was inclined forward and aft to near the stern, where it again descended to protect the rudder. Swift passenger boats on canals are generally so constructed.

The prevention of barnacles on iron ships' bottoms is a subject with which I am little acquainted. Coal pitch, or black varnish, is now so frequently used that I presume it is considered as good as the best. I expect, however, we still want, and may long look for a lubricator which will be as efficient and economical as that with which nature has supplied the bodies of fishes. Galvanizing the iron appears to be a simple and effective method of at once preventing corrosion and barnacles. If zinc prevented barnacles on wooden ships, it would be as effective on iron. If the zinc did not protect the ungalvanized rivet heads, it would do them no harm; they could be painted as usual.

The more economical use of fuel at sea for long voyages is a subject which is receiving in some quarters that attention which it deserves, and most worthily has it engaged the attention of this Institution. Theoretically, nearly equal economy is obtained by using steam of high pressure, or lower-pressure steam of equal temperature. The former, however, requires the boilers to be supplied with fresh water, while ordinary sea water, and less complexity, gives satisfactory results for the latter. To heat the steam to that point which will, during expansion, liquefy so much as just to lubricate the pistons, appears to be the limit to superheating which the best practice has attained to; while the limit to the economy which may be obtained by the use of high-pressure steam is much further off. It has not appeared, so far as I know, from any experiment, whether it is better to use the waste heat for heating the steam or for heating the feed water. It is clear, however, that, to have the greatest economy, the feed water ought to commence its course at the top of the chimney, keep constantly going in the opposite direction to the fuel, and finally leave the boiler in the form of steam gas through the furnace. The more nearly the notions involved in this statement can be worked out in practice, the greater will be the economy both in fuel and in construction. The French have long recognized this principle, and also another of at least equal importance—that, in order to keep a chamber full of the hottest gases, it is necessary that there be no opening above to let them escape. The vessel will be kept full of the hottest gases, an infinite quantity of heating surface may be made available, and the coldest gases will overflow from openings ever so large in the bottom, whereas a small opening above would render all but a very small portion of the heating surface ineffective, as is the case in the ordinary marine boiler, with its chimney leading from the highest instead of from the lowest point of the hot chamber. The great economy obtained by the screw steamer *Thetis* a few years ago has not, so far as I know, been again equalled. Three and a half cwt. per hour of Welsh coal propelled this vessel—190 feet long and 26 feet broad, drawing about 10¾ feet of water—at the rate of 8·8 nautical miles per hour, in moderate weather, without sails, throughout the voyage from the Clyde to Liverpool. To get the amount of fuel per indicated horse power on a voyage is a very difficult matter. The ordinary method of taking the mean of the revolutions, to find the mean velocity of piston, and so the power, is erroneous, for the mean power varies as the mean of the cubes of the velocity. In order to ascertain the speed at which given vessels were propelled at the instant at which the power was determined, I made an instrument, which is described in the *Transactions of the Philosophical Society of Glasgow*, and applied it to several vessels. I do not know of anything better fitted for the purpose, and something of the sort is needed by those who would wish to know the performances of their ships at sea. The pressure indicator, applied to fast-running engines, has been a source of continual trouble and uncertainty, from the vibrations of the springs, and from sometimes being improperly placed. The new indicator of Richards happily removes the former objections, and the experiments of Mr John Elder show how the latter is to be avoided. Some experiments made by the Industrial Society of Mulhouse showed that the power indicated by the card was the actual work performed by the engine,—that the friction of the indicator was in proportion to the friction of the engine.

The prevention of smoke has been the subject of many essays and experiments in this and other countries. The results of the most careful trials made at Mulhouse, in France, show that in ordinary boilers the greatest economy was obtained when making the densest smoke—when the quantities of air entering the furnace were little more than theory indicated as being necessary for the perfect combustion of all the coal. In boilers, however, where the feed water was heated by the hot gases passing to the chimney, by an apparatus having a surface of nearly double the original surface of the boiler, smoke was entirely prevented, and a saving of from 12 to 14 per cent. of fuel effected, the quantity of air then admitted being more than double the theoretical amount needed for perfect combustion. The maximum efficiency was obtained with the greatest supply of air. These experiments show the direction to be taken by those who wish to economize the coal in their furnaces--viz., by reduced draught, very careful firemen, and dense smoke in ordinary land boilers; by quicker draught, more ordinary firemen, less smoke, more economy is obtained in boilers having properly constructed feed heating apparatus, the economy increasing with the amount of heating surface, probably according to the laws first enunciated at this Institute. From these and other experiments in our own country, I venture an inference in which I am not alone—viz., that the most economical way of preventing smoke with bituminous coal is by making imperfect combustion of a considerable portion of the coke, and burning the gases so produced with air above the fuel. The easily ignited gas—carbonic oxide—produced from the hot coke, when little air is supplied, is probably hot enough to ignite when it comes in contact with the air passing over the surface of the fuel; and, if produced in sufficient quantity, its ignition will ignite the coal gases, when perfect combustion will be the result, with the least air, and therefore the greatest economy. The draught can be reduced, and an abundant supply of carbonic oxide produced, by having thicker fires of hot coke, and the volume of coal gases can be made to bear any proportion to the coke gases by suitable charges of fresh coal over the coke. Mr Gorman has somewhere given a nearly similar explanation of the effects produced by the ordinary method of preventing smoke, but he believes the principle to be erroneous, and, instead of encouraging the production of carbonic oxide gas, his object is to prevent at certain times the formation of carbonic acid, which, he says, is produced in such quantities as to prevent the igniting of the coal gases. This he accomplishes by periodically shutting the ash pit. But it is not apparent that carbonic acid has the effect he ascribes to it. Chemists do not agree with him. His plans, however, are said to be economical, and, whether from the absence of carbonic acid or the presence of carbonic oxide, may be proved by others. If the supply of air over the coal is through a constant opening, as in Mr Williams' plan, the supply of gas and smoke should also be made as constant as possible. Mr Williams accomplished this by the alternate firing of the sides of the furnaces. Such a course necessarily increases the ratio of the volume of the carbonic oxide to the coal gases, when the igniting the one at a red heat ignites the other, which requires a white heat. If the furnaces are fired in the usual manner, the air admitted over the fuel may be varied to suit the supply of the gases, but when the thickness of hot coke is considerable, there will be little need of any variation. It is clear that smoke can be prevented, but whether with a gain or loss depends on many circumstances, and that which may have caused the gain very difficult to determine. Gains reported to be made with patent plans are more often the result of the firemen's skill than of the efficiency of the patent. Mr Graham, of Manchester, who appears to have studied the economy of his boilers with the greatest care, found the same difference of firemen as was found at Mulhouse, where firemen were competing for a prize—viz., 13 per cent. between the best and worst.

It appears from the newspaper reports that the steamer *Great Eastern* is likely at last to be sent on the voyage for which she was constructed, and for which she is in all probability admirably adapted. It is not likely that any short sea passage or overland route will ever compete with the direct track by sea with such vessels as the big ship properly managed, for I expect the longer distance will be traversed in shorter time and with fewer discomforts.

In conclusion,—as to the construction of armour vessels, I believe the plan I proposed to my father some years ago, but which his prudence prevented him from submitting to the proper quarter, will yet be adopted. The Admiralty are driving slowly towards it. It is to construct the upper or vulnerable part solely of iron as thick as may be wanted, in plates of the largest dimensions that may be desired, and fastened together as in ordinary shipbuilding. The ships will then be strengthened instead of weakened by their armour, and, therefore, so much lighter that a vast deal more of it can be applied.

On the Expansive Energy of Heated Water.

By Dr W. J. Macquorn Rankine.

Read 28th October, 1863.

As the question of the quantity of mechanical energy which a given weight of water, heated to a given temperature, is capable of exerting in the act of partially evaporating without receiving heat, until it falls to a given lower temperature, has been raised in connection with recent researches as to the bursting of steam boilers, I may point out that the complete solution of that question for any given liquid, together with a numerical example in the case of water, is given under the head of Proposition XVII. of a paper "On Thermodynamics," which was communicated by me to the Royal Society in December, 1853, read in January, 1854, and published in the *Philosophical Transactions* for 1854.

That solution is expressed by the following formula (page 161, Equation 65):

Energy exerted by each pound of fluid—

$$= K \left\{ t_1 - t_2 \left(1 + \text{hyp. log. } \frac{t_1}{t}\right) \right\}; \qquad (1.)$$

in which K denotes the dynamical value of the specific heat of the liquid, being the product of its specific heat expressed in the ordinary way by "Joule's Equivalent;"

t_1 and t_2, the initial and final absolute temperatures; the absolute zero being 274° Cent., or 493°·2 Fahr. below the melting point of ice.*

Another equation (Equation 63 of the paper) gives the following value for the excess of the final volume to which the mixed liquid and vapour expand above the original volume of the liquid:—

$$\frac{K \text{ hyp. log. } \frac{t_1}{t_2}}{\frac{dp_2}{dt_2}}; \qquad (2.)$$

* In the original paper the absolute zero of heat was assumed to be 272½° Cent. below the melting point of ice. The value now adopted, 274° Cent., is deduced from later experimental data.

in which $\frac{dp_2}{dt_2}$ denotes the rate at which the pressure, in lbs. on the square foot, varies with temperature, at the final temperature.

When applied to the water in a steam boiler these equations take the following form :—

The value of K for liquid water is

772 foot pounds per degree of Fahrenheit in a pound of water, or
1389·6 foot pounds per centigrade degree in a pound of water, or
423·55 kilogrammetres per centigrade degree in a kilogramme of water.

The final absolute temperature is 212° Fahr. + 461°·2 = 673°·2 Fahr.

The corresponding value of $\frac{dp}{dt}$, for Fahrenheit's scale and British measures, is 42; and 772 ÷ 42 = 18·38.

Let T denote the initial temperature, on Fahrenheit's ordinary scale; so that t_2 = T + 462°·2.

Then

Energy, in foot pounds, exerted by each pound of water,

$$= 772 \left\{ T - 212° - 673°{\cdot}2 \text{ hyp. log.} \left[\frac{T + 461°{\cdot}2}{673°{\cdot}2} \right] \right\} ;* \ldots (3.)$$

Final volume of expansion of mixed water and steam in cubic feet per pound,

$$= 18{\cdot}38 \text{ hyp. log.} \left[\frac{T + 461°{\cdot}2}{673°{\cdot}2} \right] \ldots\ldots\ldots\ldots\ldots (4.)$$

It is worthy of remark, that *the energy developed depends solely on the specific heat of the substance in the liquid state, and the initial and final temperatures,* and not on any other physical property of the substance.

The following table gives some results of the formula :—

The first column contains the temperature on the ordinary scale of Fahrenheit, with intervals of 36° F. = 20° Cent.

The second column contains the expansive energy of one pound of water in foot pounds.

The third column contains the velocity, in feet per second, which that energy would impress on a projectile of the weight of the water itself; that is, one pound.

The fourth column, the final volume of expansion of the water and steam, in cubic feet per lb.

* This agrees with the formula given by "J. B." in the *Engineer* of the 2nd October, 1863, p. 200.

For convenience, a fifth column is added, containing the initial absolute or total pressures in lbs. on the square inch.

The last line of the table has reference to the case in which the water would be totally evaporated.

TABLE I.

Initial Temp. Fahr.	Energy. Foot lbs.	Velocity. Feet per sec.	Final Expansion. Cub. feet.	Initial Absolute Pressure. Lbs. on the sq. in.
212°	0	0	0	14·70
248	726	214	0·95	28·83
284	2779	423	1·87	52·52
320	6052	624	2·73	89·86
356	10422	819	3·56	145·8
392	15826	1010	4·36	225·9
428	22156	1194	5·11	336·3
...	...	...	...	...
about 2360	about 912500	about 7666	26·36	unknown

In the absence of logarithmic tables, the following approximate formulæ may be used for temperatures not exceeding 428°:—

$$\text{Energy, nearly} = \frac{772\,(T - 212°)^2}{T + 1134°\cdot 4};\ldots\ldots\ldots\ldots(5.)$$

$$\text{Expansion, nearly} = \frac{36\cdot 76\,(T - 212°)}{T + 1134°\cdot 4}\ldots\ldots\ldots\ldots(6.)$$

NOTE.—Added 19th October, 1863.

In explanation of the formulæ and tables it may be added, that the mechanical energy in column 2 is the equivalent of the heat which disappears during the process, being the difference between the whole heat expended and the latent heat of that portion of the water which, at the end of the process, is in the condition of steam at atmospheric pressure.

For the information of those who consider that the liquid portion of the water, owing to its small compressibility, acts like a volley of hard projectiles, a table is added, showing, for each of the initial temperatures in the previous table, what fraction of a pound of water continues in the liquid state, and how much of the energy developed is possessed by that liquid water.

TABLE II.

Initial Temp. Fahr.	Proportion of the water which remains liquid. Lbs.	Energy possessed by that liquid water. Foot lbs.
212°	1·000	0
248	0 964	700
284	0·931	2587
320	0 897	5429
356	0·865	9015
392	0·835	13215
428	0·806	17858
...	...	...
about 2360	0	0

In the formulæ and tables it has not been considered necessary to take into account the small increase which the specific heat of water undergoes as the temperature rises.

After reading the paper :—

Professor RANKINE said he would state to the Institution the occasion of his writing it. Mr Airy, the Astronomer Royal, Professor Miller, of Cambridge, and some other gentlemen, had been for some time engaged in researches on this point; and Professor Airy read, at the late Meeting of the British Association at Newcastle, a paper, containing the results of calculations by Professor Miller and by himself, and of some experiments that he had caused to be made. That paper had not yet been published at full length, so that he (Professor Rankine) did not know the precise results at which the authors had arrived. As he had published in 1853 an Equation deduced from the simple application of the principles of Thermodynamics, which gave the theoretical solution of this question, and with very little calculation, he thought it desirable that he should refer back, as he had done in the present paper, to that formula, which was as it were buried in a volume of the Royal Society's *Transactions*, and that he should re publish it, and draw up tables of its results; and he believed that they would be found practically to agree with those of the Astronomer Royal and Professor Miller. He wished it to be understood that in the paper he was not putting forth a theory of boiler explosions. It might be considered as a matter of fact, that a pound of water imprisoned in a vessel and raised to a high temperature, and suddenly allowed to escape, would exert the mechanical energy set down in those tables; for although they were founded on theory, yet, as there was no doubt of the accuracy of the theory, the results might be regarded as matter of fact. Those interested in boiler explosions, and who were following out a train of reasoning, might use those facts, and draw what conclusions those facts, combined with their own experience and observation, dictated.

The PRESIDENT said they were indebted to Dr Rankine for bringing that paper before them ; and he thought it would be better for them to postpone the discussion upon it until next meeting, before which the paper would be printed and in the hands of the members.

A DISCUSSION took place on this paper on 25th November, 1863, when Mr J. BROWNLEE spoke as follows :—

Since our last meeting the communication (then referred to by Dr Rankine) of the Astronomer Royal to the British Association "On the Expansive Energy of Heated Water," has been published in full. The results as stated are, that the expansive energy of a cubic foot of water heated to 307°·1 Fahr. is 41,300 kilogrammetres = 298,729 ft. lbs.; and as the cubic foot of water is estimated to weigh 59·75 lbs., this corresponds to 298,729 ÷ 59·7 = 5,000 ft. lbs. per lb. of water. As computed by Dr Rankine's formula, that energy is

$$772 \left[97 - \left(1{\cdot}02 \times 673{\cdot}2 \text{ hyp. log. } \frac{307{\cdot}1 + 461{\cdot}2}{673{\cdot}2}\right)\right]$$
$$= 772\ (97 - 90{\cdot}74) = 4{,}833 \text{ ft. lbs.*}$$

The difference of those computations (5,000 − 4,833 = 167 ft. lbs.) arises from the Astronomer Royal having assumed that the 95·1 × 1·02 = 97 units of heat supplied to the water, while raising the temperature from 212° to 307°·1, would finally be found undiminished in quantity in the vapour, converting $\frac{97}{965{\cdot}7}$ parts of the water into steam, the volume of which steam is thereby, at the terminal atmospheric pressure, estimated to measure $\frac{97}{965{\cdot}7} \times 26{\cdot}3 = 2{\cdot}64$ cubic feet. Whereas by Dr Rankine's formula 6·26 of those 97 units of heat supplied to the water are supposed to be lost by the steam while expanding and repelling the resisting force, the residue, 97 − 6·26 = 90·74 units, only remaining, and constituting the latent heat of the final volume of vapour. Then, again, taking 965·7 as the latent heat of atmospheric steam, and 26·3 cubic feet as the volume of 1 lb. of that steam, $\frac{90{\cdot}74}{965{\cdot}7} \times 26{\cdot}3 = 2{\cdot}47$ cubic feet would be the volume generated from each pound of water while expanding under pressure, and

* In this computation I have made allowance for the slightly greater capacity for heat of the water between 212° and 307°·1. The mean specific heat between those temperatures being 1·02—that of cold water being taken as unity.—J. B.

falling in temperature from 307°·1 to 212°. The final volume, as assumed by the Astronomer Royal, being about one-sixth of a cubic foot per pound of water more than this; and his conclusions having been arrived at by so estimating the volume of the steam at various pressures while expanding, those conclusions are consequently, I believe, slightly beyond the truth.

The heat lost by the steam when expanding and performing work, it may be observed, seems to have been altogether neglected by the Astronomer Royal. The method which he has adopted in making his calculations is therefore not only less accurate, but also involves great labour, compared to that discovered, I presume simultaneously, by Professors Rankine and Clausius. Although I have never seen the paper containing Equations (1) and (2), referred to by Dr Rankine as having been communicated in 1853 to the Royal Society, I have several years since seen other expressions in the writings of both Rankine and Clausius in which those equations are combined. To complete the expression as given in the writings referred to for the work of 1 lb. of steam when generated at a temperature of 307°·1, then expanded to 212°, and finally expelled into the atmosphere at the latter temperature, it is only necessary to add to 4,833, already found as the energy of the heated water, the following quantity:—

$$772 \times \frac{95{\cdot}1}{307{\cdot}1 + 461{\cdot}2} \times 897 = 772 \times \frac{95{\cdot}1}{768{\cdot}3} \times 897 = 85{,}692 \text{ ft. lbs.};$$

and the maximum duty of that steam is

$$4{,}833 + 85{,}692 = 90{,}525 \text{ ft. lbs.},$$

which pound of steam would require for its production from water at 212°, 900·5 + ·305 × 307·1 = 994 units of heat.

Firstly, To raise the temperature from 212° to 307°, that is through 95°·1, requires 97 units of heat; and, *Secondly,* To evaporate at the latter temperature requires an additional 897 units. Now, in the above equation it will be observed that the number 95·1 is the difference between the inferior and superior temperature, 768·3 is the absolute temperature, corresponding to 307°·1 Fahr., and 897 is the latent heat of steam at that temperature, as determined by Regnault. It is here of special importance to remark that the work obtained from the first 97 units of heat expended in elevating the temperature is much less per unit of heat than from that expended in evaporating the liquid.

If we divide the 897 units of latent heat into 768·3 parts, we have 95·1 of those parts converted into useful work; whereas not more than 6·26 of the 97 parts of heat expended in raising the temperature can possibly be rendered effective; or while it is possible under the conditions specified to utilize nearly $\frac{100 \times 95 \cdot 1}{768 \cdot 3} = 12\frac{1}{3}$ per cent. of the latent heat, it is not possible to utilize more than $\frac{100 \times 6 \cdot 26}{97} = 6\frac{4}{10}$ per cent. of the heat expended in elevating the temperature.

I have been led to make those remarks from having observed that Sir W. G. Armstrong, in his inaugural address to the British Association, while alluding to the engines of Stirling, Ericsson, and Siemens, said that "Those engines were all based upon the principle of employing fuel to generate *sensible* heat, to the exclusion of *latent* heat, which was only another name for heat which had taken the form of unprofitable motion among the particles of the fluid to which it was applied." The engines alluded to are supplied with a respirator, which is intended to absorb and restore the sensible heat, and are therefore, as one would more reasonably suppose, based upon the principle of employing the fuel chiefly in generating latent heat—that is, in preventing the temperature of the fluid from falling while expanding. If the words *sensible* and *latent* were therefore transposed in the extract I have taken from Sir W. G. Armstrong's address, his remarks would read much nearer the truth. The great latent heat of the vapour of water is generally thought to be unfavourable to the use of that fluid as an agent for motive purposes. It has, however, been shown that a non-condensing steam engine, working with steam at a pressure of about five atmospheres, may possibly utilize nearly $12\frac{1}{3}$ per cent. of the latent heat of the steam; and there is no heat engine of any description whatever that can possibly utilize more than $12\frac{1}{3}$ per cent. of the heat expended, if confined between the same limits of temperature, 307°·1 and 212° Fahr.

Dr MACQUORN RANKINE said he was gratified to find that Mr Brownlee had paid attention to the subject of his paper. He had not had time himself to make a comparison between the results arrived at by the Astronomer Royal and Professor Miller and his own. However, Mr Brownlee had investigated the matter thoroughly, and had drawn a comparison quite correctly, he had no doubt. The difference which Mr Brownlee had found between his results and those of the Astronomer Royal and Mr Miller arose from the fact, neglected by them, that in the performance of work there was a disappearance of heat; but it so happened that, in the case to which those calculations related, there was but a small proportion of work performed, so that the disappearance of heat was but small; and hence their error in neglecting to calculate such loss made no great difference in the final results in the special cases to which their calculations referred. The difference became very great in computing the temperature at which the water would entirely evaporate.

If the disappearance of heat in performing mechanical work was neglected, that temperature was found to be about 966° above the ordinary boiling point; but when that disappearance of heat was taken into account, that temperature proved to be about 2150° above 212°. It was due to Mr Brownlee to say, that although at a later date than that at which his own (Dr Rankine's) paper was published—namely, 1853—he had independently investigated the matter, and got results which corroborated his own. At the previous meeting he set down the explosive power of 1 lb. of gunpowder at 300,000 ft. lbs., and he believed that that was right with respect to the mechanical energy. There was a great deal more in the form of heat, but that was all which appeared in the mechanical form; and there was considerable frictional resistance and loss in all kinds of firearms. The greatest result was obtained when the projectile was comparatively a light one. In small arms something like 240,000 ft. lbs., or $\frac{8}{10}$ths of the entire amount, were realized; but in large cannon a smaller proportion was realized, such as from 160,000 to 180,000 ft. lbs. of work from 1 lb. of gunpowder. That would nearly agree with the Astronomer Royal's conclusions in his paper on "The Numerical Expression of the Destructive Energy in Explosions of Steam Boilers, and on its Comparison with the Destructive Energy of Gunpowder." In the tables in his own paper he had calculated the velocity with which the particles of water and steam flew asunder when set free. That was calculated upon the supposition that the whole energy was used exclusively in propelling the particles of water and steam; but if anything else were swept along with them the velocity would be less. There would always be foreign matters to carry along. Thus, if water heated to a high temperature exploded, it had always to displace a mass of the air, or of steam at atmospheric pressure, and this would somewhat reduce the velocity.

On the motion of the PRESIDENT, a vote of thanks was passed to Dr Macquorn Rankine for his paper, and to Mr Brownlee for his remarks.

On Turned and Bored Joints for Gas and Water Main Pipes.

By Mr John Downie.

(SEE PLATE I.)

Read 28th October, 1863.

Of late years the introduction of turned and bored junctions for piping (in lieu of the usual expensive "lead joint" with rope yarn) has formed an important item in the first cost of our city mains for the distribution of gas and water; and the increasing demand for this class of pipe has necessitated the introduction of specially adapted machinery for their rapid production. The great and almost puzzling diversity of opinion among engineers generally as to the best form and proportion of turned and bored joints is pretty well exemplified in the dozen diagrams, Plate I., now exhibited to the meeting, selected out of many that have been executed for different parts of the world; and the object of this paper is to point out some of the *practical* difficulties in the making of a perfect joint by this plan, and to submit what the writer considers a more simple and efficient design of turned and bored joint, and one that would probably meet some of the requirements of laying in ground slightly irregular or undulating, without the necessity of making intermediate lead joints, or introducing "special" pipes, to get over the difficulty of rigidity that is sometimes complained of in the usual turned and bored joint. Until recently, the largest sized mains with turned and bored joints were those executed for the Sydney Water Works, viz., 30 in. diameter. But now this plan is being adopted for 3 and 3½-feet pipes for water mains working under a good head of pressure; and, seeing this is the case, it is really a most important matter to have the best, the safest, and the cheapest arrangement that can be devised for such purpose introduced into the manufacture of this article: and hence the high value that may be set on the practical opinions elicited by bringing the subject before an institution such as ours, among whose members we have the engineers of our gas and water works, where the system of turned and bored joints has been so largely and successfully carried out, as also the manufacturers of the article in question, and others equally competent to give reliable opinions on this important subject.

One objection frequently made to the turned joints by the opponents of the system is the want of flexibility. It is admitted that where you get a stretch of perfectly straight piping they do capitally; but for slightly curved or undulating ground, or where subsidence is likely to take place *after* laying, they are not so applicable; and where the depth of the turned and bored part is considerable, such as shown in the sections of the Launceston, Dundee, Buenos Ayres, Liverpool, Sydney, and Hobart-town mains, this objection may possibly obtain. The others, being shorter in the bearing part—viz., the Glasgow, Trieste, Hamilton C.W., and Fylde mains—meet this difficulty in part; and it has recently been proposed to meet it still more by the introduction of curved instead of straight turned and bored surfaces, as shown in the diagram, fig. 12, of 36-in. water main for Liverpool. A very slight examination of this last will show that there will be very great difficulty indeed experienced to get the two curved surfaces *exactly* coincident; and the instant they leave the line of centres to which they have been bored and turned, the joint must of necessity leak more or less. It is due to the engineer to state, that when these *practical* difficulties were pointed out to him, he at once altered his design to that shown in fig. 13, to which the work is now being executed quite satisfactorily.

The turned and bored alternative joint, fig. 10, which the writer has the pleasure of submitting to the consideration of the meeting, differs from the others only in this, that the socket has rather less taper than the other specimens shown, the same usual depth being retained; but the *breadth* of the turned portion of the *spigot* end, it is suggested, should be only equal to, say, the thickness of the pipe at that part, and be slightly rounded at the point—in short, with the usual half-round bead made flat at the bearing part, and rounded off by the cutter tools, to permit of easy entrance, and if necessary slight inclination, to adapt it to subsidence of ground or to curves or undulations. It is also submitted that with the narrow bearing a much better, tighter, and more certain joint will be obtained, and less chance of misfits in the manufacture, as compared with deep bearings, which seldom fit throughout their entire length in practice, although theoretically they are supposed to do so: and the writer will be glad to have the opinions of the members of the institution as to whether the conditions enumerated are likely to be fulfilled, should the new design with narrow or short bearing surfaces, such as described, be adopted for this class of work.

In the foregoing remarks nothing has been advanced as to the relative saving to corporations and public companies by the adoption of the turned and bored plan of jointing, it being now generally admitted that such saving ranges from 30 per cent. to 50 per cent. according to size of mains, when compared with the usual lead and yarn joint. The larger and heavier the piping, the less proportionally does the *tool* work bear per ton on their produce. Then, again, we have the advantage of rapidity of laying—a very great desideratum indeed in London, or such a city as ours, where the street traffic is enormous and daily increasing, since much, if not all of the laying of turned and bored jointed pipes may be done at night, and the trenches filled in and the roadway all causewayed over and ready for the traffic next morning, without causing the tedious and annoying obstruction occasioned to the public by the usual lead-jointing process. Several specimens of joints are exhibited for the members' inspection; among others, a French application of rubber joint in lieu of lead, called the "Systême de Lavril," now being applied to water mains for Tunis in Algeria. These have a degree of flexibility very suitable for undulating or irregular ground; but for first cost and endurance they do not compare favourably with the usual metallic bearing, and are not likely to obtain a favourable footing in this country, where cheapness and efficiency are of the first importance.

In the discussion which followed;—

Mr J. M. Gale said he thought there could be but one opinion as to the superiority of turned and bored joints over the old system, when properly done. If they had a bad joint, in the common way of jointing, there was a great escape of water, and considerable damage might be done; but with a bad joint on the turned and bored system the escape was not extensive, and the latter plan was certainly the safest. They had never been applied in Glasgow to larger sizes than twelve inches until a year ago, when he had tried them with 15-in. pipes, and they had done remarkably well, there being no leakage whatever on a length of three-quarters of a mile. The longer the turned bearings were made, the more difficult was it to make a tight joint. In the Sydney Works, which were executed ten years ago, the pipes were jointed very much like those of the Gorbals Gravitation Company, done sixteen years since. All the other joints shown in the diagrams were of the alternative class, except that for Buenos Ayres. The advantage of the "alternative" was, that, if a bad joint were made, lead could be run into the joint into the space left for the purpose. Mr Bateman used this plan in the Manchester Water Works twelve years ago. He thought that perhaps Mr Downie had brought down the bearing surface of the spigot end rather too fine in the specimen before them. He would like to know whether those large turned and bored pipes were being laid in Liverpool, and, if so, how the pipes were rammed home.

Mr Downie answered that he had not as yet heard the results with those being laid at Liverpool; and, in reply to other questions, said that the depth of the bearing surface of the joint, in his proposed plan, was reduced to about five-eighths of an inch. Where the depth of surface was great, they often found great difficulty in getting a true bearing over the entire surface; but with his plan they got a very good bearing. On laying the Liverpool 36-in. pipes they applied a luting of soft twine and a somewhat viscid composition of tar and naphtha, which insured perfect tightness. Some engineers were in the habit of running up the lead space in turned and bored joints with Roman cement, others with a preparation of asphalt, and one eminent engineer uses lead in all turned joints, considering such to be the *ne plus ultra* of jointing; but all this is really unnecessary where the work is properly done.

Mr J. M. GALE said, in reply to inquiries as to the means of forcing home the pipes, that in Glasgow they had been in the habit of driving home pipes below 8 inches with a mallet, and pipes from 8 to 15 inches were driven home by swinging one against the other in the trench; but with the 15-inch pipes they were apt to chip the faucet, and if the same plan were adopted with a 36-inch pipe he thought serious injury would follow.

Mr DOWNIE said that perhaps, if a stout piece of wood, which seamen called a "Scotchman," as it could bear a good deal of chafing and fatigue, were introduced between the ends of the pipes, it might answer the purpose and prevent any damage.

Mr GALE said they had tried putting wood between the pipe lengths, but it was unsuccessful, as the softness of the wood diminished the sharpness of the blow.

Mr R. BRUCE BELL thought that hydraulic pressure might be applied.

Mr GALE thought large pipes would require to have some such power applied.

Dr MACQUORN RANKINE wished to know whether success had attended the use of thimble joints, where the two pipes were connected by a collar outside.

Mr DOWNIE exhibited a French patent of the sort of joint Dr Rankine referred to; and another thimble joint of cast-iron in three pieces, with a rubber band. In the French joint there was a gland introduced for screwing down the rubber, thereby making a flexible joint. The thimble joint was much used in Paris, with lead instead of the rubber.

Mr WILLIAM JOHNSTONE had used the thimble joint very extensively on a five-mile water pipe course, where, he was sorry to say, the contractor who supplied the pipes had not made a good job. The faucets were very defective, and they had to introduce thimbles very often; but he found that the thimbles formed the strongest parts of the pipe, and in no instance gave way. The pipes were of cast-iron, six inches in diameter, and the faucets ten inches long. They had spigot and faucet bored and turned joints, but were not formed so as to admit "alternative" lead joints on any proving faulty.

Mr Downie said there was one peculiarity with his plan, that there would be fewer misfits, and, with the small bearing, they would get a certain amount of flexibility, and yet be perfectly tight under pressure. One of the joints exhibited was driven home at an angle of one inch in three feet, or to a curve of about 200 feet radius, and was tight under a 300 feet head of water.

The President remarked that the sharp meeting edge was what Perkins had been led to adopt in his engines, to obtain tight joints under great pressure.

In answer to Mr W. Smith, Mr Downie said that he bored out the entire socket, with the exception of a very small portion.

Mr W. Smith asked if he had ever tried large pipes with snugs or flanges, so that they could be drawn together with bolts.

Mr Downie answered that he had done so.

Mr W. Smith said that by the use of such bolts the pipes could be adjusted to any curve.

Mr Downie agreed with Mr Smith, if a special joint were made to suit, and referred to figs. 14 and 15, which showed a 5-inch pipe made with a ball-and-socket joint, which enabled them to go round all the curves that were required.

A vote of thanks was then awarded Mr Downie for his paper.

On the Glasgow Water Works.

By Mr J. M. Gale.

(SEE PLATES II., III., IV.)

In this paper it is proposed to give—

I. A short history of the water supply to Glasgow.

II. The leading features of the different schemes proposed from time to time.

III. An account of the Glasgow Company's Works at the date of the introduction of the Loch Katrine supply.

IV. A description of the Gorbals Water Works.

V. A description of the Loch Katrine Water Works.

VI. Some remarks on the distribution in the city.

I. History of the water supply to Glasgow. *Read 25th Nov., 1863.*

Few cities in Britain have increased in population and importance so rapidly within the last half century as Glasgow. In 1811 the population was 110,000, and in 1861, or fifty years later, it had increased to 446,000. During this period the city has spread far beyond its original limits, and the area occupied by the merchants' counting houses and residences in the early part of the century has been transformed into a mass of densely inhabited courts and lanes, while the open fields far to the west and south have been covered with streets and villas.

The first works for the supply of water to the city, though quite adequate to the wants of the town when projected, have had to be reconstructed more than once, and the last time on a scale and with a magnificence unequalled by any in the empire.

The first water works the city had, if they can be called such, were those established by Mr Harley, who erected pumps at Willowbank, and forced water through pipes into a tank in the upper part of Nile Street, from which it was carted through the town, and is said to have produced a revenue of £4,000 per annum. The first Water Company was incorporated by Act of Parliament in 1806, under the name of the Glasgow Water Company, and they began to supply water to the city in 1807. In the latter year another Company, under the title of the Cranstonhill Water Company, was started, and they obtained an Act of

Parliament in the succeeding year. The works of both Companies were completed about 1809, at which time the population of the city was about 100,000.

The Glasgow Company established their works at Dalmarnock, on the banks of the Clyde, about three and a half miles, by the river, above Glasgow Bridge; and under the advice of Mr Telford, C.E., erected two pumping engines on the north bank of the river there, and others at Gallowmuir, a short distance east from the Infantry Barracks. The Cranstonhill Company drew their water from the river also, at a point about three-quarters of a mile below Glasgow Bridge, opposite "the village of Anderston," and constructed reservoirs on Cranstonhill, but for some time the pumping was done by the proprietor of a mill adjoining the Company's works.

The two Companies laid parallel lines of pipes in most of the streets in the city, and from time to time extended their works under various Acts of Parliament, to meet the increasing demand for water. The river opposite Anderston soon became unfit for the purposes of the Cranstonhill Company, and in 1819 they abandoned their works, and erected a new pumping station about one mile below the Glasgow Company's works. The Cranstonhill Company was projected for the avowed object of giving the city the benefit of competition, and the inhabitants probably got whatever benefit this could give; but the undertaking was an unprofitable and disastrous one for the shareholders from the commencement. Between 1824 and 1827 the Company disposed of one-half of their whole capital at about one-fifth of its nominal value; and from 1808 to the amalgamation of this Company with the Glasgow Company in 1838, a period of thirty years, the whole dividends paid to the proprietors amounted in all to less than 20s per cent. The Glasgow Company's works were more profitable. They paid no dividend till 1814; but for a number of years prior to 1833 they paid 7 per cent., and in 1828 their shares were selling at 120 per cent. premium.

The competition of the two Companies virtually came to a close in 1833, by an arrangement which was proposed to be confirmed by Act of Parliament in 1834; but the bill was defeated by the opposition of the Town Council, who wished to preserve the competition; and it was only in 1838, upon the third application to Parliament, that the Companies were successful. The capital of the united Company was, by this Act, reduced from £326,050 to £267,550, and the profits limited to 7 per cent. By these arrangements the Cranstonhill Company lost about £45,000.

The population of the city had increased in 1838, when the two works were finally amalgamated, to about 250,000. The quantity of water supplied by both Companies was about 6,500,000 gallons a day, being at the rate of twenty-six gallons a head over the whole population. Under the united Company the works were very much increased. Two new powerful engines were erected at Dalmarnock, and filters upon the Lancashire principle were constructed at both works; the only filtration practised previously being through the bank of the river into brick tunnels placed below the level of the bed of the river.

The Water Company had now got quit of competition; but their troubles were only beginning. The water supplied from the river was very rarely quite free from objection. During floods it was much discoloured with clay, which the filters were quite insufficient properly to remove; and the summer and autumn floods were highly charged with peat from the extensive mosses in the upper parts of the river. These defects induced the Town Council in 1834, as part of their opposition to the proposed amalgamation of the two Companies, to employ Messrs Grainger and Miller, of Edinburgh, to look for a better source of supply for the city. This was the commencement of a struggle which the Water Company waged for more than twenty years, with varying success, and under which it finally succumbed in 1856.

As Glasgow is almost surrounded by high grounds, there are a large number of sources from which it could be supplied by gravitation; and a number of schemes on this principle have been from time to time projected, and various engineers and companies have occupied themselves with the question. Some of these schemes have never come to any maturity; but a few of them have been fully investigated. The engineering features of the principal projects will be described hereafter, the various sources that have been proposed being shown on the Map.

The result of Grainger and Miller's investigation in 1834 was the recommendation of the Earn Water, a tributary of the White Cart, as a proper source of supply; but the Council did not follow out the project. In 1836 a new Water Company was formed, with Mr Thom, of Rothesay, as engineer; and, after examining a number of sources, including the Clyde at Stonebyres, he prepared parliamentary plans for two projects—one to bring water from the North Calder, at a point near Airdrie, and the other from the river Avon below Stonehouse. He seems to have had a difficulty in recommending either scheme, but ultimately abandoned the Avon and preferred the North Calder. The plans for the latter were, however, found defective, and the Company abandoned their bill.

In 1837 Mr Stirrat, of Paisley, who had acquired some information on the subject of water supply in connection with the Paisley Water Works, proposed the Rowbank and the Cowden Mill Burns—streams deriving their supply from the high grounds between the valley of Loch Libo and the Laveron Water, and that of the Black Cart, as sources of supply for Glasgow.

In 1838 Mr M. M. Pattison, a gentleman who took some interest in improving the supply of water to the city, tried to revive the North Calder and Avon schemes, but without success. In 1843 a number of the old projects were revived, and two new ones were started by Mr Smith of Deanston—one to pump water from Loch Lomond, and another to form reservoirs on Dumbarton Moor, at the sources of the river Kelvin; while Grainger and Miller, after another examination of the country, reported in favour of the Endrick Water—a stream flowing from the north side of the Campsie Fells into Loch Lomond. The Allander Water, flowing from the Kilpatrick Hills, and the Clyde at Hyndford Bridge, were likewise suggested as sources of supply at this time.

Nothing was done, however, till the early part of 1844, when Messrs Kyle and Robson examined the proposals to bring water from the Clyde above Hyndford Bridge, and from the Avon one and a half miles below Strathaven. Mr Kyle made surveys of the Endrick scheme also, and in the latter part of the year a new Company was again established, with Mr Rendal, of London, as engineer. He preferred the Avon to all the other sources, and proposed taking the water from the river above Strathaven. Parliamentary plans were deposited; but it was found that the proposed capital of the Company would not execute the works. The bill was abandoned, and the city again left in the hands of the old Company. The failure of so many schemes for improving the supply of water to the whole city led to the Gorbals Company being started in 1845, for the supply of that portion of the city lying on the south side of the river, from the Brock Burn—a small stream about six miles south from Glasgow; and this succeeded better.

From 1834 to 1845 the Glasgow Company were not idle; and, in preparing for opposing the various rival schemes started from time to time, they seem to have become convinced that, sooner or later, their works would have to be abandoned. As early as 1837, and prior to the final arrangement with the Cranstonhill Company, they ordered an examination of the whole country, with the view of constructing new works, by Mr Wilson and Mr Anderson, their secretary and manager; and in 1840-42 they employed Mr Simpson, of London, to examine all the schemes that had been proposed up to that time. In 1844 the late venerable Principal Macfarlan suggested the Perthshire lochs to Mr Mackain, then the engineer to the Water Company, as a source where an inexhaustible supply of the purest water could be obtained.

In 1845 the quantity of water supplied to the city was 9½ million gallons a day. The population had increased to 320,000, so that the quantity supplied per head was now thirty gallons a day. In this year a new Company was started, by Messrs Lewis Gordon and Laurence Hill, to bring water to Glasgow from Loch Katrine, in the Perthshire Highlands, at the head of one of the tributaries of the river Forth; and these gentlemen state that their attention was first drawn to this locality in May, 1844. The prospectus of this Company was issued in September, 1845, and the scheme was supported by a large number of influential inhabitants. Although up to this time the Glasgow Company had expended £415,000 upon their works, they, to protect themselves from this and the Gorbals scheme, which was also started this year, resolved to construct new works themselves, and prepared a scheme to bring water from Loch Lubnaig, a lake on another of the tributaries of the Forth. The promoters of the Loch Katrine scheme were assured by the Glasgow Company that theirs was a *bona-fide* project for the improvement of the water supply, and on the payment of £1,000 they allowed the Loch Katrine scheme to drop. The Glasgow Company opposed the Gorbals Bill in Parliament, but were unsuccessful. Both bills received the sanction of Parliament in 1846, and both Companies began to prepare for executing their works. The Glasgow Company commenced the gaugings prescribed by the Act to fix the compensation water to be sent down the river Teith. These were continued for three years, at the expiry of which time it was found that the compensation was excessive, that sufficient storage had not been provided, and that the scheme was impracticable. During these investigations the Gorbals Company had completed their works, and the new water was introduced into the city in February, 1848. With few exceptions, the whole inhabitants in Gorbals took the new water, it being much better, and the supply more constant, than that of the old Company; and the revenue of the latter fell at once £4,000.

In 1849 the Gorbals Company proposed to extend their works, by including some additional tributaries of the White Cart, and to supply the whole city. The plans were prepared by Mr William Gale, their engineer, and deposited preparatory to an application to Parliament; but from the depressed state of the money market generally the proposal was not supported. The delay of the Glasgow Company in commencing their new works, and the magnitude of the undertaking, induced the public to believe the Loch Lubnaig scheme to be visionary, and the stock of the Company, from its evident insecurity, fell in 1850 to 50 per cent. discount. But now the Town Council began to take an active interest in the water supply, and immediately the Glasgow Company's shares rose. As early as 1845, overtures had been made by the Council for the purchase of the old works; and in the end of 1846 notices were given by the Water Company for a bill to authorize the sale; but it was not till September, 1850, that Sir James Anderson, then Lord Provost, got a Committee of the Council appointed to consider the whole question. This committee came to the resolution that the supply of water to the city should be in the hands of the Council, but no steps were taken to carry out their views.

In 1852 the population had increased to 360,000, and the quantity of water supplied to the city was 14,000,000 gallons a day, of which eleven were pumped by the Glasgow Company, and three were supplied by the Gorbals Company. The consumpt per head had reached thirty-five gallons a day on the north side and thirty-eight gallons on the south. In March of this year the Loch Katrine scheme was revived by Dr Rankine and Mr John Thomson, who in two letters advocated the scheme, and the propriety of the Council taking the matter into their own hands; and in October the Council confirmed their previous resolution to do this. The Gorbals Extension scheme was again brought forward, and the Glasgow Company proceeded with an amended Loch Lubnaig Bill. Plans for the two latter schemes were lodged in November.

The Council now obtained the services of Mr J. F. Bateman, of Manchester, to advise them in their future proceedings. The Gorbals Extension Bill was lost on standing orders; and the Council, in March, 1853, on the advice of their engineer, resolved to oppose the Loch Lubnaig Bill, as not being the best scheme that could be laid out in that district for the supply of the city. The opposition to the bill was formidable, including, in addition to the Town Council, a number of landowners, the proprietors of the Deanston mills on the river Teith, the commissioners of the Forth Navigation, and the Admiralty. The works were laid out on an extensive scale, and, following the suggestions made by Messrs Rankine and Thomson, it was proposed to bring in 20,000,000 gallons a day at once, and to prepare for ultimately bringing in 40,000,000. The principal features of the opposition by the Town Council were the difficulty of constructing and maintaining the aqueduct across the Flanders Moss—a soft moss, thirty or thirty-five feet deep, near the Lake of Menteith, which was proposed to be crossed by an inverted syphon pipe, 4 feet in diameter, 1⅝ inch thick, and under a pressure of 300 feet for 1¾ miles—and that a sufficient quantity of good water could be got from the Endrick Water, and in the neighbourhood of Killearn, for the present purposes of the city, such a scheme having the advantage of being capable of future extension to either

Loch Lubnaig or Loch Katrine. The Council were successful in their opposition, and the second Loch Lubnaig Bill was rejected. The Admiralty opposed the bill on the grounds of injury to the navigation of the Forth below Stirling, and to the anchorage of St. Margaret's Hope above Queensferry.

After the rejection of the bill, Mr Bateman was instructed to complete his examination of the whole country, with the view of the Council themselves promoting a bill during the next session. He found the Endrick was unfit for the purpose, and recommended Loch Katrine, where a supply of the very finest water was to be got in abundance. Plans were prepared and lodged in November, 1853, and the inquiry before a committee of the House of Commons commenced on the 20th March, 1854. Arrangements had been made with the Glasgow Company for the purchase of their works; but the Gorbals Company opposed the bill, and started the famous lead question. The Admiralty also opposed for the interests of the Forth, and the result was that the bill was rejected. The Council, who from the first had resolved to prosecute only the very best scheme that could be devised, now engaged Messrs Stephenson and Brunel to reconsider the whole question, including all the sources that had been proposed, and the objections to the Loch Katrine scheme started in the previous session of Parliament. In a very able report these engineers preferred the Loch Katrine scheme, and the bill was accordingly renewed in the session of 1854-55, and carried.

The works were commenced in the spring of 1856, the opening ceremony taking place on a rising ground on the line of aqueduct near the top of Loch Chon, on the 20th May, 1856; and on the 14th of October, 1859, Her Majesty the Queen was present at the ceremony of opening the works, and herself turned the sluice which first admitted the water from the lake into the aqueduct. The water was introduced into the city on the 28th December, and by March, 1860, the supply was general throughout the town.

On the 23rd of October following, the Council and a number of the most influential citizens entertained Mr Bateman to a banquet, as a tribute of respect and honour to the genius and skill of their engineer. In the face of doubts and distrusts freely expressed, and of unparalleled difficulties, arising from the wild and rugged nature of the district through which the aqueduct passed, the whole works, involving an outlay of upwards of £900,000, and extending over thirty-four miles of country, were completed in less than four years. It is a work which will bear comparison with the most extensive aqueducts in the world, not excluding those of ancient Rome; and it is one of which any city may well be proud.

II. The various schemes proposed. *Read 25th Nov., 1863.*

During the twenty years the means of improving the supply of water to the city were discussed, a number of schemes of considerable merit, involving large works and complicated engineering questions, were projected; and as the principal features of these are scattered over a large number of pamphlets and written evidence not easily accessible, a short description of some of them may be useful.

They may be divided into two classes,—1st, The schemes requiring the construction of storage reservoirs; and, 2nd, The lake projects. The economy of construction and freedom from risk of the latter were often urged against the reservoir schemes; while they, on the other hand, contained an element of gradual development and extension, affecting materially the cost, which the lake schemes possessed in only a slight degree.

The first scheme proposed was by Messrs Grainger and Miller in 1834, who selected the Earn Water, to the south of Glasgow, in the county of Renfrew. It discharges into the White Cart at a point seven miles distant from the city, and at an elevation of 300 feet above the Clyde at Broomielaw. They proposed three storage reservoirs upon the Earn, and a large compensation reservoir on the Cart near to Eaglesham. The area of the drainage ground to the lowest reservoir on the Earn was stated at 5371 acres; and they calculated the quantity of water available for the city at 10,000,000 gallons a day, which was considerably more than the quantity at that time supplied by both water companies. The water was to have been led by a conduit along the east side of the valley of the Cart to Castleton, on the high grounds above Rutherglen, three miles distant from Glasgow, where they proposed to form a town reservoir, 260 feet above the Clyde, and about seventy feet above Garnet Hill, which at that time was the highest ground within the limits of the city. The estimate was about £200,000, including new distributing pipes.

The North Calder scheme, proposed by Mr Thom in 1836, included two storage reservoirs near Airdrie, and an aqueduct seven miles long, to a town reservoir, which, however, was so low that all the high grounds in the city, including Rottenrow and Blythswood Hill, would have been supplied by pumping. The quality of the water was found to be objectionable from peat and the steeping of flax. The cost was estimated at £160,000, including distribution in the city.

The principal feature of the Avon scheme, proposed by Mr Thom, was a fine situation for a storage reservoir at Stonehouse, capable of holding 300,000,000 cubic feet. The water was to be drawn by an aqueduct to a town reservoir on Cathkin Hills, above Rutherglen, 150 feet above the Clyde, and about three miles from Glasgow, the whole distance being about twenty-one miles. The scheme would have yielded 15,000,000 gallons a day for the town; but the water of the Avon during some seasons of the year is deeply tinged with moss. The drainage area is shown by violet and orange colour on the map.

The Clyde above the Falls has been frequently suggested as a source of supply—first, it is believed, by Henry Bell in 1780. The scheme is shown in yellow on the map, and as matured by Messrs Kyle and Robson in 1844, consisted of a conduit twenty-eight miles long, from a point on the river 1½ miles above Hyndford Bridge to a town reservoir at Cathkin, 442 feet above high water. They proposed a settling reservoir at Hyndford Bridge, on the north bank of the river, 46½ acres in area, twenty-seven feet deep, and at an elevation of 605 feet, and two others along the line of aqueduct. The conduit was to have crossed to the south bank of the Clyde a little above Lanark Cotton Mills, and to have continued on that side to Cathkin. Compensation reservoirs would have been required, and there are some good sites for these upon the Douglas Water, which falls into the Clyde a little below Hyndford Bridge. The Clyde water at Hyndford is, however, deeply tinged with moss during the summer floods.

The Endrick scheme, proposed by Mr Kyle in 1844, was to construct a reservoir on the stream above Fintry Mill of forty-five acres in extent, and to carry a conduit down the valley of the Endrick and along that of the Blane to a reservoir near the village of Torrance, and thence to a town reservoir on Hamilton Hill, 272 feet above high water. The total length to the town reservoir was twenty-seven miles. Mr Kyle proposed to intercept the streams crossed by the conduit on the south side of the Campsie Hills, and to run a catch-water drain north and west of the reservoir on the Endrick by Culcreuch House, and thus to include 33½ square miles, or 21,000 acres of watershed.

The Avon scheme, proposed by Mr Rendal in 1844, included some expensive and peculiar arrangements for separating the moss water. The large reservoir 2½ miles above Strathaven would have contained 285,000,000 cubic feet, but the site of the main embankment turned out bad. The water was to have been led by an aqueduct into a town reservoir above Rutherglen in this case also. The scheme would have furnished about 14,000,000 gallons a day. The district is coloured orange on the accompanying map.

The Loch Katrine project was first suggested by Messrs Gordon and Hill in 1845. The line of the conduit proposed by these gentlemen was forty-five miles long, thirty-eight of which were to have been open, with a town reservoir on the high lands above Port-Dundas, 246 feet above high water. They estimated that 32,000,000 gallons a day could be got by either raising the loch four feet or drawing it down four feet, at a cost of £250,000 exclusive of new distributing pipes, or £400,000 including these.

The Loch Lubnaig scheme, as proposed by the Glasgow Water Company in 1845, was to draw the water from the loch by ten miles of an aqueduct, and 22½ miles of cast-iron piping, into a reservoir at Firhill four acres in extent, about two miles from the city, and at an elevation of 263 feet above average high water level. It was not proposed to raise the level of the loch, but power was taken to draw it down seven feet. 22,000,000 gallons a day was the ultimate quantity proposed to be drawn from the loch, or 7¾ inches of available rainfall over the drainage area; but only 8,640,000 gallons were proposed to be brought into the town at first. The aqueduct was to have been six feet in diameter, with a fall of four feet a mile, and the pipes four feet in diameter, with a fall of a little over four feet a mile, except the last 5½ miles, where the fall was only fifteen inches a mile. With the assistance of the then existing town reservoirs belonging to the Company, this might have been sufficient, but the scheme otherwise seems to have been hastily matured. Time was not given for adjusting the amount of the compensation water with the mill-owners and others interested in the flow of water in the Leny and Teith; and the quantity to be discharged down the river from the loch was fixed by the Act to be the average flow, including floods, during May, June, and July, for any number of years Mr James Leslie and Mr William Fairbairn, who were appointed arbiters under the Act, might fix. Three years were taken—viz., 1847, 1848, and 1849—and 11,502 cubic feet a minute, or 103,518,000 gallons a day, was found to be the average flow, which, over the whole year, is equal to 37½ inches of available rainfall. The rainfall during 1847 was found to be sixty-seven inches, and the water actually flowing from the ground, or the available fall, fifty-one inches, so that to supply the city with 22,000,000 gallons a day, in addition to the compensation, it would have been necessary to store nearly the whole available rainfall, while the storage provided by the Act was very small. The Parliamentary estimate for the works was £400,000.

The Loch Katrine scheme proposed by Messrs Rankine and Thomson in 1852, contains many features which were adopted in the second Loch Lubnaig Bill, and in the Loch Katrine works as they have been executed. The aqueduct was to have been thirty-six miles long, twenty-four miles being built or tunnelled, with a fall of ten inches a mile, and the remaining twelve cast-iron piping across valleys, with a fall of five feet a mile. They proposed to make the built part of the aqueduct, from the first, large enough to pass 40,000,000 gallons a day, but to lay only one four-foot pipe across the valleys in the meantime. This pipe, with the above fall, would deliver 20,000,000 gallons a day. The water was to have been led into a town reservoir on one of the small hills on the north side of the city, at an elevation of 250 feet above high water. The estimate for the aqueduct and town reservoir was £260,000; for distribution to meet the wants of the city, £200,000; and, to complete the distribution of 20,000,000 gallons a day, and for additions to the town reservoir, a further sum of £140,000—in all, £600,000.

It may be well here to describe the general physical features of these Lake districts, and of the country which lies between them and Glasgow. The city itself stands upon the coal measures; but a few miles distant these are thrown out, both on the north and south sides, by rather extensive bands of trap. Southwards the coal measures re-appear in Ayrshire, but on the north side the trap is followed by the earlier formations. Tracing a line north from Glasgow, the trap is first encountered seven miles out, at Milngavie, and it forms the whole range of the Campsie and Kilpatrick Hills. It is succeeded by the old red sandstone, which extends across Scotland in a belt about ten miles wide. The upper and softer beds lie next Glasgow, and the earlier and harder, including the well-known conglomerate, further north. Next succeeds the clay slate, in a stripe about four miles wide; and, lastly, there is the mica slate, which forms all the hills in the upper part of Loch Lomond, and all the high mountains of Perthshire, including Ben Lomond, Ben Venue, Ben Ledi, and Ben More. These latter rocks form the watershed of the valleys of Loch Lubnaig and Loch Katrine. They are precipitous, very hard, almost insoluble, and yield water of the very purest quality. It is altogether a wild mountainous district, with no cultivated land, or land capable of being cultivated: heath there is in abundance, but there are few deep mosses. The quality of the water flowing from the valleys of Loch Lomond, Loch Ard, Loch Katrine, and Loch Lubnaig may be considered practically the same. It has a hardness, varying in different localities and at different seasons of the year, from 0·5° to 1·0° on Dr Clark's scale, and has all the properties of distilled water. This extreme purity led to a very extensive and elaborate inquiry as to its action upon lead, which will be referred to afterwards.

The following tables give analyses of water from Loch Katrine and Loch Lomond, made during the progress of the inquiry into the action upon lead.

ANALYSES OF LOCH KATRINE WATER.

	Graham and Hofmann. May, 1854.	Dr Miller. Water Drawn on 14th May, 1854.	Dr Penny. Water Drawn in March & June, 1854.
	Grs. per Gall.	Grs. per Gall.	Grs. per Gall.
Organic Matter,	0·819	1·12	0·900
Sulphate of Lime,	0·378	0·56	0·381
Do. Potash,	trace.	,,	,,
Do. Soda,	0·280	,,	,,
Chloride of Calcium,	,,	0·16	0·144
Do. Sodium,	0·448	0·29	,,
Alkaline Chlorides,	,,	,,	0·433
Carbonate of Magnesia,	0·154	trace.	0·216
Do. Soda,	0·147	,,	,,
Sesquioxide of Iron,	trace.	,,	trace.
Silica,	trace.	0·16	0·170
TOTAL,	2·226	2·29	2·224
Hardness on Dr Clark's Scale,	Under 1°	0·6°	0·8°
Gases, per Gallon,—	Cub. Ins.	Cub. Ins.	Cub. Ins.
Carbonic Acid,	0·09	0·05	0·080
Oxygen,	2·38	2·31	2·424
Nitrogen,	4·66	4·33	4·777
TOTAL,	7·13	6·69	7·281

ANALYSES OF LOCH LOMOND WATER.

DR PENNY, 1854.

	From Loch opposite Inversnaid.	From Outflow of Loch.
	Grs. per Gall.	Grs. per Gall.
Organic Matter,	1·175	1·145
Mineral Matter,	1·650	1·875
TOTAL,	2·825	3·020
Hardness,	0·85°	1°
Gases, per Gallon,—	Cub. Ins.	Cub. Ins.
Carbonic Acid,	0·28	0·34
Oxygen,	2·14	2·08
Nitrogen,	4·52	4·25
	6·94	6·67

RAINFALL IN LOCH KATRINE DISTRICT.

	Elevation, 275 feet. — At Loch Vennachar.	Elevation, 420 feet. — At Loch Drunkie.	Elevation, 270 feet. — At Bridge of Turk.	Elevation, 1,800 feet. — Between Glen Finlass and Ben Ledi.	Elevation, 380 feet. — At Glen Gyle, head of Loch Katrine.	Elevation, 830 feet. — On summit of hill above Tunnel at Loch Katrine.	Elevation, 325 feet. — At Loch Dhu.	Elevation, 60 feet. — At the Inn at Aberfoyle.	Elevation, 1,500 feet. — On hills between Loch Ard & Loch Katrine. — Ledard.	Elevation, 1,800 feet. — Head of Duchray Valley. — Benlomond.	Elevation, 320 feet. — At Mugdock Reservoir.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
1854, ...	×	×	64·5	61·9	103·3	×	×	56·1	67·1	109·0	×
1855, ...	×	×	39·0	56·1	65·5	×	×	34·6	×	69·9	×
1856, ...	×	×	48·3	×	79·3	×	×	36·7	74·1	81·0	×
1857, ...	×	×	54·8	48·3	91·6	×	×	47·6	74·2	85·5	×
1858, ...	×	×	60·2	55·2	84·8	×	×	41·5	97·1	90·4	×
1859, ...	×	×	65·2	48·0	93·7	×	×	52·6	85·3	91·8	×
1860, ...	×	×	59·8	53·8	94·2	×	×	40·4	73·5	83·5	×
1861, ...	72·7	71·7	74·4	70·4	112·5	89·2	93·2	71·6	103·1	99·9	×
1862, ...	69·0	78·1	71·9	66·0	105·1	96·9	101·1	77·0	102·7	114·7	60·6
Average,	70·8	74·9	59·8	57·4	92·2	93·0	97·1	50·9	84·6	91·7	60.6

× No Returns for these years.

The fall of rain in some parts of the district is very great. In the valley of the Duchray, on the eastern slope of Ben Lomond, and in Glen Gyle, on the east side of Benhonie, there is in some years upwards of 100 inches of rain. On the western slope of the hills, and in the more open parts of the district, by Aberfoyle and Loch Vennachar, the fall is not much above half this amount. A Table of the Rainfall is given on the preceding page.

The valleys of Loch Lubnaig, Loch Katrine, and Loch Ard, with other tributaries, unite in forming the river Forth, which at Alloa, 10½ miles below Stirling, expands into the estuary of the Frith of Forth. About three miles above Stirling the Forth receives the river Teith, which drains the valleys of both Loch Lubnaig and Loch Katrine. For many miles above its junction with the Teith, the Forth is a sluggish stream, with little fall, and usually much discoloured. It also brings down much floating peat from the extensive mosses above, thrown in from time to time to clear the ground. The valley of the Teith rises much more rapidly than that of the Forth, and a little above Callander it separates into the valleys of Loch Lubnaig and Loch Katrine. In each of these valleys there are three natural lochs. In the first there are Loch Doine, Loch Voil, and Loch Lubnaig, with a collective water area of 1,300 acres; and in the latter, Loch Katrine, Loch Achray, and Loch Vennachar, with an area of 4,000 acres. The drainage area of the Loch Lubnaig valley to the outlet of Loch Lubnaig, coloured green on the map, is 44,600 acres, or about seventy square miles; and of the Loch Katrine valley to the outlet of Loch Vennachar, shown in red on the map, 45,800 acres, or nearly seventy-two square miles. To the outlet of Loch Katrine alone the drainage is 22,800 acres, or about thirty-six square miles. The water surface of the lochs in the Loch Lubnaig valley is one thirty-fourth of the drainage area, and in the Loch Katrine valley to the outlet of Loch Katrine one-eighth; and to the outlet of Loch Vennachar rather more than one-eleventh of the drainage area. There is thus three times as much water surface in the Loch Katrine valley as in the Loch Lubnaig valley. Loch Lubnaig has an area of 574 acres, and is 393 feet above mean high water at Glasgow. Loch Katrine is about 7½ miles long, with an area of 3,000 acres, and an elevation at summer level of 358 feet above high water spring tides at Glasgow. Allowing two feet for the difference between spring and mean high water at Glasgow, the difference in level between the two lochs is thirty-three feet in favour of Loch Lubnaig.

The second Loch Lubnaig bill promoted by the Glasgow Water Company had Mr J. M. Rendal, of London, as engineer in chief, and Messrs Leslie and Mackain as the engineers for the execution of the works. The service reservoir was proposed to be near Milngavie, about eight miles from Glasgow, at an elevation of 315 feet, and of a capacity of 480,000,000 gallons; and the length of the work from this reservoir to Loch Lubnaig was twenty-five miles—sixteen miles being an aqueduct, and nine miles cast-iron pipes across the valleys of the Teith, Forth, Endrick, and Blane. The aqueduct was to have a fall of 1 in 4,000, or nearly sixteen inches a mile, and to be of sufficient capacity to pass 40,000,000 gallons a day. There were five long tunnels on the line, of an aggregate length of 5¾ miles, and these were proposed to be 7½ feet diameter. The cast-iron syphon pipes to be laid down in the first instance were to pass one-half the quantity of water the aqueduct would bring forward, or 20,000,000 gallons. They were to be four feet diameter, with a fall of 1 in 1,000, or a little over five feet a mile. From the service reservoir at Mugdock there were to have been two pipes to the city; one, forty inches in diameter, for the supply of the low districts, and the other, twenty-one inches diameter, for the high parts of the town. It was proposed to draw down Loch Lubnaig six feet, and to raise Loch Doine fifteen feet, giving in all 372,000,000 cubic feet of storage. Loch Katrine was to have been converted into a compensation reservoir for the millowners. It was to have been raised two feet, and drawn down three feet, giving a power over the loch to the extent of five feet, equal to a storage of 645,000,000 cubic feet. A further quantity of water for compensation was to have been discharged from Loch Lubnaig down the Leny, of 1,000 cubic feet a minute, or 9,000,000 gallons a day, making the total compensation water about 50,000,000 gallons a day, and for this ample storage was provided. The storage provided for the city in the Loch Lubnaig valley was eighty days' supply, including the 9,000,000 gallons of compensation water for the Leny, when 20,000,000 gallons were being sent in; but only forty-seven days' supply when the whole 40,000,000 gallons were being sent in, and this was far from being sufficient. The estimate for the works was £488,195, exclusive of the cost of re-arranging the distributing pipes in the city.

The scheme urged against the Loch Lubnaig bill by the Town Council in 1853 was to appropriate the upper waters of the Endrick, and was similar to that proposed by Mr Kyle in 1844. The area is coloured yellow on the map. Mr Bateman proposed two reservoirs on the stream—one above and the other below the Loup of Fintry. The upper reservoir would have contained 360,000,000 cubic feet, and the lower 50,000,000, with a drainage of 11,000 acres. In addition to this, it was proposed to intercept the water from 8,000 acres above the line of aqueduct between Fintry and Strathblane; but the floods from this portion were not proposed to be stored. The level and dimensions of the aqueduct were fixed with reference to a future extension to Loch Lubnaig or Loch Katrine. Thirty-six inches of rainfall was calculated as being available for the purposes of the works, which were calculated to yield 17,000,000 gallons a day for the city, at a cost of £343,000, as against £500,000 for the Loch Lubnaig scheme. In the course of a subsequent examination it was found that the Endrick was much discoloured by moss.

In the Loch Katrine scheme, as submitted to Parliament in 1853-54, it was proposed to construct the aqueduct, and those other parts of the works which could not be easily increased afterwards, on a scale sufficient to pass 50,000,000 gallons a day to the city, and to lay across the valleys one four-foot pipe in the first instance, to deliver 20,000,000 gallons. The loch was to be raised four feet, being the range of ordinary floods, and drawn down three feet, giving a storage capacity of 910,000,000 cubic feet, equal to 114 days' supply to the city at 50,000,000 gallons a day, or 120 days, allowing for the flow of the streams during such a drought. The site for a service reservoir proposed for the Loch Lubnaig scheme was adopted for this, and the line of the aqueduct from Killearn to the reservoir was practically the same. The total length of the aqueduct to the service reservoir was 25¾ miles, and from the reservoir to the Exchange about eight miles more—in all nearly thirty-four miles. The built and tunnelled part of the aqueduct was twenty-two miles long, with an inclination of 1 in 6,336, or ten inches a mile. The piping across the valleys of the Duchray, the Endrick, and the Blane, was 3¾ miles in length, and had a fall of 1 in 1,000, or rather more than five feet a mile. The most convenient place for drawing the water from Loch Katrine, and for passing through the ridge which separates Loch Katrine from the valley of Loch Chon and Loch Ard, was found to be at Calagart, 2½ miles from the top of the loch. The country, for the first eleven miles from the loch, is very rugged and intricate; and in this district it was difficult to fix upon the best route for the aqueduct. Nearer Glasgow the country is more open, and the line of works was more easily traced. The tóp-water level of the service reservoir was proposed to be 311 feet 9 inches above high water spring tides, and to contain 537,000,000 gallons, being twenty-five days' supply for the city at 20,000,000 gallons a day, and ten days' supply when the full quantity of 50,000,000 a day is being sent in. It was proposed to have two main pipes from the reservoir at Mugdock to the city, each thirty-six inches diameter. The compensation water to the river Teith was, by agreement with the proprietors of the Deanston mills, to have been 40,500,000 gallons a day, or an average of 4,500 cubic feet a minute, to be given out at the rate of 6,000 cubic feet a minute for twelve hours of the day, and 3,000 cubic feet a minute for twelve hours of the night. To obtain this quantity of water, in addition to that for the town, it was proposed to raise Loch Vennachar to its flood level, or five feet nine inches above its summer level, and to draw it down six feet. The area of the loch is 865 acres, and the storage was calculated at 425,000,000 cubic feet. Loch Drunkie, a small loch of eighty-three acres, lying to the west of Loch Vennachar, was proposed to be raised twenty-five feet, giving additional storage of 120,000,000 cubic feet. The following table gives these quantities in a more connected form:—

	Area at Summer Level.	Extent to which Lochs can be Raised or Lowered.	Height of Raised Level above Ordnance Datum.	Capacity.	Drainage Area.	Proportion of Storage to each Acre of Drainage Area.
	Acres.		Feet.	Cubic Feet.	Acres.	Cubic Feet
Loch Katrine, ...	3000	Raised 4′ 0″ Drawn 3 0 7 0	367	910,000,000	22,800	39,912
Loch Vennachar	865	Raised 5′ 9″ Drawn 6 0 11 9	269	425,000,000	21,500	19,767
Loch Drunkie, ..	83	Raised 25′ 0″	416	120,000,000	1,500	80,000
TOTALS, ...	3948			1,455,000,000	45,800	

The quantity of water sent into the city from Loch Katrine during the past year was 17,000,000 gallons a day; so that in Loch Katrine there is upwards of 300 days' supply at this rate. A certain quantity is, however, always run down the river to Loch Achray and Loch Vennachar. Taking the capacity of the whole lochs, and adding the compensation water to the 17,000,000 sent into the city—in all, 57,500,000 gallons a day—there is 156 days' water in store when the lochs are full. When the full quantity of water the aqueduct will discharge is supplied to the city, the storage is equal to 100 days' supply, without taking into account the natural flow of the streams.

The estimate for the whole of these works was £525,000, and £50,000 more for distribution in the city—in all £575,000. The objection to the quality of the water on account of its alleged action upon lead, and the opposition of the Admiralty for injury to the Forth, proved fatal to this bill; but it was successfully prosecuted in the session of

1854-55, and the works have all been executed upon the scale above described.

The question of the solvent action of very pure water upon lead, and the injury to health attaching to the use of such water, is no doubt an important one, and has received the attention of the best chemists in the world. The question as regards the Loch Katrine water was first raised by Dr Penny, of Glasgow, who was engaged by the Gorbals Company, then opposing the Loch Katrine scheme. The Town Council consulted the most eminent chemists in London and Scotland, and a most extensive inquiry to determine the question was set on foot at an ultimate cost of £5,000. The inquiry embraced many of the water works and rivers in Scotland, in Cumberland and Westmoreland, in Wales, in the district round Manchester, in Ireland, and in America. The results may be briefly stated as follows:—All pure waters act more or less upon lead: in some cases the action ceases after a time; in others it is continuous. The action is first an oxidation of the lead by the air in the water, and then a dissolving of the oxide by the carbonic acid, forming a carbonate of lead visible to the eye, but which appears to be also slightly soluble. Any quantity of lead in water above one-tenth of a grain per gallon is considered dangerous. Carbonate of lime possesses the property of preventing the action of water upon lead more than any of the other substances usually found in water. The laboratory experiments with the Loch Katrine water gave results quite alarming. If the same piece of lead is kept constantly in the same portion of water, the corrosion of the lead goes on uninterruptedly. If the water is changed at intervals of twenty-four hours the action diminishes, though manifest in one experiment at the end of sixteen successive days. In another the action decreased from eight grains per gallon per day to one-third of a grain per gallon at the end of eight days, at which point it remained stationary. The laboratory experiments varied a good deal from the quality of the lead employed, a small percentage of impurity affecting the results materially, and five per cent. of tin preventing the action entirely; from the extent of lead surface exposed to the water; and from the state in which the surface of the lead was, whether soiled as got from the shops, or scraped clean to remove all accidental coating and oxidation. The practical question to be determined, however, was—Would the water become contaminated with lead in passing through lead pipes and cisterns in the ordinary circumstances in which the water would be delivered in Glasgow? and to establish this, an extensive series of experiments with old and new pipes and cisterns was instituted at Loch Katrine during 1854 and 1855. No action was found on old pipes and cisterns, and the action on new ones after six days was found to be too small to be injurious. It was anticipated that, in passing along the twenty-two miles of aqueduct, ten of which is through the old red sandstone, the water would change somewhat in character, by taking up lime from the rocks in passing, and by the admixture of streams or springs containing compounds of lime; and this has been realized. The water as delivered in Glasgow contains nearly one grain more per gallon, and is sensibly harder than the water of the lake. From recent experiments by Dr Wallace, it is found that the amount of lead taken up by the water under the usual circumstances of supply is not such as to give rise to any apprehension.

ANALYSES OF LOCH KATRINE WATER.
DR WALLACE, 1854 and 1861.

	Drawn from Loch, 1854.	Drawn in Glasgow, 1861.
	Grs. per Gall.	Grs. per Gall.
Lime,	0·19	0·47
Magnesia,	0·10	0·12
Sulphuric Acid,	0·33	0·36
Chlorine,	0·33	0·30
Alkalies and Carbonic Acid,	0·12	0·51
Alumina and Phosphates,	0·10	0·16
Oxide of Iron,	,,	trace.
Silica,	0·01	0·06
Organic Matter,	0·80	0·84
TOTAL,	1·98	2·82
Gases, per Gallon,—	Cub. Ins.	Cub. Ins.
Carbonic Acid,	0·07	0·38
Oxygen,	2·51	2·54
Nitrogen,	4·92	5·58
TOTAL,	7·50	8·50

The cases of Inverness and Whitehaven were frequently referred to during this inquiry, where waters of the same purity as the Loch Katrine water are supplied to the inhabitants without any bad results ever having been discovered. The table on the following page gives analyses of these waters.

The opposition of the Admiralty, at the instigation of the Commissioners of the Forth Navigation, who hold jurisdiction over the river from Stirling to Alloa, and who had expended about £9,000 in improving the channel, was the cause of the bill of 1853-54 being rejected; and it was only upon Lord Provost Stewart enlisting the influence of Lord Palmerston, then Secretary of State for the Home Department, that the Admiralty consented that the works should proceed. They opposed this scheme, as they had opposed the Loch Lubnaig bill, on the grounds of alleged injury to the scour of the channel by storing the floods in the lochs.

ANALYSES OF INVERNESS AND WHITEHAVEN WATER.

Messrs MILLER, PENNY, and REDWOOD, 1855.

	Inverness. — Drawn from River Ness.	Whitehaven. — Drawn from River En.
	Grs. per Gall.	Grs. per Gall.
Organic Matter,	0·80	0·46
Fixed Salts,	1·70	1·60
TOTAL,	2·50	2·06
Hardness,	0·8°	0·7°
Gases, per Gallon,—	Cub. Ins.	Cub. Ins.
Carbonic Acid,	0·746	0·47
Oxygen,	2·294	2·35
Nitrogen,	4·737	5·37
	7·777	8·19

Every engineer will of course admit the importance of land floods in clearing a river for the purposes of navigation; but when any river expands into the dimensions of an estuary, the effect of the land floods is altogether lost in that of the tidal scour. The Admiralty included in the possible injury to the Forth damage to the anchorage of St. Margaret's Hope, above Queensferry, which was stated to be the only harbour of refuge for ships of war between the Humber and the Frith of Cromarty. For seven miles above Queensferry the estuary has a depth of sixty feet at low water, and may be safely considered an arm of the sea, beyond the influence of land floods. The opinions advanced by the Admiralty engineers were fairly met and amply discussed; but it would be beyond the limits of this paper to enter upon them. It was clearly proved that the Loch Katrine scheme would interfere much less with the scour of the land floods than the Loch Lubnaig scheme, and some very conclusive arguments, drawn from gaugings of the river and its tributaries at different points, showing the influence the lakes in their natural state have in storing floods, were adduced by Mr Bateman. These proved that the district with the greatest lake surface yielded the least flood water, and that the water from such a district could be impounded in reservoirs with a minimum injury to the scour from land floods. The Loch Katrine district was shown to have the advantage over that of Loch Lubnaig in this respect in the ratio of three to one. A diminution of the land floods to a slight extent was not denied, and ultimately this troublesome question was compromised by a payment of £7,000 to the Forth Commissioners, to be expended in the improvement of the river.

The Admiralty urged the adoption of Loch Lomond as a source of supply free from the objection that the scour of the Clyde was being benefited at the expense of the Forth. The drainage areas to these rivers are shown by blue and red boundaries on the map. The quality of the water is unquestionable, and the quantity practically unlimited, and it might have an advantage in first outlay, and in the subsequent expenditure being regulated by the demand; but the cost of pumping, as the loch is only about twenty feet above high water, would have been from £15,000 to £20,000 a year, equal to an outlay of £400,000 to £500,000, exclusive of works. As other sources existed which did not involve pumping, the cost of this was an insuperable objection to the Loch Lomond scheme.

There only now remains to be noticed one other scheme for the supply of the city with water—viz., that proposed by the Gorbals Water Company for the extension of their works. It is shown in green on the map. In its essential features it was the scheme proposed by Grainger and Miller in 1834, extended to meet the increased requirements of the city. The project was first started by the Gorbals Company in 1848, and again in 1852; but upon neither occasion were its merits and defects brought out in Parliament. The existing works of the Gorbals Company are upon the Brock Burn, a tributary of the White Cart, which flows through Pollokshaws and Paisley, and discharges into the Clyde a little below Renfrew; and the proposal was to impound the water of other tributaries, including the Laveron Water, the Earn Water, and the upper sources of the Cart itself. The details of the scheme, as proposed in 1848, varied from that proposed in 1852; but as presented before Stephenson and Brunel in 1855, it included about 18,500 acres of gathering ground, exclusive of the Brock Burn, already appropriated, and which was estimated to yield 4,000,000 gallons a day for the use of the city. After a careful inquiry the minimum available rainfall of the district, which geologically is altogether trap, was estimated at thirty inches, and the reservoirs and other works shown on the Parliamentary plans of 1852 were estimated to yield 17,000,000 gallons a day in addition to that available from the existing works. Additional gathering ground on the Cart extending to 12,000 acres was pointed out, from which 8,000,000 or 10,000,000 gallons a day could have been got, making the total yield of the district for the purposes of the city, and after deducting a liberal allowance for compensation, 30,000,000 gallons a day. It was shown and admitted that up to 30,000,000 gallons a day the Gorbals scheme had the advantage of requiring a less immediate outlay than the Loch Katrine one, with the power of graduating the expenditure as the demand increased for at least fifteen years. The comparison as to cost was in favour of the Gorbals scheme up to 20,000,000 gallons a day, to the extent of probably £120,000, and about the same difference would have continued up to 30,000,000; but beyond this the scheme could not have been extended without including some sources which are objectionable in point of colour. Messrs Stephenson and Brunel, in comparing it with the other projects involving artificial reservoirs, including the Endrick, Clyde, Avon, &c., say—"After a careful consideration of all the circumstances, and an examination of the country, we have come to the conclusion that the extension of the present Gorbals Water Works, as proposed by Mr Gale, is the only plan which complies with the requisite conditions of quality and quantity;" and, "in our opinion, it is the only scheme which can be usefully considered, in comparison with the proposed appropriation of the waters of the lakes." Each of these two schemes "offers some advantage peculiar to itself, which renders it more difficult than might at first be supposed to arrive at any positive conclusion as to any general superiority of the one over the other." The Loch Katrine scheme was laid out on a scale of 50,000,000 gallons a day, and with such a magnificent project the Gorbals scheme could not compete.

III. The Glasgow Company's Works at the date of the introduction of the Loch Katrine supply. *Read 23rd December, 1863.*

By the Act of 1855 the works of both the existing Companies were transferred to the Town Council, which body was constituted a commission for the future administration of the water supply. The Gorbals Company, who had expended £180,000 upon their works, were guaranteed 6 per cent. per annum; and the Glasgow Company, who had expended £448,000, 4½ per cent. on their ordinary capital, amounting to £303,700, and 6 per cent. on the preference stock, amounting to £41,680. The remainder of their capital was borrowed money.

The whole of the Glasgow works, with the exception of the piping in the city, were superseded in March, 1860, upon the introduction of the Loch Katrine supply. There were three pumping stations and thirteen pumping engines, of 900 horses power in the aggregate, distributed as follows:—

At Dalmarnock,	1 of	18	horses power,	18	
„	4 of	80	„	320	
„	2 of	180	„	360	
					698
At Cranstonhill,	1 of	10	„	10	
„	3 of	30	„	90	
					100
At Drygate,	2 of	50	„	100	
					100
	13				
					898

The engines were all single-acting condensing beam engines, with the exception of the two at Drygate. The two largest at Dalmarnock were erected about 1840, after the amalgamation of the Cranstonhill and Glasgow Companies, and, with the engine house and boiler shed, are stated to have cost £23,000. The others were older, and made by Bolton & Watt. The three 30 horses power engines at Cranstonhill were erected when the works were moved from Anderston in 1819.

The two 180 horses power engines at Dalmarnock, named respectively "Samson" and "Goliath," were made and erected by the Neath Abbey Company, Wales. They are upon the Cornish principle, and were of the most approved construction at the date of their erection. The cylinders are seventy-two inches diameter and ten feet stroke. "Samson" was used for pumping water to the high districts of the city against an indicated pressure of 85 lbs. on the square inch. The pump barrel is twenty-four inches diameter and ten feet stroke, discharging into a main twenty inches diameter. It made 780 strokes an hour, or thirteen a minute latterly, and threw 21,884 cubic feet an hour, or over 3,000,000 gallons a day. "Goliath" was used for pumping water to the low districts against an indicated pressure of 40 lbs. on the square inch. The pump barrel is thirty inches diameter and ten feet stroke, discharging into a main thirty-six inches diameter. It made 840 strokes an hour, or fourteen a minute, and threw 38,000 cubic feet an hour, or over 5,500,000 gallons a day. There were eight boilers to these two engines, each twenty-five feet long, seven feet diameter, with internal flues three feet diameter. The boilers were worked at 15 lbs. on the square inch.

Taking the average of the last thirteen years the engines worked, one waggon (24 cwts.) of coal kept one engine working for 1·65 hours;

and the effective work, taking an average for the same length of time, was 186,000 foot pounds per lb. of coal consumed. The cost of pumping, taking all the engines at Dalmarnock and Cranstonhill together, as ascertained from the accounts of the Water Company by Dr Rankine, was, during a long series of years, at the rate of almost exactly 400,000 gallons raised one foot for a penny; that is, 4,000,000 foot pounds for a penny.

The area of ground occupied by the filters, subsiding reservoirs, and other works at Dalmarnock, was twenty-two acres, and at Cranstonhill twelve acres. There were three main pipes leading from the Dalmarnock Works to the city, one of fourteen inches diameter, with flange joints, laid in 1808, one of twenty inches laid in 1821, and one of thirty-six inches diameter laid in 1830. From the Cranstonhill Works there was one main of twenty-one inches diameter laid when the new works were erected in 1819. There were also five reservoirs on elevated sites in the city, one at the Drygate pumping station, one in Rottenrow, one on the top of Garnethill, and two at the old Cranstonhill Works in Anderston.

At Dalmarnock the pumping engines were upon the north bank, and the filters and subsiding reservoirs on the south bank of the river. For thirty years the only filter consisted of a brick tunnel or culvert built along the south bank, and below the level of the bed of the river. The river bank is of sand, and the joints of the brick work were left open, to allow the water to percolate into the culvert from the river. The quantity of water supplied by the tunnel has been stated at 3,000,000 gallons a day on an average. It varied with the state of the river, being least when the river was low, and at those times the water contained more lime than the river water, and a little iron. As the town increased, this quantity of water was found insufficient, and other filters were constructed in 1839, which were added to from time to time. The filtered water was at first conveyed across the river to the pumping engines by a fifteen-inch spherical-jointed pipe designed by James Watt. Three additional pipes, one of eighteen inches, one of twenty-five inches, and one of forty inches, were laid in later years.

At the Cranstonhill Works there was a similar tunnel along the bank of the river, and filters in addition. They were more extensive than those at Dalmarnock in proportion to the quantity of water passing through them, and the quality of the water was usually better.

The supply of water was constant in the lower parts of the town, and intermittent in the upper. The pumping station at Drygate was used for forcing water to the highest levels within the limits of supply, including Garngad Hill, Blythswood Hill, Garnet Hill, the West-End Park, and Partick Hill. The water was delivered by the engines at Dalmarnock into a reservoir capable of holding about 800,000 gallons, at an elevation of about 100 feet above high water; and from this level it was forced to the requisite additional height by two horizontal high-pressure engines, erected one in 1854 and the other in 1857. These engines have been already described to this Institution by the late Mr Mackain, who designed them.

The Clyde water was sometimes quite unobjectionable, and in the usual state of the river it is a good soft water, and pleasant to the taste; but during floods it comes down much discoloured with clay, and for certain seasons of the year it is deeply stained with peat. Large subsiding reservoirs and perfect filtrations would have removed this colouring matter to a great extent, but there never were filters sufficiently extensive to pass the large quantity of water required by the city, amounting, as it did latterly, to 14,000,000 gallons a day; and in some states of the river nearly one-half of the whole quantity supplied from the Dalmarnock works was pumped into the city direct from the river. The increase in the population, and in the number and extent of manufactories and dye-works on the banks of the river above the water works, was also latterly urged against the quality of the water. As regards quantity there never was much to complain of, except perhaps in the higher levels, to supply which the engine power of the Company did not keep pace with the increase of the city.

IV. The Gorbals Water Works, *Read 23rd December, 1863.*

The Gorbals Water Works draw their supply from the Brock Burn, a small stream having its sources near Brother Loch and Long Loch, in the south-east of Renfrewshire. The works are shown in red on the accompanying map. The surface water is collected in reservoirs, and after being filtered is supplied to the city by gravitation. The hills on that side of Glasgow are all trap, and yield very fine water where not injured by peat. The following are analyses by Dr Penny:—

ANALYSIS OF THE EARN WATER.

DR PENNY, 1854.

	Grs. per Gall.
Organic Matter, ...	1·665
Mineral Matter, ...	3·275
TOTAL, ...	4·940
Hardness, ...	2°

ANALYSIS OF THE GORBALS WATER.

Dr Penny, February, 1854.

	Grs. per Gall.
Organic Matter,	1·531
Carbonate of Lime,	1·152
Sulphate of Lime,	0·946
Sulphate of Magnesia,	0·284
Muriate of Magnesia,	0·344
Alkaline Chlorides,	0·720
Oxide of Iron,	0·043
Silica,	0·177
TOTAL,	5·197
Hardness,	3·2°
Gases, per Gallon,—	Cub. Ins.
Carbonic Acid,	0·55
Oxygen,	2·25
Nitrogen,	4·70
TOTAL,	7·50

The lowest reservoir is four and a half miles from the upper sources of the stream, and about six miles from Glasgow. The drainage area has been variously stated, but the amount given in Mr William Gale's first Report upon the scheme, in July, 1845, was 2,560 acres, and this appears to be nearly correct.

There are four reservoirs, of the following dimensions and capacity:—

	Height of Top Water above Ordnance Datum.	Depth of Water when Full.	Area of Water Surface.	Capacity.
	Feet.	Feet.	Acres.	Cubic Feet.
Balgray Reservoir,	352	40·0	153½	119,492,266
Ryat Linn Reservoir,	313	27·9	21	11,976,389
Littleton Reservoir,	297	14·0	4	1,353,368
Waulkmill Glen Reservoir,	296	49·3	47¾	36,541,310
TOTALS,			226¼	169,363,333

There are thus 66,000 cubic feet of storage to each acre of watershed; and it is found sufficient not only to equalize the flow of the stream during a dry year, but also to assist such a year, and thus slightly to increase the minimum yield of the stream. The fall of rain in the neighbourhood of the reservoirs varies from 60 to 36 inches per annum, and increases about 30 per cent. towards the upper end of the drainage ground, as shown by the following table:—

FALL OF RAIN IN THE GORBALS DISTRICT.

	Elevation 300 feet.	Elevation 550 feet.	Elevation 700 feet.
	Gorbals Works*	Middleton.	Black Loch.
	Inches.	Inches.	Inches.
1849...........	47·55	†	†
1850...........	46·20	†	†
1851...........	44·71	†	†
1852...........	60·42	†	†
1853...........	39·97	†	†
1854...........	44·60	†	†
1855...........	30·80	35·50	39·90
1856...........	38·87	42·25	51.50
1857...........	35·04	41·70	45·70
1858...........	43·94	51·70	†
1859...........	51·02	57·65	†
1860...........	40·47	44·72	†
1861...........	57·00	66·08	69·25
1862...........	57·60	68·98	68·70
Average,...	45·58	51·07	55·01

* Average of two gauges at the Gorbals Works. † No returns for these years.

These works were not all executed at the same time. The three lower reservoirs were constructed during 1847 and 1848, and the uppermost and largest during 1853 and 1854. This gradual development was intended from the first; and the clauses in the Act regulating the quantity of water to be given out as compensation to the parties interested in the lower part of the stream were framed accordingly. It was intended, when the whole was developed, that the compensation water should be one-fourth of the whole available water of the stream during a dry season. The quantity was fixed at 9½ cubic feet per minute for each 10,000,000 cubic feet of storage. It now amounts to 161 cubic feet a minute, or 1,450,000 gallons a day. The quantity of water available for the city from the whole stream was estimated in 1846, when the first Act was got, to be 4,000,000 gallons a day, and experience has proved this estimate to be a correct one. The compensation water is therefore 27 per cent. of the whole, or a little over a fourth; but any loss on this head, by reason of the size of the reservoirs, is more than made up by increased security against scarcity during dry seasons, and increased purity of the water by subsidence.

At the rate at which these works are at present being drawn upon for the supply of the city, the reservoirs contain, when full, about 220 days' supply; but if 4,000,000 gallons a day were being sent into the city, the storage would be equal to 194 days' supply, including compensation water in both cases.

A new course for the stream has been constructed along the margin of the reservoirs, commencing at the top of the Balgray reservoir, where an embankment has been thrown across the original stream, to allow of the water being run to waste or passed into the reservoir—the discharge being regulated by two ranges of sluices, each twenty feet wide. This channel also admits of the water from the stream being passed down to the lower reservoirs, where there are arrangements for admitting it; and this is frequently done when the stream is not in flood. The upper reservoirs thus form, and in fact are treated as settling ponds. The new channel is about 1½ miles long and 16 feet broad, and receives the by-washes from the reservoirs. It has a fall of 1 in 500 along the edge of the reservoirs; but in passing from the level of one reservoir to that of another the falls are rapid—in some cases over rock and in others over strong masonry.

The main embankment of the Balgray reservoir is 520 yards long, 47 feet high, and 28 feet wide at top; and the westerly embankment 330 yards long, 25 feet high, and 12 feet broad at top. The embankment of the Ryat Linn reservoir is 176 yards long, 36 feet high, and 14 feet wide at top. That of the Waulkmill Glen reservoir is 200 yards long, 12 feet broad at top, and 60 feet high. All the embankments are formed with slopes of three to one on the front, and two to one on the back, with pitching and puddle walls in the usual way. In no case was there any difficulty in finding a water-tight foundation for the puddle. Fig. 44, Plate IV., is a section of the principal embankment of the Balgray reservoir.

The manner of drawing the water from the reservoirs will be best understood by referring to this drawing. The arrangements at the Balgray and Waulkmill Glen reservoirs are similar. In each case there are two cast-iron pipes through the embankment, twenty-four inches in diameter, and connected at the reservoir side with a large cast-iron upright cylinder, with openings at various heights furnished with sluices; and the whole is encased in a tower of masonry, communicating with the top of the embankments by a foot bridge. Water can thus be drawn from the reservoirs at various levels, and the valves can be removed or repaired in case of accident. In the case of the Ryat Linn reservoir there is no tower; but there are two pipes through the embankment, each seventeen inches diameter—one with a sluice worked along the inside face of the embankment, and the other with a valve on the outside of the embankment.

The conduit from the lowest reservoir to the filters is an arched stone culvert, 4 feet broad by 4 feet high, and 340 yards long. There is a self-acting apparatus where the pipes through the lowest embankment discharge into this conduit, which admits of the flow from the reservoir being regulated by a sluice placed at the filters.

There are two distributing tanks and two sets of filters: each set can be worked while the other is under repair. Each set of filters is divided into three transverse sections, any one of which can be cleaned without stopping the action of the others. The filters are upon the Lancashire principle, the sand being removed when foul, washed, and again replaced. When any filter has ceased to discharge its proper quantity of water, about one inch of sand is removed, and a new filtering surface exposed. The sand is washed, when removed from the filter, by an upward current of water in cast-iron boxes. The area of the filtering surface is 34,000 square feet, or 3,800 square yards; and during the last year the average quantity of water passed through was 3,350,000 gallons a day, or 875 gallons a square yard per twenty-four hours. If the full yield of the stream, or 4,000,000 gallons a day, were passed through, it would be at the rate of 1,045 gallons per square yard a day—equal to a vertical descent of the water of ·15 inch per minute; and the filters have often done as much as this without any difficulty. The question of the velocity of the water in filtration is, however, relative to the quality of the water before passing to the filter. The practice of our best authorities, in dealing with the average qualities of river and stream waters in England, is to pass only 700 gallons a day through one square yard of filtering surface, which is at the rate of one-tenth of an inch of vertical descent per minute. That the Gorbals filters do more, and still produce water that can be seen through in the distributing tanks to a depth of sixteen feet, shows that the water is comparatively pure before filtration. The whole cost of filtration is under £30 per annum per million gallons a day, exclusive of the loss of sand in washing. £15 is found to be a liberal allowance for this loss, making the total cost of filtration £45 per annum per million gallons a day. In comparing the proposed Gorbals extension with the Lake schemes, the cost of filtration, which the latter did not require, was variously estimated from £200 down to £120 per annum per million gallons a day, and this sum capitalized was added to the estimated cost of the works. These estimates may not be more than enough in the case of some waters, but the filtration costs less at the Gorbals.

The two tanks into which the water passes from the filters are each

220 feet long, 66 feet broad, and 19 feet deep. They contain 3,250,000 gallons, and are 240 feet above ordnance datum when full.

The main pipe to the town passes from these tanks, the inlets being furnished with valves and copper wire-cloth strainers. The main is twenty-four inches diameter, but it is not sufficient to discharge the whole water the stream and reservoirs would give, with a sufficient effective pressure in the city. Provision was made when the works were constructed, at the difficult points, for a second twenty-four inch main being laid down.

V. The Loch Katrine Water Works. *Read 25th Nov., 1863.*

On a granite tablet built into a pediment over the entrance to the Loch Katrine aqueduct at the loch there is the following inscription:—

GLASGOW CORPORATION WATER WORKS.

Designed in 1853 and 1854, . . ROBERT STEWART, Lord Provost.
Act of Parliament, 1855,
Works commenced, 1856, } . ANDREW ORR, Lord Provost.
Works completed, 1859, . . . ANDREW GALBRAITH, Lord Provost.

Opened by HER MAJESTY QUEEN VICTORIA, 14th October, 1859.

JOHN FREDERIC BATEMAN, Engineer.

Three successive Lord Provosts had their energies devoted to the forwarding of this undertaking, while many who were interested or took an active part in the scheme in its early progress did not live to see its completion. Five out of seven engineers who were engaged in promoting or opposing the scheme died during the four years the works were in progress.

The system of lochs within the limits of the Loch Katrine Water Works includes Loch Katrine, Loch Achray, Loch Drunkie, and Loch Vennachar. Of these, Loch Achray is not interfered with, while the extent to which the others have been rendered available for the purposes of the works has been already stated.

The works at the outlet of Loch Vennachar consist of a dam of masonry across the mouth of the loch, and a new channel for the river, to enable the water to be drawn down below the old summer level. The new channel is 700 yards long and 50 feet wide. At the lower end is placed the compensation gauge weir, 100 feet wide, formed by a continuous cast-iron plate brought to a thin edge at top. At the upper end of the channel next to the loch there is a range of cast-iron sluices built into a piece of masonry 110 feet long and 15 feet thick, with eleven arched openings for discharging the water. Three of the sluices have a clear width of 4 feet and a height of 4 feet; four are 6 feet wide and 2 feet high; and the remaining four are at the upper end of salmon stairs, formed to allow the fish to get into the loch at its different levels. The salmon stairs are each 6 feet wide between the walls, and have a general inclination of 1 in 12. These sloping channels are formed into a succession of deep pools by planks upon edge placed across the channel, over which the water falls. The height of the planks is varied as the level of the water in the loch changes, so as to keep a depth of from 15 to 20 inches always flowing over. The top of the dam is roofed in, and forms a sluice house for protecting the working gearing. The waste weir of the loch is 150 feet wide, and is a continuation of the masonry of the dam across the top of the new river channel. Raising the level of the loch involved several road diversions, and at the upper end, where the ground is flat, about 150 acres of meadow land, known as Lanrick Mead, are covered when the loch is full. These works cost about £26,000.

The level of Loch Drunkie has been raised twenty-five feet by two earthen embankments, with puddle walls in the usual way, and the area of the loch increased about sixty acres. The northerly embankment is 150 yards long and twenty-one feet high; the other, which is at the original outlet of the loch, is forty yards long and thirty-two feet high. Through this embankment there is a cast-iron pipe twenty-four inches diameter, with a valve at the outer end to regulate the discharge.

The works at the outlet of Loch Katrine are similar to those at Loch Vennachar, but upon a much smaller scale, as the quantity of water to be discharged is less. There are two sluices 4 feet broad and 4 feet high, and two salmon stairs 6 feet wide, in the masonry dam, and a waste weir 100 feet long. It looks a simple piece of work to control 5,500,000,000 gallons of water.

The point at which the aqueduct leaves the loch is about five miles up from the outlet. The basin at the inlet to the aqueduct is fifty-five feet long by forty feet wide inside, with three iron sluices, each 4 feet by 4 feet, for regulating the flow in the aqueduct, and a line of strainers across the middle to keep fish, &c., from passing down. These works are shown by Figs. 1, 2, 3, 4, and 5, Plate II. The basin is a very fine piece of masonry, and, with the cottage and surrounding scenery, forms one of the most interesting parts of the works. It was here, on the 14th of October, 1859, that the inaugural ceremony by Her Majesty was performed.

The loch is surrounded by precipitous hills of considerable elevation, and the first piece of work on the line of aqueduct was to pierce by a tunnel the ridge separating it from the Loch Chon valley. The tunnel is 2,325 yards long, and upwards of 500 feet under the top of the ridge.

To facilitate the driving of the tunnel, twelve vertical shafts were sunk, of an aggregate length of 1,173 yards, or about one-half of the length of the tunnel. Five of the shafts are each about 450 feet deep. This tunnel and others are shown on the longitudinal sections of the aqueduct placed at the top of Plates II., III., and IV.

The following description of the aqueduct near Loch Katrine was given by Mr Bateman at the Banquet after the completion of the works:—"It is impossible to convey to those who have not personally inspected it, an impression of the intricacy of the wild and beautiful district through which the aqueduct passes for the first ten or eleven miles after leaving Loch Katrine. After finding the narrowest point at which the ridge between Loch Katrine and Loch Chon could be pierced, the country consists of successive ridges of the most obdurate rock, separated by deep wild valleys, in which it was very difficult in the first instance to find a way. There were no roads, no houses, no building materials—nothing which would ordinarily be considered essential to the successful completion of a great engineering work for the conveyance of water; but it was a consideration of the geological character of the material which gave all the romantic wildness to the district that at once determined me to adopt that particular mode of construction which has been so successfully carried out. For the first ten miles the rock consists of mica schist and clay slate—close, retentive material, into which no water percolates, and in which consequently few springs are to be found. This rock when quarried was unfit for building purposes: there was no stone of a suitable description to be had at any reasonable cost or distance, no lime for mortar, no clay for puddle, and no roads to convey material. Ordinary surface construction was therefore out of the question; but I saw that if tunnelling were boldly resorted to, there would be no difficulty, beyond the cost and time required in blasting the rocks, in making a perfectly water-tight and all-enduring aqueduct; there would be no water to hamper and delay us in the shafts and tunnels, and little would require transporting through the country but gunpowder and drill iron. This course was therefore determined upon, and my expectations have been realized to the very letter. The aqueduct may be considered as one continuous tunnel. As long as the work continued in the primary geological measures, we had no water; and even after it entered the old red sandstone, and where it subsequently passed through trap rock, there was much less than I expected; so that our progress at no part of the work was very materially interfered with by those incidents which usually render mining operations costly and uncertain."

The rock, however, especially the mica slate, proved extremely hard and difficult to work. At several points along the side of Loch Chon the progress did not exceed three lineal yards in a month at each face, although the work was carried on day and night. The average progress through the mica slate was about five yards in a month. In drilling the holes for blasting, a fresh drill was required for every inch in depth on the average; and about sixty drills were constantly in use at each face. The contractors for the first 7½ miles were at an early date obliged to relinquish their contract, and it was carried on and completed by the commissioners. The cost of the gunpowder alone consumed in this contract was £10,540, and there was about 175 miles of fuse burned in firing it. The average cost per yard of this length of the aqueduct was over £13, or £23,000 per mile. Fig. 11, Plate II., and Figs. 12 to 20 inclusive, Plate III., are cross sections of the aqueduct, showing the general construction in various kinds of ground. The built and tunnelled part is all capable of passing 50,000,000 gallons a day.

The aqueduct bridges over the ravines are, on account of the nature of this district, somewhat peculiar. There are five extensive ones, of the lengths respectively of 124, 154, 212, 147, and 332 yards, all of similar construction. Fig. 8, Plate II., is an elevation of one of these bridges. At the ends of the bridges, or shallowest parts of the ravines, the aqueduct is a cast-iron trough, supported on a solid dry stone embankment of the stone of the district, carefully set by hand, nine feet wide at top, with a batter of three inches to the foot on each side. The deeper parts of the valleys are crossed by malleable-iron tubes, 8 feet wide by 6½ feet high inside, supported by piers at intervals of fifty feet. The bottoms and sides are ⅜-inch thick, and the tops $\frac{7}{16}$-inch thick, strengthened by angle and T iron. Fig. 10, Plate II., shows a section of these tubes. The cast-iron troughs shown in Fig. 9, Plate II., are 8 feet broad and 4 feet deep and ⅝-inch thick, and will pass upwards of 20,000,000 gallons a day. Provision is made for adding 2½ feet to the height of the sides when additional water is required. The bottoms of the malleable-iron tubes are three feet below the bottoms of the troughs. The tubes will pass 50,000,000 gallons a day without alteration. The aqueduct at the crossing of small mountain streams, of which there are a good many, is carried in cast-iron troughs similar to those already described, supported upon cast-iron beams over the space left for the stream; one of these is shown by Figs. 6 and 7, Plate II.

The first valley which intervenes requiring to be crossed by piping is that of the Duchray Water, about fifty-five chains wide. The pipes are four feet diameter in nine feet lengths, with spigot and faucet joints, run up with lead in the usual way. At the lowest point the pipes are under a pressure of 165 feet. The river itself is crossed by cast-iron girders of sixty feet span; and here, as well as at the small basins at each end of the piping, and at other places where masonry was required, provision is made for laying two additional lines of pipes, one four feet and the other three feet in diameter.

After passing through the ridge of old red sandstone conglomerate by the Clashmore tunnel, the aqueduct for five miles is for the greater part in open cutting, with masonry sides and dry rubble arch, covered with two feet of puddle.

The Endrick valley, like that of the Duchray, is crossed by a four-foot syphon pipe 2¼ miles long, and under a pressure in the bottom of the river Endrick, where the pipes are 1⅝ inches thick, of 235 feet. The pipes are carried across small depressions in the valley by resting them upon stone piers, and at the crossing of two roads and of the Forth and Clyde Railway they are further supported by cast-iron brackets. The pipes at these exposed places have flange joints. There is a short tunnel, 110 yards long, on this length of piping, of dimensions sufficient to carry the three lines of pipes.

The construction of the aqueduct for the five miles extending from the valley of the Endrick to the valley of the Blane presents the same general features as those already described. Good building stone was abundant in this district, and the bridges are all of masonry. Fig. 21, Plate III., is an elevation of one of the aqueduct bridges near Killearn, at nineteen miles from Loch Katrine; and Figs. 22, 23, 24, 25, and 26, are details of the Ballewan Aqueduct bridge. Figs. 27, 28, 29, 30, show the manner in which small streams were carried under this portion of the aqueduct.

The piping across the Blane is about fifty-four chains long, with a depression of 125 feet. The Blane Water itself is crossed by a stone bridge, and there are basins at each end of the pipes, as before.

The last piece of the aqueduct is a tunnel 2,640 yards long through a ridge of amygdaloidal trap separating the valley of the Blane from the valley of the Allander. The tunnel is 250 feet below the summit of the hill.

Mr Bateman has summarized the works along the line of aqueduct in nearly the following words:—"There are in the whole work eighty distinct tunnels, upon which forty-four vertical shafts have been sunk for facilitating and expediting the completion of the work." Besides the two tunnels specially described above, there are "others, 700, 800, 1100 and 1400 yards in length. Not to speak of smaller constructions, there are twenty-five important iron and masonry aqueducts over rivers and ravines, some 60 and 80 feet in height, with arches of 30 feet, 50 feet, and 90 feet in span. The number of people employed, exclusive of iron founders and mechanics, has generally been about 3,000; and for the greater part of these, huts and roads, and all other accommodation, had to be provided, the country for the most part being of the wildest and most inaccessible description." . . . "At the picturesque 'turf and timber' village of Sebastopol, as the miners called it, at the head of Loch Chon, several hundreds of work people were accommodated. Provision stores, reading rooms, a school house and church, and a resident medical man and schoolmaster were provided for them."

The aqueduct, from its commencement at Loch Katrine to the Mugdock reservoir, is 25¾ miles long—13 of which were tunnelled, 3¾ miles are iron piping across valleys, and the remaining 9 miles are open cutting and bridges. Where the ground was cut open the surface was restored after the aqueduct was built. At the bridges the aqueduct is covered with timber, to prevent its being choked by snow. The most of them are furnished with grooves in the masonry to receive stop planks, and with discharge sluices to facilitate the emptying of the aqueduct when it is necessary to inspect or make repairs. Overflows are constructed at a number of the bridges to discharge the water, if it should be necessary to stop the flow suddenly at any point.

The total cost of the aqueduct was £468,000, or an average of £18,000 per mile.

It has been already stated that the four-foot pipes across the valleys on the line of aqueduct were intended to deliver 20,000,000 gallons a day. By the well-known modification of Eytelwein's formula, deduced from Du Buât's experiments and more elaborate formulæ, the computed discharge is 21,500,000 gallons a day nearly, and by Weisbach's formulæ 21,750,000 gallons a day. These pipes have, however, discharged 24,000,000 gallons a day without their being completely gorged, and their ultimate discharge has therefore yet to be determined. The whole of the pipes used in the works were coated with coal pitch and oil, according to the process patented by Dr R. A. Smith, of Manchester, and first used by Mr Bateman in the Manchester Water Works. This coating, when well done, imparts a smooth glassy surface to the pipes, and prevents, at least for a number of years, the usual and, it may be said, inevitable oxidation. Weisbach found that for wooden pipes 2½ and 4½ inches diameter, the co-efficient of resistance was 1·75 times as great as for "metallic pipes" giving a discharge about fourteen per cent. less; and M. Morin has shown, in a paper which it is believed is published in detail in the *Mémoires des Savants Etrangers*, the influence the state of the surface has upon the discharge of a pipe, amounting, in the case of cast-iron pipes coated with pitch, and of glass pipes, to an increase of nearly one-third in the discharge.

It has also been pointed out by M. Morin, whose deductions are principally from observations by M. Darcy, director of the water works of Paris, that for large sizes the diameters of the pipes seem also to exercise a more decided influence on the discharge than has been hitherto assigned to them. The observations of Du Buât, upon which Prony and Eytelwein based their formulæ, were with pipes nineteen inches diameter and under, while the pipes used by Weisbach did not exceed 5½ inches diameter. Late observations on the flow of gas through pipes by M. Arson, engineer of the Paris Gas Company, tend to confirm the views of M. Morin.

At the Mugdock reservoir the water is first discharged into a basin, from which it passes over cast iron gauge plates, forty feet wide, brought to a thin edge. The depth of water passing over these plates is regularly recorded, and the discharge computed. Fig. 31, Plate IV., is a plan, and Figs. 32 to 36 inclusive, details of the gauge basin. From the basin the water falls into an upper division of the main reservoir, about two acres in extent, and from this it is discharged into the reservoir. The reservoir has a water surface of sixty acres, and a depth, when full, of fifty feet, contains 548,000,000 gallons, and is 317 feet above ordnance datum. It admits of repairs being made upon the aqueduct without interrupting the supply of water to the city, and contains about thirty-two days' supply at the rate at which the city is at present drawing. Two earthen embankments were necessary to form the reservoir; the main embankment is 400 yards long and 68 feet high, and the easterly embankment 240 yards long and 50 feet high; each with a puddle wall in the centre and pitching on the front slope, in the usual way. Fig. 37, Plate IV., is a cross-section of the first-mentioned of these embankments.

The water is drawn from the reservoir by pipes laid in a tunnel through the hill between the two embankments, there being no pipes through the embankments themselves. At the end next the reservoir there is a stand pipe, so arranged that water can be drawn at various heights, and about 50 yards from the reservoir the water passes into a circular well cut out of the rock, forty feet diameter and sixty-three feet deep, and is strained by passing through copper wire-cloth forty meshes to the inch, arranged in oak frames, forming an inner well of octagonal shape, twenty-five feet diameter, and from this latter the water finally passes into the two lines of pipes leading to the city. Water can also be drawn direct from the gauge basin, and from the upper compartment of the reservoir into the straining well by a line of four-foot pipes through the bottom of the reservoir. These works, including road and stream diversions, cost about £56,000.

The two pipes leading from the straining well are each forty-two inches diameter, and are intended to deliver the whole 50,000,000 gallons a day; but on emerging from the tunnel, which is 440 yards long, they are diminished to thirty-six inches, and they are continued of this size to the city. The two lines of pipes are laid side by side for about three miles, after which they diverge—one line being carried by the Great Western Road, for the supply of the low districts of the city, and the other by Maryhill, for the supply of the high districts. These pipes come together again, and are arranged so as to communicate, when necessary, at St. George's Road, up to which point their respective lengths from the straining well are 7 miles for the low district main, and 6½ miles for the high. Each of these lines of pipes crosses the river Kelvin and the Forth and Clyde Canal, and at these places provision is made for additional pipes. Eleven feet were added to the width of the Kelvin Bridge on the Great Western Road, by cast-iron girders, to carry the low district mains. The two middle spans are each ninety-three feet, and the two side arches thirty-seven feet span.

The total cost of the works was as follows:—

Works at the Lochs,	£36,000	
Aqueduct, 25¾ miles long,	468,000	
Mugdock reservoir,	56,000	
Main pipes, 36 inches diameter,	123,000	
Distribution in the City,	78,000	
Total for Works,		£761,000
Land and Compensation,	£70,000	
Parliamentary expenses, engineering, and sundries,	87,000	
		157,000
Total,		£918,000

VI.—The Distribution in the City. *Read 16th March, 1864.*

It was stated in a previous part that one of the 36-inch mains from Mugdock reservoir to Glasgow supplied the low district, and the other the high districts of the city. The low district main is brought in by the Great Western Road, and supplies the West End of the city as far as St. George's Road; east of this point the supply is restricted to the district lying below a contour line 50 feet above high water. There are two junctions between this main and the Gorbals pipes; and by these the supply from the Gorbals Works is supplemented, as the 24-inch main pipe from these works is not now sufficient to supply the large population upon the south side of the river. The high district main supplies the whole of the city east of St. George's Road, and above the 50 feet contour. The quantity of water intended to be ultimately discharged by the low district main will produce a loss of head of 19 feet a mile; but it will retain, during the time of greatest drought, an effective pressure of 116 feet where it enters the district of distribution. The high district main is intended ultimately to lose head at the rate of 12 feet a mile, and will retain an effective pressure on the top of Garnet Hill, when the velocity of the water in the pipe is greatest, of 52 feet. A few isolated outlying districts, including Garngad Hill and Springburn, require cisterns to secure a supply during certain hours of the day; but, with these exceptions, the supply is constant at high pressure. When the loss of head in the mains, arising from an increased consumption in the city, exceeds the amounts above stated, and reduces the effective pressure below what is necessary or desirable, additional mains will require to be laid from Mugdock.

To diminish the extent of the districts affected by any accident to the pipes, two junctions are formed between the high and the low district mains—one near Cannisburn Toll, about 3 miles from Mugdock, and another at Clarendon Place, St. George's Road. There are other junctions between the principal branch mains in the city, and in this way each district can be supplied in more than one direction.

At the Mugdock reservoir, self-acting closing valves, intended to shut off the water on the occasion of a pipe bursting, are attached to each line of pipes; and stop valves are fixed at intervals along the line of mains both in the country and city. On the side next the reservoir, at each stop valve, there is a momentum valve, designed to prevent concussion in the pipes by the too sudden closing of the stop valves. On the top of each rising ground there is an air valve, and in the bottom of every hollow a cock for flushing out the pipes, and for emptying them when repairs are to be made. Manholes are placed at intervals along the lines of the large mains, and close to all the large valves, to afford admission to the inside of the pipes for inspection, and to make repairs.

The self-acting closing valves were designed for the purpose of immediately shutting off the water in the event of a burst pipe, without relying upon the watchfulness of the men in charge. The arrangement was suggested by Sir William G. Armstrong, of Newcastle, and was first introduced by Mr Bateman in the Manchester Water Works. It was subsequently introduced in the Liverpool Water Works. The valve is of the character of a large "throttle valve" fixed across the pipe, and in its normal position presents little obstruction to the flow of the water. It is held in its position by a disc, which projects into the pipe, and is fixed at the end of a long lever or pendulum, being prevented from yielding to the pressure of the water acting against it by reason of its velocity, by counterbalance weights, adjusted to resist the ordinary or any fixed velocity. If a burst upon the main, or any other accident, produces a velocity in excess of this, the disc yields to the increased pressure, and lets loose a catch, which allows a heavy weight attached to the axis of the large throttle valve to close the valve. A simple mechanical arrangement is introduced for preventing it from closing too rapidly, whereby the mass of water in motion would be too suddenly arrested; and the same contrivance is, by means of a small force pump, made available for re-adjusting it in its horizontal position. Upon several occasions when the mains were first subjected to the pressure from the reservoir, and upon one or two occasions lately, these valves acted under the circumstances under which they were designed to act, and were the means of preventing considerable loss and damage. Upon two occasions, and before the machines, which are delicate in their action, were properly adjusted, they gave false alarms.

The great difficulty to be overcome in opening or shutting a large stop valve under any considerable pressure is the power required to move it. The pressure exerted by a column of water of 100 lbs. on the square inch against a slide valve 36 inches in diameter, is 45 tons; and to overcome the friction of the ordinary brass facings, by the usual appliances of screw and lever under this pressure, with a moderate number of men, is practically impossible. In designing the Manchester Water Works, Mr Bateman resolved to overcome this difficulty, and open competition was invited for a large valve that could be opened and shut by one man. Sir Wm. G. Armstrong's idea was adopted of dividing the valve into compartments, one of them being reduced in area so as to be equivalent to a small valve, and easily opened by one man. The smaller division is the first opened, and the passage of the water through this opening so much reduces the pressure upon the slide of the larger compartment that it also can be opened with ease. In shutting, the small slide is the last closed. This arrangement was adopted by Mr Hawksley in the Liverpool Water Works; but from the great size of the valve when the opening was made, the full diameter of the pipe, and the difficulty of fixing them in the streets, the total opening in the valve was reduced so as to require one foot of head to pass the same quantity of water through the valve as the pipe was intended to deliver. This modification has to some extent been introduced in the stop valves used in the Glasgow Water Works; and all valves above 16 inches in diameter are of this construction. Figs. 42 and 43, Plate IV., show the general arrangement of one of these valves for a 36-inch pipe. The clear water way is 4½ square feet, against 7 square feet, the area of the pipe, the smaller slide having an area of 1 square foot, and the larger 3½ square feet. To pass this contraction with a velocity of 4·4 feet a second in the pipe, which is the velocity the water in the high district main will have, when the loss of head amounts to 12 feet a mile, the velocity is increased to 6¾ feet a second in passing the valve. According to Weisbach, and considering the contracted area to be of the nature of a diaphragm, the head absorbed in passing would be about 5 inches; but as the approaches are curved, the actual loss is probably less than 3 inches. In the case of the low district main, where the velocity of the water is greater, the loss of head will be 1 or 2 inches more. There is not a more important item in the whole economy of a large work for the supply of water than the stop valves; and to have a machine certain in its action, and of good workmanship, is of the first importance to those engaged in the management of the distribution. The Armstrong valves have given the greatest satisfaction in the Glasgow Water Works; and they must be looked upon as one of the greatest improvements lately introduced in the distribution of water under pressure. The only alteration upon them that the experience in Glasgow has suggested, is still further to reduce the area of the small slide, both for the purpose of giving increased power in opening and closing, and to obviate concussion due to rapidly stopping the flow in the pipe when shutting the valve.

The momentum valves placed in front of the self-acting and large stop valves are designed to prevent concussion in the pipe by the sudden closing of the valve. In the stop valves this is effected partly by the construction of the valve itself, which cannot be shut quickly; but in the large pipes it was thought proper still further to diminish risk of accident from this cause. They are simply safety valves constructed upon the principle of the equilibrium or double-beat Cornish valve, and are so adjusted and weighted that they open and discharge a little water when the pressure exceeds that to which they have been adjusted. Figs. 38, 39, 40, 41, Plate IV., show the construction of these valves.

In arranging piping on a large scale, it is of great importance to provide for the free and rapid escape of the air from the pipes when they are being filled with water, and for the subsequent discharge of that which accumulates on the summits, from being disengaged from the water in the ordinary working. An air valve which allows of air being discharged under both the above circumstances, and which is self-acting, was designed during the progress of the Manchester Water Works. It is the same in principle as Bateman and Moore's fire cock. In the Glasgow Works they have been placed on the summits on all pipes down to those of 6 inches diameter.

At the junction of the two great mains from Mugdock at St. George's Road, pressure gauges are attached to the pipes, and a record of the indications kept night and day. These gauges not only afford valuable information of the available pressure at all times on the mains, but they also indicate with unerring accuracy when any accident has occurred to any of the leading mains either in the city or between the city and the reservoir, and thus admit of action being taken sooner than could be done under any other arrangement.

In a city increasing so rapidly as Glasgow it was necessary to provide for great alterations in those districts which are at present only partly built upon. The districts to be permanently supplied by the two mains at present laid down were restricted to the more densely built parts of the city, and the suburbs were left to be provided for by future mains, in the manner in which their development might indicate. The sizes of the distributing pipes were arranged with reference to the number of families any given district or street would probably ultimately contain; but in the centre of the city, and in those localities occupied by warehouses and factories, and in which fires are frequent, the sizes were fixed more with reference to the demand for water during fires than to the quantity consumed for domestic or trade purposes. The distributing pipes branching from one main have been interlaced with those branching from another, so that any fire can easily be reached from the fire cocks attached to both mains; and in the event of accident to either main, there would still be water in half the fire cocks in the district.

The pipes of the Glasgow Water Company were retained and incorporated in the new arrangement where the sizes would suit; but from the mains lying with the wide end to the east, while the new supply entered from the west, and from the greater part being old, and many of the branch pipes too small and much corroded, the cost of the re-arrangement was very great. Further complications arose from the pipes of the old Cranstonhill Company having been connected to those of the Glasgow Company; from the Glasgow Company having at one time a separate system of pipes for the supply of unfiltered water; and from the extensions of the piping to keep pace with the demand for water not having been executed after any fixed plan, but with reference only to economy, or the exigency of the moment. Four and five lines of pipes in a street were common, and some streets had more than this number, while the stop valves were of very imperfect construction. The pipes were connected and interlaced in a most confused manner, and after no regular system; and only a few of the workmen connected with the establishment were aware of their various ramifications. All this has been altered and simplified, and those not wanted have been lifted. Every pipe has a stop valve where it leaves the distributing main, and a cleansing cock at the further end. Large pipes only are connected, and these connections are opened during repairs only.

The pipes which were laid down by the Gorbals Company in 1847 did not require any alteration. They had all turned and bored joints up to 9 inches diameter; and this joint, with a space for lead in the event of the joint proving defective, was extended to 12-inch pipes in the piping connected with the Loch Katrine Works; and lately pipes of 15 inches diameter with this joint have been put down with the most satisfactory result.

There are 2,700 fire cocks in the city, placed at intervals of 40 yards in the more densely built parts of the city, increased to 60 yards in the suburbs. They are upon the principle of the common ground cock, with the water admitted to the inside of the key, which is hollow. Previous to the introduction of the Loch Katrine water there were only 570 fire cocks in the city, mostly of objectionable construction; and as the pressure on the mains was never very great, fire engines were indispensable, while most of the water had to be carted to the engines, causing great confusion in the adjoining streets during a fire. All this has been altered: the fire engines are now seldom used, the pressure from the mains being sufficient to reach the highest houses; and the carting of water is entirely discontinued, and a considerable annual saving is the result.

In addition to these, there are 1,200 of Bateman and Moore's fire cocks, which are applied as cleansing cocks and air valves. They are available in cases of fire, as well as the cocks above mentioned, and are extremely useful in discharging the air in filling the pipes. In Manchester and many other towns these cocks are used exclusively as fire cocks, with the best results.

The water meter is another very important and useful instrument connected with the distribution of water. Those used in Glasgow are Kennedy's patent, which is a piston meter, constructed on the principle of measurement by capacity. There are about 500 of them in use here, and the revenue derived from the sale of water to manufacturers and others is £15,000 per annum. It has risen £6,000 a year during the last three years, and is still increasing. The importance of having a thoroughly good machine for the measurement of water under pressure cannot be over-estimated. Fifteen years ago such an instrument was not known, but a competition invited by the Gorbals Company, in 1848, was the means of bringing out several.

In 1838 the consumption of water per head in Glasgow, over the whole population, was 26 gallons. In 1845 it had increased to 30 gallons a head. In 1852 it was 35 gallons a head on the north side of the river, supplied from the Glasgow Works, and 38 on the Gorbals side. When the Loch Katrine scheme was designed in 1853-54, 40 gallons a head was adopted as a liberal allowance, and one thought to be in excess of all future requirements; but it has now reached 42½ gallons a head per day. The quantity of water sent into the city during the first six months of this year was on an average 16,900,000 gallons a day from the Loch Katrine Works, and 3,300,000 gallons a day from the Gorbals Works—in all, 20,200,000 gallons a day, which has been supplied to a population of about 476,000 persons. Of this quantity 1,639,000 gallons a day have been sold by meter for trade puposes, equal to 3·4 gallons per head—leaving 39 gallons a head as the net consumption for domestic and other purposes. The quantity of water used in the manufacturing towns of Lancashire is about 20 gallons a head a day for all purposes. In Manchester, with a population nearly the same as Glasgow, it is 22 gallons a head, and the quantity sold for trade purposes is from 5 to 8 gallons a head. In Sunderland, with a population of 130,000, it is 15 gallons a head, of which 3 goes to manufacturers. In Nottingham it is 17 or 18 gallons a head, of which 5 or 6 are sold for trade purposes. The great excess of the consumption of water in Glasgow is due, in great measure, to waste from imperfect water fittings. Some allowance should probably be made for the difference in the circumstances of the distribution in Glasgow as compared with the towns above mentioned, but there is still a large quantity, probably 15 gallons a head, which runs to waste without benefiting any one, and which, if saved, would soon materially reduce the water assessment.

Twenty-five years ago the gross revenue of the two Water Companies was a little less than £25,000 per annum, while now the annual revenue of the Water Commission is £90,000. So rapidly have the population and manufactures of the city increased that the Commissioners have, since 1856, been enabled to expend nearly a million in executing the new water works, and at the same time to pay the large annuities guaranteed to the Water Companies, without adding materially to the amount of the water rate. It appears certain that a few years of similar prosperity will enable the Commissioners to reduce the rates even below the amounts levied by the old Water Companies.

This paper was illustrated by specimens of the rocks traversed by the aqueduct, and by photographs of the principal works. In the discussion which took place on 25th November, 1863 :—

Dr Macquorn Rankine said he knew personally much of the history of the water supply schemes for Glasgow, and he was struck with the accuracy and fairness of Mr Gale's statements. He had one thing to add about the revival of the Loch Katrine scheme in 1852. Mr Gale had only mentioned the letters that were published by Mr

Thomson and himself (Dr Rankine) recommending the project; but he thought it would be well to add that the scheme then went the length of the formation of a provisional committee, composed of gentlemen of high standing, that it was brought before the community in the way joint stock companies usually are, and that it only fell to the ground because of the Town Council resolving to take the water supply into their own hands. But for that resolution, the promoters of this scheme would have gone to Parliament in the following session. Mr Thomson and himself, when they revived the Loch Katrine project, had received much information respecting it from Messrs Gordon and Hill, and the merit of originating the scheme was due to those gentlemen, although Mr Thomson and himself had tried to improve their plan in its details; but Messrs Gordon and Hill were specially to be remembered for their having discovered that there was a point in the ridge between Loch Katrine and the valley of Loch Ard where a tunnel could be driven through the hill. That was, he thought, the great original discovery which showed the Loch Katrine Water Works to be a practicable scheme. From what he had heard, he believed it had suggested itself to them in the following manner:—They had been looking out for a water supply amongst the tributaries of the Forth, and going by Loch Ard they visited Loch Chon. They found that its elevation was not sufficient, and it seems that they were looking northwards, when one said to the other, "Loch Katrine lies on the other side of that hill; it may be possible to bring it through with a tunnel." They mounted to the top of the ridge, and then came to the conclusion that the tunnel was practicable; and so it was that the Loch Katrine scheme originated.

Mr Walter Neilson drew attention to the beautiful and interesting photographic views of the water works exhibited; and suggested that the President should apply to the Water Commissioners for copies of them for the library of the Institution.

In the discussion which took place on 23rd December, 1863:—

Mr W. Johnstone said they were very much indebted to Mr Gale for having brought that very important subject before them; and while great credit was due to Mr Gale for doing so, and to Mr Bateman, who was the architect and engineer of this great work, yet they should not overlook the labours of the late Mr William Gale, in connection with the water supply of Glasgow, as of great importance. He was a very intimate and old acquaintance of his own, and he knew that Mr Gale looked upon the Gorbals scheme with great pride, having spent many anxious days upon it, and being earnestly desirous of seeing the water brought from that source. He was very glad to know that all the late

Mr Gale's predictions with reference to the supply from the Gorbals Works, of which he was engineer, had turned out to be quite correct, both as regarded the purity and quantity; and he thought it was due to his memory for them to record their high esteem for his labours, in bringing such an excellent supply of water into this city.

Mr Walter Macfarlane said the subject which Mr Gale had so ably brought before them commended itself to them all. There was one part of that undertaking that he would like to call attention to—namely, the large wrought-iron tubes that crossed the mountain rivulets. Mr Gale described them in his paper thus:—"The deeper parts of the valleys are crossed by malleable-iron tubes, 8 feet wide by $6\frac{1}{2}$ feet high inside, supported by piers at intervals of 50 feet. The bottoms and sides are $\frac{3}{8}$-inch thick, and the tops $\frac{7}{16}$-inch thick, strengthened by angle and T iron." The Loch Katrine scheme was one he had taken a deep interest in from the commencement; and in the autumn of 1861 he had laid out a short excursion for himself, in order to examine the works. Beginning at Loch Katrine, he went along the line of operations to Balfron, examining their construction and extent. Those wrought-iron tubes appeared to his mind defective, when he considered that they were 8 feet wide by $6\frac{1}{2}$ feet high, and only $\frac{3}{8}$-inch thick, and made of wrought-iron. No doubt they were sufficiently strong as conduits, but there was not sufficient allowance made for the tear and wear of future years. Works of that kind were of a permanent nature—not, like railways, subject to derangement through alteration of plans: they were intended to last for centuries. That thickness of wrought-iron would soon decay through the continued moisture of the atmosphere acting on the joints and rivets. He was of opinion that wrought-iron was not a suitable material for such purposes, and that cast-iron ought to have been adopted for its more lasting properties. He called attention to this matter, because the Loch Katrine Water scheme would be an example for similar undertakings. At the same time he desired to bear testimony to the admirable manner in which the works had otherwise been conceived and executed.

Mr Alexander Smith remarked that the tubes referred to by Mr Macfarlane carried out two purposes—namely, that of suspension, as well as forming a mere channel to convey the water. No engineer would adopt cast-iron for suspension in such a case as that, where the distance between the piers was fifty feet. He had no doubt from the strength of the tube that, with the ordinary means of preserving it, it would last a very long time indeed. He had had an opportunity of examining the works minutely, and he believed the strength of the tubes was very considerably beyond the strain that they required to bear. For shortlengths, if supported every few feet on girders, he had no doubt that cast-iron would answer; but he thought that the engineering practice of the present day, particularly as regarded the use of wrought-iron in suspension, would bear out Mr Bateman in the plan he had adopted for carrying out this work.

The PRESIDENT asked how the tubes were preserved?

Mr GALE said they were painted before being put up—with oil first, and then with common paint of a slate colour. They were of very easy access to repaint. The tubes could not be compared with steam boilers, which were continually contracting and expanding; for here the temperature was very equable. As yet there was no decay going on, as they kept painting the iron during the summer time; and they stopped the flow of the water every three months, to examine both the wrought-iron tubes and the cast-iron troughs. The great difficulty of transit of heavy girders in that country was a principal reason in deciding Mr Bateman to make those tubes of malleable-iron. The bridge over the valley of the Duchray was of cast-iron girders; one girder was broken in transit, and whilst there were but two in the bridge altogether, one was cracked. The difficulty of conveying heavy castings there was very great.

Mr D. M'CALL asked if there were any objections to cast-iron arches for supporting conduits across valleys. They could be cast in ten-feet segments, or other convenient lengths for carriage, and fixed together on the spot. He meant cast-iron arches like those crossing the Kelvin at the Great Western Road. Railway works were subject to considerable shocks from passing trains, whereas water was a weight which gave an equable strain. He thought, therefore, that cast-iron was better for water conveyance, and more easily maintained than wrought-iron.

Mr ALEXANDER SMITH said that Mr Fairbairn proved that wrought-iron for sustaining a dead load was much superior and cheaper than cast-iron; and the bridge that Mr Fairbairn and Mr Stephenson put over the Menai Straits was built after the most careful experiments that had ever been made, and the result been recorded in a way that had been valuable to engineers ever since.

Mr D. M'CALL replied that the Menai Bridge was of an extraordinary span, and could not be well accomplished with cast-iron.

The PRESIDENT believed the difficulty of transit was one of the chief reasons for Mr Bateman adopting malleable instead of cast-iron. He agreed with Mr Macfarlane that the atmosphere had a great effect on malleable-iron; but, from the ready access they had to those tubes, this objection was greatly reduced. He was glad to find that the pitch coating of Dr Angus Smith, which was employed for preserving the cast-iron from oxidation, had been found to so materially reduce the friction. He expected similar results from the pitch coatings which were now often applied to iron ships.

Mr DOWNIE asked whether, when they came to clean those troughs they found much deposit in the interior of the tubes? and whether, in the removal of that deposit, they removed any oxide or scale?

Mr GALE answered that in the bottoms of the malleable-iron tubes a slight deposit of very fine sand was found. That arose in consequence of the malleable-iron tube bottom being slightly below that of the cast-iron troughs. Last summer they found, when painting, that some of the paint had worn off, but it had not gone the length of forming a scale so as to injure the iron. It would have to be looked to carefully, however.

Mr DOWNIE thought it was very important that so much facility existed for repairing or renewing parts of such works. He believed Mr Bateman had very carefully considered every point when designing the works, and he had no doubt he would have the very best reason for the adoption of malleable-iron in these tubes; and Mr Gale had indicated one very good reason for it. The tubes were all built on the spot. The iron plates, &c., composing the structure, were oiled with boiled linseed oil after having been heated, and then painted, so that every precaution was taken to preserve them. After they were erected they were all carefully gone over and thoroughly painted when in position. Had Mr Bateman desired it, he could have made them of cast-iron; but that would have been done at probably three or four times the cost of the malleable-iron, which he did not seem to think he was justified in expending, especially when he knew that they might be replaced at any future time. The deterioration going on was extremely trifling; and, should it ever be required, he had no doubt the resources of Glasgow would enable that whole aqueduct to be renewed in a week. No doubt cast-iron pipes laid on girders, as suggested, and coated like those tubes, would last for a very much longer time—they would be almost indestructible; but then the matter of cost stepped in again. It might be well if Mr Gale informed them whether there was any oxidation going on in the cast-iron troughs, and whether the difference in that respect was great between the cast and the wrought-iron.

Mr GALE said the sides of the cast-iron troughs showed no oxidation, but the bottoms were all corroded. That was attributed to the fact that the iron rust used in making the joints was carried along by the men's feet and trodden over the plates.

Mr MACFARLANE could not entertain the idea that a work of that importance ought to depend upon a yearly painting; for, if so, it was entirely useless. No protection they could put on the iron would stand. A single coat of paint, which must necessarily be put on when the tubes were damp, and was not allowed thoroughly to dry before a stream of water was let in, would certainly be ineffectual in preventing oxidation. If they could give wrought-iron work three coats of paint, and allow a reasonable time for drying between each, it might do some good. But that great work must not depend upon paint, or it would soon get into shreds and patches. Mr Smith had dwelt upon the necessity of wrought-iron being used for suspending, but his remarks bore upon the lasting properties of the materials only.

Mr DOWNIE believed the whole matter resolved itself into a money question; for undoubtedly the first cost of a tube of equal area and its supporting framework in cast-iron would have been very much greater than to renew a part of the wrought-iron tube occasionally. The present tubes might last fifty years or so, and who knew but they might require an extra tube ere then. Cast-iron would cost more for such a purpose, because they would not only require the mere material of the tube for the quantity of water required to be passed, but there must also be a structure to carry it. In any case, it would be desirable to have a substructure distinct and separate from the superstructure itself. He thought it was very much a money question.

Mr WM. JOHNSTONE said he quite agreed with Mr Downie that this was a money question. Mr Macfarlane had said that railway works had to be renewed, and that water works ought to be constructed in a more permanent manner; but he did not himself see any more difficulty in renewing such works than in renewing a railway bridge, which very often had to be rebuilt from the foundation up to the level of the rails. He thought it was a mere question of cost—whether it was cheaper to erect a tube of that sort of cast-iron, with girders to support it, or of malleable-iron, to be renewed every ten, twelve, or fifteen years?

Mr DOWNIE said the subject of coating the pipes was a very interesting one. Mr Gale had mentioned that 24,000,000 gallons per day had passed through the 4 feet mains. That he believed was rather in excess of the calculated quantity. He would like to know from Mr Gale whether this would cause an alteration of the formulæ, and whether it was due to the coating alone?

Mr GALE replied that the formulæ they worked upon had been deduced from a very large number of experiments, but not with pipes so large as 4 feet. But the formulæ had been also deduced from experiments with pipes in a normal state, as they came from the foundry, and previously to being coated or corroded. It was only lately found that the coating had any effect upon the discharge of water through the pipes. That had been ascertained by M. Darcy, the director of the Paris Water Works, and his experiments formed the subject of a very elaborate paper, drawn up by General Morin, and read before the Institute in Paris, which showed distinctly that the surface of the pipes had a great influence on the discharge of water. In the paper, General Morin stated that cast-iron pipes coated with pitch, and glass pipes, gave an increased discharge of about one-third. Possibly those experiments were not sufficiently extended; for it did not appear that the Glasgow Water Works' mains would deliver one-third more than the formulæ gave. The coating was a preventative of rust for ten, twelve, or fifteen years. He had, however, been recently in some of the pipes under ground, and found indications that the coating was beginning to give way; and he had no doubt that, before the malleable-iron tubes required renewal, the cast-iron syphon pipes over the valleys would be spotted so as to pass no more water than if never coated; and therefore it was just as well not to refine too minutely on the formulæ, in the case of large works intended to last a good many years.

Mr ALEXANDER SMITH thought Mr Bateman stated at a meeting in Glasgow, soon after the completion of the works, that the capacity of the 4-feet pipes had never been tried before, and he gave it as his opinion that such pipes would discharge more than the formulæ had allowed for them hitherto, reasoning in this way in consequence of the immense amount of water passing through, and the little friction. He thought Mr Bateman was quite right, for in a 4-feet pipe there would only be a half of the friction of a 2-feet pipe. He believed that the coating was most effective, and that the larger the pipe the formulæ would be the more deficient, from the fact that the larger the pipe the less friction would there be in comparison to the quantity of water passed through.

Mr GALE said that the difference due to increased diameter was taken account of in the ordinary formulæ. It was observed by General Morin that this influence was not sufficiently taken account of, but he believed the influence of the increased diameter in these 4-feet pipes was much less than that which was due to the coating.

In answer to Mr Downie, Mr GALE said he did not know whether the pipes would ever pass 30,000,000 gallons per day, and it was unnecessary to speculate upon the subject, as next year he expected to be able to tell the Institution exactly how much they would pass, as they were about to raise the sides of the cast-iron troughs.

The PRESIDENT remarked that a pipe which would remain permanently smooth—which would continue to have the reduced friction for ever—would be very desirable. Coppered ships were said by Mr Scott Russell to have less friction than iron ones. Their surface was smoother.

Mr MACFARLANE said that all coating of a mechanical kind, if it did not enter into chemical combination with the iron, would have but a temporary result.

The PRESIDENT said that some metallic coatings, such as lead paint, were said to often increase the evil they were intended to prevent, owing to the decomposition of the paint allowing the metallic lead to act galvanically on the iron.

In answer to questions by Mr Downie, Mr GALE described the filters which were at first used at the Gorbals Works. He said the water passed through three compartments of the filter, one after the other. The first compartment contained broken freestone, the second gravel, and the third sand. In order to clean the sand, it was intended to force a current of water up through the filtering material. That was found to be impracticable, as they could not get a sufficient current; and the filters could not be cleansed except by taking the whole of the stuff out. The filters were altered by Mr Mackain when the works passed into the hands of the City Corporation. The sand of the filter was worked down to eighteen inches, and the whole was washed in boxes by an upward current of water, and replaced on the filter. The sand that was used at the Gorbals Works was first got from the Big Cumbrae, latterly it was obtained from Corrie Bay and Brodick Bay, Arran. The sand should not be too fine, or the filter would be a very expensive one. With very pure water there was no necessity for fine sand. The sand used in the Gorbals Works was fine enough, for uniformly they could see through sixteen feet of water to the bottom. The sand got from Arran was disintegrated quartz. It was found, with the Lancashire filter, that it worked well with from 3 inches up to 4 feet of pressure. Mr Gale then drew on the board and explained the self-acting supply regulator for the filter. A sluice of that kind had been first set up at Greenock, and was now working well there. The straining well at Mugdock was not meant to be a filter, but merely to keep out sticks, straws, or fishes from the water mains. He did not think that the water was clearer or purer after than before passing through the strainer.

In the discussion which followed the reading of the paper on the 16th March, and in reply to questions, Mr GALE said that the stop valves were not patented by Sir W. G. Armstrong. There was no provision made to clean the pipes inside; but up to this time they had been protected from the action of the water by being coated with Dr Angus Smith's composition. They were, however, beginning to show signs of oxidation. The increased velocity of the water passing through the pipes, at which the throttle valve would close, was a little over four and a half feet per second. The water might flow unimpeded at that rate, but a very slight increase closed it.

Mr DOWNIE admired the excellent provision made in the self-acting and stop valves for slow closing; but it occurred to him that they might be simplified a little. The peculiarity of contracting the area was not quite approved of by all engineers. They rather liked to have the full area, though they should have a larger valve to lift. He would like to know if Mr Gale would not prefer to have a less proportion of area in the smaller division of the stop valves than in the one described?

Mr GALE thought no one could refuse to admit that this was an excellent valve, notwithstanding the actual loss of head that occurred in passing through it. This loss was but small, and the saving of time in closing and in cost and convenience was considerable. He thought, however, that the smaller slide might be properly reduced to one-half of the present area.

In answer to Mr Downie, Mr GALE said that there were air valves upon every summit, and he could not see why an air valve was needed at the stop valve, seeing no air could lodge there. The scouring valves were from 6 to 12 inches in diameter.

Mr J. G. LAWRIE remarked that hitherto engineers had a great reluctance to use double-beat valves for safety valves, like those adopted for the momentum valves, and he would like to know whether there was not considerable difficulty experienced in keeping them in order. They were now discarded for safety steam valves Did they not find the frictional resistance of the stuffing box very uncertain?

Mr GALE replied that he had found no difficulty with them. They had no stuffing boxes, but simply a cup leather on the lower valve disc, the water escaping only at the other disc.

The CHAIRMAN referred to Mr Gale having mentioned the failure of Dr Angus Smith's composition for coating pipes: he would like to know what would be the durability of those pipes, and what other coating Mr Gale would use for similar work?

Mr GALE thought it could not be said to be a failure. It certainly showed signs of giving way in some instances, but still he would strongly urge its use, as he knew of no better composition; and as for the durability of the pipes, he would say that some of them would last an indefinite length of time. He had lately an opportunity of seeing one of the large pipes in the Duchray valley which was spotted, while those on either side were not at all affected by oxidation.

Mr J. G. LAWRIE suggested whether the oxidation which had been observed on some of the pipes had not arisen incidentally from the pipes on which the oxidation appeared being improperly coated.

Mr Gale believed that was the true explanation; for it was well enough known that if there were too much or too little oil used the coating was defective.

Mr Downie said that the coating process required much attention, both as to the time of application and the mixture of the composition. One difficulty experienced was in having to drive off from the varnish, or coating matter, so much of the volatile oils, on the dipping pans being first filled with the mixture. He agreed with Mr Gale, as the red spots had only been seen on one or two of the pipes yet, that these must have been improperly coated.

Mr R. Brown would like to hear opinions as to whether it was better to heat the pipes before they were put into the composition, or to put them in and then heat them until they were penetrated by the composition.

Mr Gale said that Dr Smith recommended to heat the pipe first, but he believed that it was the practice in Scotland not to do that. He did not think it mattered very much which plan was adopted.

Mr Downie said the process of heating the pipes first was a very unprofitable one, and not attended with any advantage to the coating of the pipes. He strongly condemned the practice of permitting pipes to get covered with rust, so as to form scale, before they were coated, as it prevented the composition from adhering to them.

Mr R. Brown said that the Shotts Iron Company had always been in the habit of heating the pipes before putting them into the mixture. They were put on to a large gridiron, and brought to a proper heat, when they were immersed in a horizontal trough, and left there for a certain time. He had found that way of coating pipes to be as cheap as and more efficient than the other.

Mr Downie thought the proper mode was to dip them vertically; but when they were only allowed to remain in the mixture for a short time, it was found that they were not properly coated, although plenty of the composition adhered to them. They must remain in the pan a considerable time, and attain the same temperature as the varnish. The time required varied from twenty-five to thirty minutes.

On Trials of the Speed of Steam Vessels in a Tideway.

By Prof. W. J. MACQUORN RANKINE.

Read 20th January, 1864.

(1.) When the speed of a steam vessel is tested by running up and down through a measured distance in a tidal current, *two* runs are not sufficient to give her true speed through the water, unless they are made at equal intervals of time before and after half-tide, which can but seldom happen. In all other cases *three* runs are the smallest number that can give an accurate result; because of the alteration of the velocity of the current in the course of the trial, and in many cases of its direction also, when the tide turns during the experiment.

When the runs are made over a short distance, such as a "measured mile," and at nearly equal intervals of time, it is sufficiently accurate to take the mean of the speeds of the first and second runs, and the mean of the speeds of the second and third runs; and then to take the mean of those means, or *second mean.* When more than three runs have been made, there will be a series of second means, which are to be added together and divided by their number for the final mean; and this, as is well known, is the rule followed in calculating the results of trials of steamers of the Royal Navy.

(2.) But when the distance run is great, such as the 13·66 nautical miles between the Cloch Lighthouse and the Cumbrae Lighthouse in the Firth of Clyde, even the second mean of three runs is not sufficiently accurate, especially if the intervals of time between them are to any considerable extent unequal. In such cases the correct rule is as follows:—

I. Calculate the apparent speed of each of the three runs as usual, by dividing the distance by the time.

II. Find the two intervals of time between the middle instants of the first and second, and of the second and third runs. Reduce those intervals to the corresponding angular intervals by the following proportion :—

As $12^{h.}$ $24^{m.}$ (the duration of a tide)
: is to a given interval of time
: : so is 360°
: to the corresponding angular interval.*

* Note (added 1st February). The following rule is convenient :—Divide the time in seconds by 124; the quotient will be the angle in degrees.

III. Multiply the *first* apparent speed by the cosecant of the first angular interval;
the *second* apparent speed by the sum of the cotangents of the two angular intervals;
the *third* apparent speed by the cosecant of the second angular interval.

IV. Add together the products, and divide their sum by the sum of the before-mentioned multipliers; the quotient will be the true speed through the water.

When four or more runs are made, they are to be taken in sets of three, and treated as above, and the mean of the results taken as a final mean.

(3.) To illustrate the use of the above rule, and the errors which may arise from the common practice, the following supposed example is given:—

Distance run between Cloch and Cumbrae Lights, 13·66 knots.

	h.	m.	s.
FIRST RUN—Down.			
Passed Cloch, - - -	0	29	36
Passed Cumbrae, - -	1	34	23
Time of run, - - -	1	4	47
SECOND RUN—Up.			
Passed Cumbrae, - -	1	58	36
Passed Cloch, - - -	3	11	24
Time of run, - - -	1	12	48
THIRD RUN—Down.			
Passed Cloch, - - -	4	7	6
Passed Cumbrae, - -	5	10	53
Time of Run, - - -	1	3	47

MIDDLES OF RUNS.

	h.	m.
First, - - -	1	2
Second, - - -	2	35
Third, - - -	4	39

INTERVALS.

Time h.	Time m.	Angles °
1	33	45
2	4	60

Runs.		Apparent Speed. Knots.	Multipliers.	Products.
First, ...	...	12·642	1·4142	17·878
Second,	...	11·176	1·5773	17·628
Third, ...	...	12·849	1·1547	14·837
Sums,	...	...	4·1462	)50·343
True speed,	...	...	...	12·142 knots.

To show the errors which would arise from the common methods—whether by taking the mean of two runs, or the second mean of the three, or the ordinary mean of the three—the following calculations are given :—

Apparent Speed.	Means of Two Runs.	Second Mean.	Errors.
12·642			
	11·909		— ·233
11·176		11·960	— ·182
	12·012		— ·130
12·849	Mean of three runs.		
3)36·667(	12·222		+ ·080

The preceding are examples of errors which are likely to be of ordinary occurrence; but occasional errors may reach double the amount. The maximum speed of the current has been assumed at one knot per hour.

In the discussion which followed;—

Mr W. M. Neilson said the variations in the force of the current at different points would cause more error in the calculations of a trial trip than what was indicated in the paper; even an inefficient man at the wheel might produce as great a deviation. He wondered that the shipbuilders on the Clyde had not insisted long before that on having a suitable measured mile for testing their boats in still water; for the trial of ships between the Cloch and the Cumbrae Lights was not a test that could be fairly compared with the trials on the Thames and elsewhere; and he was satisfied that if they had a measured mile it would be greatly to the advantage of the Clyde shipbuilders.

The President remarked that there had been a measured mile on the Clyde, of the character Mr Neilson desired, for the last fifteen or twenty years. It was in the Gareloch, at a place where there was very little tidal current, and had been measured by Mr Kyle for Mr Robert Napier. He thought it was very satisfactory to know that the Admiralty had adopted a mathematically correct mode of calculating ships' speeds.

Mr W. Simons did not think that the shipbuilders on the Clyde could be charged with jockeying. He considered that they tested their steamers more fairly than others; for, undoubtedly, the twenty or thirty miles run on the Clyde, in testing a steamer, was a much better test than running for a few minutes, as on the Thames. There it seemed to him jockeyism prospered, instead of the speed being properly tested. With regard to the measured mile in the Gareloch, it was practically useless; for it was out of the district, and they had to pass through a dangerous gut to get to it. They should have a series of measured miles—not a single measured mile; for the customers of the Clyde shipbuilders would not be satisfied with a trial unless they run forty or fifty miles at a stretch. There were various things that Dr Macquorn Rankine had not taken notice of in his paper, such as the different speed caused by ebb and flood tides, by screw and paddle vessels, and other points, which it would have been interesting to have had calculated.

The PRESIDENT understood that Professor Macquorn Rankine intended to add a note to his paper, which might be published along with his paper, if the Council thought proper. He expected that he would be present at the next meeting of the Institution, so that perhaps it would be well, seeing the late hour of the evening, that they should adjourn the further discussion of his paper.

Mr MORE remarked that the trials on the Thames must be very unsatisfactory, for he understood that they ran the vessel the single mile, and turned and ran up again, so that they had an opportunity at each turn of getting up a good head of steam for the next run. That was a very different way of testing a ship's speed than by running her thirty, forty, or fifty miles in one direction.

SUPPLEMENT—*Added 1st February.*

(4.) It is easy to see that the greatest errors from taking the mean speed of two runs only will occur when the tide turns between the runs; and that the error will be against or in favour of the vessel according as she runs down against the flood and up against the ebb, or down with the ebb and up with the flood. When the interval between the middle instants of the two runs is two hours, or thereabouts, the error in such cases may amount to about half the greatest velocity of the current.

(5.) The most convenient number of runs for practical purposes is probably four. It is to be observed that the apparent speeds of four runs can be combined into four different sets of three; and that the most accurate way to treat them is to apply the rule given in section 2 of this paper to each of those four sets, and take the arithmetical mean of the four results.

(6.) Cases may occur in which intervals of more than a quarter tide, or $3^{h.}$ $6^{m.}$, elapse between the middle instants of two runs of a set. In such cases it becomes necessary to subtract, instead of adding, certain multipliers and products :—in algebraical language, certain multipliers and products in the calculation become negative instead of positive. The principles according to which it is to be decided whether a given multiplier is positive or negative are those of ordinary trigonometry, and are summed up in the following table :—

Intervals. Time.	Intervals. Angles.	Cosecants.	Cotangents.
Between $0^{h.}$ $0^{m.}$ and 3 6	Between 0° and 90	positive.	positive.
Between 3 6 and 6 12	Between 90 and 180	positive.	negative.
Between 6 12 and 9 18	Between 180 and 270	negative.	positive.
Between 9 18 and 12 24	Between 270 and 360	negative.	negative.

(7.) The rules in the preceding part of the paper enable a practically accurate result as to the speed of a steamer to be deduced from three runs, or better still from four runs, in a tideway, in the absence of all information as to the times and velocities of the current; provided only that there is nothing extraordinary in the tides of the locality, such as the double and triple tides which occur in some estuaries. The method of calculation is such as to cause the effects of the tidal currents on the different runs to neutralize each other, independently of their velocity and of their times of turning, provided the duration of a complete tide is $12^{h.}$ $24^{m.}$, or thereabouts. Rules might be added for correcting the effects of diurnal tides, and of the monthly inequalities, to be used when the runs are made on different days; but to do so would be an unnecessary refinement.

(8.) It may, however, be desirable to add the rule which is to be used when the *time of slack water* is known, but not the velocity of the current. In this case a correct mean can be deduced from two runs, by proceeding as follows :—

I. Calculate the intervals of time from slack water to the middle instants of the two runs respectively, and reduce them to the corresponding angles, as in section 2.

II. Multiply the apparent speed of each run by the *sine* of the angular interval belonging to the *other run.*

III. If the runs were both made in the same current (ebb or flood), divide the sum of the products by the sum of the multipliers; if the tide turned between the runs, divide the difference of the products by the difference of the multipliers; the quotient will be the true speed.

IV. When three runs have been made, they are to be combined by pairs in three ways, the result of each pair computed by the preceding rules, and the arithmetical mean of the three results taken as the true speed. Four runs can be combined by pairs in six ways.

(9.) When all particulars as to the tidal currents are known, velocities as well as times, the true speed of a ship can be deduced from one run, by computing and allowing for the distance that she is drifted by the tide during the run, and dividing the corrected distance run by the time. When the data as to the tide are, the time of slack water and the greatest velocity of the current, the following is the rule for computing the distance that the vessel is drifted during a given run:—

Calculate the intervals of time elapsed from slack water to the beginning and end of the run respectively; convert those intervals into the corresponding angles, as in section 2; multiply the greatest speed of the current by difference of the cosines of those angles (if both are acute or both obtuse); or by the sum of those cosines, if one angle is acute and the other obtuse; the product will be the distance drifted.

(10.) A few runs, such as three or four, over a long distance, are a much more satisfactory test of the qualities of a steam vessel than a much greater number of runs over a short distance, provided the results are computed by an equally accurate method. The object of the present paper is to point out the means of preventing the errors which arise from the use of imperfect or unsuitable methods in calculating the results of long runs, and thus of enabling the advantages which they possess in other respects to be fully realized.

Appendix.—*Added 1st February.*

Demonstration of the Rules.

Case I.—Three runs: the times and velocities of the tide unknown. Let ϕ denote the *unknown* angle corresponding to the interval from the time of slack water to the middle instant of the second run;

a, the *unknown* maximum speed of the tidal current;

ϕ', ϕ'', the *known* angles corresponding to the intervals between the middle instants of the first and second, and of the second and third runs respectively;

v_1, v_2, v_3, the apparent speeds of the first, second, and third runs;

v_0, the true speed of the ship through the water. Then, very nearly,

$v_1 = v_0 + a \sin. (\phi - \phi') = v_0 + a (\sin. \phi \cos. \phi' - \cos. \phi \sin. \phi')$;

$v_2 = v_0 - a \sin. \phi$;

$v_3 = v_0 + a \sin. (\phi + \phi'') = v_0 + a (\sin. \phi \cos. \phi'' + \cos. \phi \sin \phi'')$.

To eliminate the two unknown quantities, a and ϕ, from these equations, multiply the first by cosec. ϕ', the second by cotan. ϕ' + cotan. ϕ'', and the third by cosec. ϕ'', and add them together; it is found that all the functions of the two quantities to be eliminated disappear, giving the following result:—

$v_1 \text{ cosec. } \phi' + v_2 (\text{cotan. } \phi' + \text{cotan. } \phi'') + v_3 \text{ cosec. } \phi''$;

$= v_0 (\text{cosec. } \phi' + \text{cotan. } \phi' + \text{cotan. } \phi'' + \text{cosec. } \phi'')$;

Whence we have

$$v_0 = \frac{v_1 \text{ cosec. } \phi' + v_2 (\text{cotan. } \phi' + \text{cotan. } \phi'') + v_3 \text{ cosec. } \phi''}{\text{cosec. } \phi' + \text{cotan. } \phi' + \text{cotan. } \phi'' + \text{cosec. } \phi''};$$

being the rule given in section 2 of the paper.

CASE II.—Two runs: the time of slack water known, but not the velocity of the tide.

Let ϕ_1, ϕ_2 denote the *known* angles corresponding to the intervals from slack water to the middle instants of the two runs;

a, the *unknown* maximum speed of the tidal current;

v_1, v_2, the apparent speeds of the two runs;

v_0, the true speed of the ship through the water.

Then, very nearly,

$v_1 = v_0 + a \sin. \phi_1$;

$v_2 = v_0 - a \sin. \phi_2$.

To eliminate the unknown quantity a, multiply the first equation by sin. ϕ_2, and the second by sin. ϕ_1, and add them together. The result is as follows:—

$v_1 \sin. \phi_2 + v_2 \sin. \phi_1 = v_0 (\sin. \phi_2 + \sin. \phi_1)$;

Whence we have

$$v_0 = \frac{v_1 \sin. \phi_2 + v_2 \sin. \phi_1}{\sin. \phi_2 + \sin. \phi_1};$$

being the rule given in the supplement, section 8; observing that, should the tide turn in the interval between the runs, one of the sines becomes negative.

CASE III.—One run: the time of slack water and the maximum velocity of the tide both known.

Let ϕ_1 and ϕ_2 be the *known* angles corresponding to the intervals of time from slack water to the beginning and end of the run respectively;

a, the *known* maximum velocity of the tidal current;

s, the distance that the vessel is drifted by the tide during the run.

Then, according to the known laws of tidal motion,

$$s = a.(\cos. \phi_1 - \cos. \phi_2);$$

observing, that if one of the angles is obtuse and the other acute, the relative algebraic signs of their cosines are reversed, so that their sum is to be taken instead of their difference; and this is the rule given in the supplement, section 9.

Let r be the distance run, t the time of running it; then the true speed through the water is,

$$\frac{r \pm s}{t};$$

the sign + or — being used according as the tide is against or with the vessel on the whole.

When the tide turns during the run, it is with or against the vessel on the whole according to its direction at the *middle instant* of the run.

In the discussion, which took place on 17th February, 1864:—

Mr J. G. LAWRIE said the ordinary way hitherto used on the Clyde of ascertaining the speed of steam vessels had been by running the distance from the Cloch to the Cumbrae, down and up, at periods of time equally before and after high or low water, in order that the speed might be as much increased or diminished on the one run as it was on the other. That appeared to give, as stated by Dr Rankine, a result as correct as could be obtained, if the speed was to be tested on this measured distance. But it might be inconvenient, as observed by Dr Rankine, to run at times equally before or after high or low water, and by this formula it was proposed to eliminate the effect of the tide, whatever that might be, and when the runs were made at any periods of the tide. It appeared to him, however, that the conditions of the formula were not such as could be legitimately assumed. It was assumed that the actual speed, in contradistinction to the apparent speed of the vessel, was the same on all the three runs; it was assumed, also, that the time of high or low water was the same at the Cumbrae as at the Cloch, and that the effect of the tide during each run was the same as it would be if the tide affected the speed uniformly at the rate that it did at the middle of each run. If the object of the formula was to ascertain the speed roughly, these assumptions might be of little moment; but as the object was to obtain an accuracy minutely differing from that obtained in the ordinary way, he thought they were inadmissible. The inaccuracies introduced into the formula, it appeared to him, by these assumptions, had the complex effect of shifting in the formula the period of slack water from its true period, and gave a result for the speed as if the trials were made at a different time of the tide, as well as with a different velocity of tide, from that at which they were made, and therefore not correct to an amount of importance. It was, moreover, common experience that the run down the river was always made in less time than the run up, irrespective altogether of the state of the tide when the runs were made, indicating a current down the river, or at all events some action in operation of greater importance than the tide itself —an action and an effect not taken into account in the formula. There was, besides, the greater difficulty, which was of very common occurrence, in the way of arriving at a correct result, arising from the influence of the wind, inasmuch as the effect of the wind varied in something like the cube of its velocity. For these reasons chiefly, he was of opinion that repeated runs on a measured mile, as was customary in the South, was the more accurate method of ascertaining the speed.

Mr ELDER had also observed that, on trial trips from the Cloch to the Cumbrae and back, in returning to the Cloch the vessels did not go quite so fast; but he thought that arose mostly from the fires getting into an inferior condition. The indicator power was seldom as great coming back as in going down. Undoubtedly what was wanted was some more correct plan of testing the speed than they had at present. He believed it was impossible to have a perfect formula, as there would always be a deficiency from causes the value of which could not be assigned; but he was very glad that Dr Macquorn Rankine had investigated a question on which he must have more information than almost anybody else. He might, however, still further investigate into the action of the wind, and an appendix might be put to the formula to correct it approximately. In illustration of the necessity for such investigations, he might state that on one occasion at the trial trip of a new steamer at Liverpool, she left the Liverpool Docks two hours before high water, as usual, when the gates opened, to run between the north-west Lightship and the Bell Buoy, and she came to the latter about ten minutes before high water. They had thus the tide against them going down in the first run, and against them coming back again; and in going down the second run, they had the tide with them about one and a half hours after high water, and in returning the tide was against them two and a half hours after high water. In these circumstances the average of the four runs made a difference of half a knot per hour, giving the vessel only 12¾ knots, instead of 13¼. He knew the rate of the tide, and from that rate of tide he was persuaded that the Admiralty rate was wrong. Another time, when the wind was strong against them, they were twenty minutes going with the tide, arriving at the Bell Buoy one hour before high water, and in coming back against the tide and with the wind they were the same time. At other times without wind, going about the same rate, the average was eighteen minutes; yet the Admiralty Surveyors would make no allowance for the wind, as it would be said that they might favour one builder more than another. It was therefore of great importance that some disinterested party like Professor Rankine, who could do so, should state his opinion.

Mr Gilchrist said they had been in the habit of taking the arithmetical mean of four or six runs. He could not understand how the mean of three runs could be depended on; for they might have wind and tide against them in two runs, and only with them in one. The last time he was down with a vessel, they made four runs in the Gareloch at the measured mile. The wind was right abeam, and all the difference of time was only two seconds more each run with the tide. There was very little tide up there, however.

Mr Lawrie believed that all difficulties, with the exception of the effect of the wind, would vanish if they used the measured mile, as on the Thames.

Mr Simons did not think that it was a satisfactory way of trying a ship, to run two or three miles. He thought a much better test was obtained in running 40, 80, or 100 miles, as customary on the Clyde.

Professor Wm. Thomson said that Professor Rankine's formula would give the most probable result that could be got with three runs; but no doubt much better results could be obtained with four runs than with three, and with six than four. The most satisfactory way to eliminate the disturbances, however, was to take a great number of runs. The average from three runs would be at a disadvantage, however, as Mr Gilchrist remarked: in consequence of the wind the allowance would not be correct. If the runs were made about six hours from slack water, then a common mean, with the apparent velocity of the middle run taken twice, and those of the others taken each singly, would bring out the right thing. If the wind remained constant, the proper allowance for it, also, would be double the velocity of the middle run, and divide the sum of the whole by four. That would correct the formula both for wind and tide, provided that they were all equal; but, inasmuch as the tide varied differently from the wind, the thing that would correct the one would not correct the other. That was a serious difficulty. One of the objections that Mr Lawrie had made to the formula it was scarcely liable to—namely, that the velocity of the tide varied in course of the run. The formula was especially adapted to take account properly of that variation. It was stated that it was "approximately" true, and they would see, if they worked it out trigonometrically, that the approximation was very close. Take, instead of the full value of a certain angle, the sine of that angle, being the angle corresponding to half the time of a run, and if the time of a run was an hour and a half, the half angle would be twenty degrees at most. Now, the error of taking the sine instead of the angle was very little, and it was obvious that the approximation was as good as possibly could be required for practical purposes. As for the various difficulties which Mr Lawrie thought the formula could not correct, he believed neither would any other. It was impossible for any formula to apply to irregular changes, such as an irregular wind blowing in varying directions, or the different velocity of current in different parts of the run; but the circumstance that, in any particular case, the differences themselves were merely differences of 100ths of a knot, showed that the difference of the theoretical average from the actual average was very little. But there were cases in which the differences were much greater, and to them the formula applied with important advantage. For instance, if the circumstances of the trial were such that only three runs could be taken, and that those runs were made near the time of slack water, then this formula would be necessary. The formula would agree very closely with the common mean if the trial were six hours before slack water. He had observed, from the discussion that took place at the last meeting of the Institution, that some very strong objections were stated to the one-mile trials. It was said that the steam was got up for the single-mile run, and that the ship thereby ran for twelve minutes at a rate that she could not keep up. Now, if it was wanted to find what speed a vessel could keep up, that must be done by a long run of many hours; but to show the ship's real power of performance with a stated pressure, the single-mile run was a much more reliable thing than to let her run for ten or twelve hours on an unmeasured course, and in varying circumstances of wind, weather, and tide.

Mr Lawrie said that if the speed of the vessel going up the river was less than the speed going down—if, for example, the engines lost ten strokes during the up run—this formula could not possibly eliminate the action of the tide; and he believed that scarcely an instance occurred in which the true speed up and down was the same. The objection taken to the short runs under Admiralty inspection was unfounded, as in practice no such thing as getting up steam for each separate run could occur. The vessel ran four or six times, as the case might be, and from the commencement until the termination of the runs nothing about the machinery was altered. The throttle valves, injection cock, feed cock, and blow off remained unaltered, and seeing that the whole time of running was therefore virtually only one long run, no bottling up could take place for a rush at the mile.

The PRESIDENT said those might be the Admiralty rules, but it was doubtful whether they were always adhered to in practice.

Professor THOMSON said, with reference to a remark of Mr Lawrie's, that if irregular variations occurred in the engine's rate, it would vitiate any possible formula. Professor Rankine's formula could only give one speed—a kind of average—something less than the greatest speed and something more than the slowest.

The PRESIDENT thought Mr Lawrie had misunderstood Dr Rankine. The greatest error—as was stated in the supplement—might amount to half the greatest velocity of the current, although it happened in the example chosen to be only 0·08 knots. The sole object of the formula was to eliminate the effect of the tidal current, and thereby enable the true speed to be got in situations where it could not otherwise be ascertained. Professor Thomson had stated what he was going to have said —that where the object of knowing the speed was to ascertain the efficiency of the hull or machinery, the short distance was better than the long, simply because the speed throughout the short distance would be more uniform than throughout the long distance. For purchasers, however, it was evident that the long distance was the best trial. The paper was undoubtedly a valuable acquisition to the marine engineer and to the shipowner.

On Trials of the Speed of Steam Vessels in a Tideway.

Letter and Explanatory Note, received 18th March, 1864.

To the Secretary of the
Institution of Engineers in Scotland.

SIR,—I have just received the Report of the proceedings of the meeting of the 17th February, at which my paper on the above subject was discussed; and as I was prevented by business engagements from attending that meeting, I beg you will be so good as to lay this letter before the Council, and submit to them my request that it may be printed in the proceedings as my reply to the discussion.

My object in writing it is to correct a mistake, as to the meaning of my paper, into which most of the members who took part in the discussion appear to have fallen. Those gentlemen seem to have imagined that I recommended three runs in preference to any other number, greater or smaller. What I did state was, that three runs were the *smallest* number that could give an accurate result; and not only did I give, in the body of the paper, directions how to proceed in the case of four or more runs being made, but in the supplement I recommended four runs as being a good number to make over such a distance as that between the Cloch and Cumbrae lighthouses.

I have also to request that the Council will permit the insertion of the annexed explanatory note.—I am, Sir, your most obedient servant,

W. J. MACQUORN RANKINE.

GLASGOW, *15th March, 1864.*

EXPLANATORY NOTE.

In every case in which four or more runs are combined in sets of three, each set of three runs will consist of two runs in one direction and a single run in the opposite direction; and the single run is to be treated as the middle run of the three in applying the rule, even although it should actually have been made before or after both the other runs. When such is the case, one of the two intervals is to be treated as a negative quantity: that is, the cosecant and cotangent of the angle corresponding to it are both to have their signs reversed. For example, the following is the arrangement of four runs in four sets of three:—

A	B	C	D
1 down	2 up	3 down	4 up
2 up	3 down	4 up	1 down
3 down	4 up	1 down	2 up

In the sets C and D the interval between the middle instants of the runs 1 and 4 is to be treated as a negative quantity, the cosecant and cotangent of the angle corresponding to it having their signs reversed.

W. J. M. R.

15th March, 1864.

On the Effects of Superheated Steam and Oscillating Paddles on the Speed and Economy of Steamers. By Mr James R. Napier, from Data supplied chiefly by Mr William Beardmore.

(SEE PLATES V. AND VI.)

Read 17th February, 1864. Mr J. G. Lawrie, *Vice-President, in the Chair.*

Mr Beardmore had his attention drawn to the subject of superheating by the trials of the Hon. T. Weatherhead's method, on board H. M. S. *Black Eagle.* After getting some preliminary information, he applied to the steamer *Magician* an apparatus which consisted of a box of tubes placed over the uptake of the boiler. The boiler previously did not generate sufficient steam for the engines. No alteration was made either in the engines or boilers. The engines were not fitted with expansion valves. The superheater increased the revolutions and decreased the consumption of coals. The increase in the speed of the engines at the first trial being considered remarkable, Mr Beardmore, in the next ships he fitted, was particular to ascertain by several experimental trips the greatest number of revolutions he could obtain with the steam at full pressure, before and after applying the superheater, and he always found an increase in the number of revolutions with the superheater. The indicator cards taken at the trials always showed a better vacuum, with less injection water, and on the steam side of the card a greater mean pressure.

The General Steam Navigation Company, he says, have now fitted upwards of thirty of their steamers with superheaters, and in no instance have any serious difficulties occurred. These vessels have been fitted without the combined process introduced by Mr Weatherhead: at the same time, he believes that Mr Weatherhead's plan might at times, with a badly constructed boiler, prevent the slide faces from being cut and the packing from being damaged.

The best arrangement of boiler for the application of a superheater, he considers, is where there is the least change of temperature in the uptake, and great care taken to have sufficient space in the fire boxes, so that the gases may be ignited before they reach the uptake.

The next trial of superheating which he made was with the paddle steamer *Caledonia,* of 220 horses power nominal, trading between London and Granton. Previously to being fitted with a superheater, this steamer consumed 126 tons of coal on the voyage, and after the alteration the consumption was reduced to 90 tons, and about one hour was saved on the average passage.

The screw steamers *Metropolitan* and *Cosmopolitan*, which at one period traded between Glasgow and London, were purchased by the General Steam Navigation Company, and they gave them new boilers with superheating apparatus. The results of the alteration in the case of the *Metropolitan*, here given, show that for about the same speed there was a saving of 24·18 per cent. of fuel.

S.S. *METROPOLITAN.*

WITHOUT SUPERHEATING.			WITH SUPERHEATING.		
	Total Time on Voyage.	Total Coals.		Total Time on Voyage.	Total Coals.
1860.	Hours.	Tons.	1861.	Hours.	Tons.
June 28.........	41	45	July 18.........	40	28
July 5.........	69	49	,, 25.........	52	34
,, 12.........	49	48	Aug. 1.........	50	33
,, 19.........	52	49	,, 8.........	60	40
,, 26.........	42	43	,, 15.........	50	33
Aug. 2.........	55	43	,, 22.........	55	42
Six Runs ...	308	277	Six Runs ...	307	210
Average......	51·33	46·16	Average......	51·16	35

The paddle steamer *Berlin* was bought by the same Company, and placed in the Hamburg and London trade, in which she gave great satisfaction; but her consumption of fuel being great, it was determined to give her new boilers, superheating apparatus, and oscillating paddles of considerably less diameter. By these alterations a decrease in the consumption of fuel of 35·8 per cent. was obtained. The speed, however, was reduced 3·3 per cent., as here shown:—

BERLIN.

With Fixed Paddles and without Superheating.

1862.	Total Time.	Total Coals.	Under Way.	
			Time.	Coals.
September 17.........	48	102	42	94
,, 24.........	43	120	43	107
October 1.........	37½	98	36	90
,, 8.........	40	106	38	98
,, 15.........	37	94	36	86
,, 21.........	64	116	36	108
,, 29.........	46	103	44	95
November 4.........	41	110	40	102
,, 12.........	44	99	40	90
,, 18.........	41	104	38	96
Ten Runs	441½	1052	393	966
Average..............	44·13	105·2	39·3	96·6

With Oscillating Paddles and with Superheating.

1863.	Total Time.	Total Coals.	Under way.	
			Time.	Coals.
September 19	41	67	37	60
,, 25........	41	74	39	65
October 8........	45	60	37	54
,, 9........	44	74	41	67
,, 17........	43	63	37	55
,, 21...... ..	40	70	38	63
,, 28........	39	63	38	56
November 1........	78	90	57	79
,, 7........	48	66	38	56
,, 11........	47	73	44	66
Ten Runs............	466	700	406	621
Average......	46·6	70	40·6	62·1

The greatest benefit from superheating the steam was always obtained where the expansion was greatest and the speed of the piston smallest, which he attributes to the great condensation of steam in the cylinder in such cases when the steam is not superheated.

The paddle steamer *Concordia*, a small vessel built for the same Company, was fitted, after some years' work, with new wheels having oscillating instead of fixed paddles, and with a new boiler with superheating apparatus; the results were an increase of 16 per cent. in speed, and a decrease of 41·6 per cent. in fuel, as here shown:—

CONCORDIA.

With Fixed Paddles and without Superheating.

1851.	Total Time.	Total Coals.	Under Way.	
			Time.	Coals.
November 15.........	24	23·10	20	19
,, 19........	27·15	23·10	22·30	19
,, 26........	22·30	23	20·30	19
,, 29........	29	29	20·30	23
December 6........	27	28	21	23
,, 10........	23·45	26·10	23·45	24
,, 17........	47·15	29	18·45	18
,, 20........	25·45	24·10	20·45	20
,, 27........	23·30	25·10	21·15	21
,, 31........	39	27·10	25	23
Ten Runs............	279	260	217	209
Average..............	27·9	26	21·7	20·9

With Oscillating Paddles and with Superheating.

1859.	Total Time.	Total Coals.	Under Way.	
			Time.	Coals.
November 15.........	20·15	16	20·15	13
„ 17.........	27·30	18·10	22	14
„ 22.........	26	16·10	17·30	11
„ 24.........	22	15	18	12
„ 29.........	21·45	15	19·45	12
December 1.........	24	15·10	21·30	13
„ 6.........	22	15·10	16·15	11
„ 8.........	19	15	19	13
„ 13.........	22·45	15·10	19·15	12
„ 15.........	26·30	16	20	11
Ten Runs............	231·45	158·10	193·30	122
Average..............	23·15	15·17	19·3	12·2

The following results were obtained with the paddle steamer *Seine*, belonging to the same Company, showing a decrease of about 1 per cent. in the speed, and of 37 per cent. in the fuel :—

SEINE.

With Oscillating Paddles and without Superheating.

1861.	Total Time.	Total Coals.	Under way.	
			Time.	Coals.
May 5................	9·45	9·10	9·45	7·10
„ 7................	10	9	10	7
„ 10................	9·30	9	9·30	7
„ 13................	9·45	9·10	9·45	7·10
„ 16................	9·45	10	9·45	8
„ 18................	9·45	9·10	9·45	7·10
„ 21................	9·30	9·10	9·30	7·10
„ 23................	10	9·10	10	7·10
„ 26................	9	9	9	7
„ 29................	10	9·10	10	7·10
Ten Runs...........	97	94	97	74
Average..............	9·7	9·7	9·7	7·4

With Oscillating Paddles and with Superheating.

1862.	Total Time.	Total Coals.	Under Way.	
			Time.	Coals.
August 7.............	11	10·10	11	8·10
„ 10.............	10·30	7	10·30	5
„ 13.............	8·45	6	8·45	4·10
„ 15.............	10	7·10	10	6
„ 17.............	9·30	7·10	9·30	6
„ 20.............	10	7	10	5·10
„ 22.............	9·15	6	9·15	4·10
„ 25.............	11	6·10	11	5
„ 28.............	8·30	5·10	8·30	4
Sept. 1.............	9·30	6	9·30	4·10
Ten Runs............	98	69·10	98	53·10
Average..............	9·8	6·91	9·8	5·4

TABLE OF PARTICULARS, AND RESULTS OF ALTERED STEAMERS.

	Caledonia.		S.S. *Metropolitan.*		S.S. *Cosmopolitan.*		*Seine.*		*Concorda.*		*Berlin.*	
			1860. June.	1861. July.			1861. May.	1862. August.	1851. November	1859. November	1862. September	1863. September
Number of furnaces	6	6	6	4	5	4	5	3	5	5	12	6
Length of fire grate .... feet	8	4·3	7·16	6·	6·5	6·?	8·	6·	7·2	—	6	7
Area of fire grate .... sq. ft.	136·	72·	103·	65·	92	70·?	96·	66·	100·	—	216	154
Diameter of tubes below water .... ins.	—	—	—	3·	3½	3	—	—	3·	2½	4	3
Length of tubes below water .... feet	—	—	—	5·75	7·5	5·	—	—	6·	6·	7½	6
Number of tubes below water	—	—	—	358·	360	398·	—	—	440·	670·	576	712
Diameter of tubes above water .... ins.	—	—	—	1¼	—	2·	—	—	—	2	—	2
Length of tubes above water .... feet	—	—	—	5·75	—	6·	—	—	—	4·75	—	6·
Number of tubes above water	—	—	—	195	—	120·	—	—	—	180	—	200
Heating surface below water .... sq. ft.	—	—	—	—	2938	1956	—	—	2384	3166	5233	3892
Heating surface above water .... sq. ft.	—	—	—	—	126?	537	—	—	120 ?	627	165 ?	944
Total heating surface .... sq. ft.	—	—	—	—	3064	2493	—	—	2504	3793	5398	4836
Absolute pressure on boiler ...... lbs. per sq. in.	27·	27·	29	30	31	31	30·	30·	31	31	30	29
Temperature on entering valve casing	—	330°	—	350°	—	350°	—	330°	—	330° to 360°	—	330° to 360°
Description of paddles	Fixed	Fixed	—	—	—	—	Oscillating	Oscillating	Fixed	Oscillating	Fixed	Oscillating
Number of paddles on each wheel .... N	20	20	—	—	—	—	—	—	16	12	27	12
Radius of outer edge of vertical paddle in feet, R	—	—	—	—	—	—	—	—	8·80	8·50	13·90	10·90
Radius of inner edge of vertical paddle in feet, r	—	—	—	—	—	—	—	—	6·50	4·83	11·20	6·40
Height of paddles .... $R - r$	—	—	—	—	—	—	—	—	2·30	3·66	2·66	4·50
Mean radius of paddles .... $(R + r) \div 2$	—	—	—	—	—	—	—	—	7·65	6·66	12·55	8·65
Distance between paddles .... $\pi(R + r) \div N$	—	—	—	—	—	—	—	—	3·00	3·49	2·92	4·53
Area of a pair of paddles, a .... sq. ft.	—	—	—	—	—	—	—	—	32·6	50·5	38·66	93·
Augmented surface of ship, 8½ ft. draught, A, sq. ft.	—	—	—	—	—	—	—	—	7350	7350	—	—
Augmented surface ÷ area of a pair of paddles .... $\frac{A}{a}$	—	—	—	—	—	—	—	—	225	146	—	—
Centre of wheel lowered	—	—	—	—	—	—	—	0	—	0	—	2·50
Number of voyages in the experiment	—	—	6	6	—	—	10	10	10	10	10	10
Revolutions per minute	18 to 20	20 to 22	—	—	35	37	—	—	23 to 27	33 to 36	16 to 18½	26 to 27
Average time per voyage	—	—	51·33	51·16	—	—	9·70	9·80	21·7	19·30	39·3	40·60
Average coals per voyage	120	90	46·16	35·00	—	—	7·40	5·40	20·9	12·20	96·6	62·10
Increase of speed, per cent.	—	about 3	—	0·30	—	—	—	—	—	16·	—	— 8·30
Decrease of fuel, per cent	—	25	—	24·18	—	22·5	—	27	—	41·60	—	35·80

The preceding Table shows the particulars and results, so far as ascertained, of the steamers referred to, the first column in the case of each steamer containing the particulars and results before, and the second column those after the application of superheating and of other alterations.

The builders of the *Cosmopolitan*, *Concordia*, and *Berlin* have kindly lent their drawings to show the original arrangements, and Mr Beardmore's drawings show the altered arrangements; from these the foregoing Table and the accompanying sketches in Plate V. have been composed.

An ingenious and simple method, by Mr Joseph Beardmore, of working the *Berlin's* slide valves is shown, Fig. 11. It happened to be shown on the drawings sent, and, although not connected with the subject of this communication, is worthy of notice.

In the discussion which followed the reading of the paper,

Mr ELDER said he thought, from looking at the drawing, that, in the various cases shown, a good deal of the acceleration in speed and saving of fuel had arisen from other causes as well as from superheating. It would have been useful had the precise alterations in the wheels and boilers been notified, as it would have aided them in coming to a more correct conclusion. With regard to the *Concordia*, she had at first very small common paddle wheels, about 17½ feet diameter. She was about 600 tons builder's measurement, and of a nominal power of 140 or 150 horses. She was about 180 feet long and 24 feet beam, so that the smallness of her paddle wheels, when deeply laden at sea, would very much detract from her propulsion. It was very evident that with superheating they had got an enormous heating surface at a great cost, namely, 3800 instead of 2500 square feet; and the question arose, How much of the increased speed and economy was to be attributed to the large heating surface, how much to the superheating, and how much to the new wheels? He believed that all three had favourably affected the result; and it would have been well to have had details, so that they might have judged of the effect of each. The quality of coals would also be an element in the calculations, for it was well enough known that the coals used on the east coast were superior to those in this part of the country. Altogether there appeared to be about 24 per cent. of saving in fuel, and that was what might be expected from superheated steam. He should also expect that, when such a saving of fuel was effected, they would probably shorten the fire grate, seeing there was not so much coal to burn, which shortening would insure more effective combustion; and it would have been useful had the paper stated whether the fire grate had been shortened, and thus enabled them to calculate how much of the saving was from superheating and how much from shortening the grate. He had himself seen 15 per cent. of saving effected by shortening the grate, and he thought most people would agree that a long fire was not so good as a short one, the reason being, perhaps, because a short grate could be better fired, and the air would more thoroughly penetrate among the coal. More evidence on the whole subject would be very desirable.

In answer to Mr Gilchrist, the PRESIDENT said that the *Metropolitan* and the *Cosmopolitan* were fitted with new boilers, in addition to the superheating apparatus. The *Cosmopolitan's* new boiler had 1956 square feet of heating surface below the water level, and 537 above it, and the temperature of her superheated steam was 350 degrees when entering the valve casing.

It was then agreed unanimously, on the suggestion of Mr Gilchrist, Mr Lawrie, and Mr Elder, that the discussion should be adjourned, in order to obtain details as to the heating surface and boilers, the length of fire bars, the amount of heating surface and sectional area, &c., &c., of the various vessels referred to, and the effect of the change to feathering from common wheels.

The discussion was resumed on the 16th March, 1864, Mr W. Simons, Vice-President, in the Chair; when the following remarks received from the President were read,—

"I beg to offer the following remarks, to re-open the discussion of the subject of Mr Beardmore's results, now before the Institution.

"I have had very little practical acquaintance with superheated steam or steam gas. The theory, however, now generally adopted, would lead one to expect a considerable saving from its use, even where the ratio of expansion of the steam in the cylinder is not great, and that where the expansion is great the saving would be very apparent; for it is now admitted that the extent to which saturated steam of about two atmospheres of pressure, not receiving heat from a jacket or other source, can be expanded with economy is very limited.

"If no alteration has been made in the ratio of the expansion of the *Caledonia*, *Metropolitan*, or *Cosmopolitan*, the saving will be altogether due to the superheating. Assuming that the original boilers of the *Caledonia* and *Metropolitan* (the drawings have not been furnished) are as much larger than their new ones as the *Cosmopolitan's* original is larger than her new one, the results are remarkable, and show that superheating boilers, with five-sixths of the heating surface of the ordinary marine boiler, produce about the same power, with about 25 per cent. less fuel. It would be satisfactory to know if this is Mr Beardmore's experience on the other ships to which he has added superheating apparatus.

"In the case of the *Concordia* there is an alteration of paddles from fixed to oscillating, to which a considerable part of the economy must be due. The 50 per cent. which has been added to the heating surface of the new boiler might, according to Dr Rankine's tables, increase the efficiency of the boiler about 12 per cent., and account for about 4 per cent. of the increased speed; and as the area of the paddles has been increased about 55 per cent., the slip would be decreased about 36 per cent. As the velocity of the piston has increased nearly 50 per cent. with the same boiler pressure, there has evidently been either a considerable increase in the ratio of expansion, which the superheating would now render economical, or the area of the steam pipe is reduced by the throttle valve, or otherwise, the effects of which on the economy of fuel are unknown to me. The original paddle wheel was perhaps too deeply immersed, and the paddles had less than the modern ideas of surface.

"The ratio of the augmented surface of the vessel to the surface of a pair of paddles is given in the table.

"The same ratio for the river steamer	*Vulcan*,	with oscillating	paddles, is	98
"	*Queen of the Orwell*,	"	"	78·5
"	*Neptune*,	"	"	93·3
"	*Admiral*,	"	"	214
"	*Concordia*,	"	"	145·5

"The *Berlin* has about 12½ per cent. less heating surface in the new boiler; but as the diameter of the wheels is greatly reduced, the velocity of the piston has increased; and no doubt, therefore, as with the *Concordia*, the pressure on the boiler being unchanged, the steam is more throttled, or the ratio of expansion is increased, and therefore, when superheated, fuel is saved: but whether the saving is to be ascribed to increased expansion, or wholly to superheating, I am not prepared to say. The area of the new paddles is more than twice that of the old, and although the slip is thereby reduced nearly 60 per cent., there is still a considerable saving left to be accounted for by the superheating. Mr Beardmore's object in reducing the *diameter* of the paddle wheel appears to have been to increase the velocity of the piston, and thereby get a greater ratio of expansion. He has probably made the best compromise he could between a less efficient diameter of wheel and a more efficient engine; and if he works expansively by reducing the area of the steam pipe, instead of with an expansion valve, as an indicator card of another vessel sent me would lead me to infer, he has perhaps made the discovery that that is the best, if not the only way, of working steam gas economically without injury to the valves. He would have increased the efficiency, and decreased the fuel still further, had he adopted Mr John

Elder's views of thin iron paddles, instead of thick wooden ones. The difference of power in the two cases required to push the paddles in and out of the water is, according to Mr Elder, very considerable. He will, perhaps, state the result of his calculations on the *Admiral*, and other vessels to which he has applied the iron.

"The alterations appear to have been made with great judgment. One would like to know, however, more about the durability of the superheaters—how long they last without repairs, what the repairs are when required, and what effect is produced on the parts of the engine in contact with the hot steam.

"The fitting of thirty or more steamers belonging to one company with superheaters speaks for itself, that the objections, if any, to its adoption are considered trifling compared with the advantages to be gained.

"In a large steamer, however, lately repairing here, and which is little more than twelve months old, a very destructive agent appears to be at work. Parts of the valve faces, valve rods, valve casings, and piston bolt guards, &c., appear as if they had been put in the fire and burned, although it is not more than two months since some of them were smooth and bright. The faces and backs of the slide valves and parts of the cylinder surface are coated with copper, as if they had been slightly electro-plated. In Plate VII., Fig. 1, is a plan of the boiler, steam pipes, and cylinders, Fig. 2 being a transverse vertical section of the boiler.

"The copper steam pipe appears to be the source from which the copper on the valves, &c., has come, for it is coated inside with a brown scale. At the bends, A, B, of the steam pipe attached to the slide valves the copper is clear of scale, and as clean as if done by an acid. Some of the scales and powder taken from this pipe, and also from the throttle valve and case, are sent for inspection. The superheating part of the boiler appears to be very effective in heating the steam and destroying the boiler, if not also the iron of the engine. It has been long known that that part of the smoke pipe of a boiler which is in contact with the steam decays very rapidly; yet in the case to which I have alluded nearly half the crown of the boiler is put in this condition by making the hot smoke and gases of combustion, and perhaps flame, at times pass over the crown on their passage to the superheater proper. The consequence is, that this part of the boiler is rapidly decaying; while that part of the crown *immediately* adjoining the heated parts, and all the remainder of the crown, is fresh and good. What is it which has caused this great decay in the iron of the engine, and the wearing away of the copper pipes? and what has converted the scale, which appears to be oxide of copper, into metallic copper on the valves? In ordinary engines using saturated steam the decay of the boiler is perhaps in some parts as rapid; but the engine lasts for years. Heat has evidently something to do with it, as the hottest parts in the steam—the smoke pipe, and the stays attached to it—decay fastest. A plate of iron about 12 inches broad, 3 feet long, and ⅜ths of an inch thick, fixed to the steam drum, has entirely disappeared in less than six months. I mention this, not as anything extraordinary or novel to engineers, who have long known how rapidly that part of the division plate between two boilers which is above the water level decays, but that others associated with us may help us out of our trouble by showing the cause; for clearly the cause of the rapid decay of some boilers and engines using steam gas or surface condenser is operative in all marine engines and boilers.

"General Morin, in a paper in a recent number of the *Comptes Rendus*, has shown that in the evaporation of water in open vessels the air or vapour produces ozone and an acid. Perhaps he will tell us if this takes place more rapidly at higher temperatures at 600° or 800° Fahr., and what acid it is which is eating our boilers and stealing our copper; for an acid of some sort it is—set free probably from the sea salts in contact with the hot plates. I expect either chlorine or sulphuric acid, or both, are present, and either would destroy the iron. Pieces of polished marble placed in different parts of the boiler in steam and water would probably show the effects of such an acid action, and might lead to a cure for the evil. I am inclined to believe now that, whatever may be the cause of the copper steam pipe wearing, the particles worn from this pipe are the cause of the quick decay which has been so unaccountable in some boilers supplied with fresh water from a surface condenser. Such boilers keep all they receive. I have seen specks of copper in a tube taken from such a boiler; and I have learned lately that the deposit of copper on the valves, &c, of an engine, although rare, has been observed by others in locomotives, as well as in marine engines, and by some who will probably communicate their views.

"In concluding the present remarks, the President would express his wish that the subject may meet with the thorough discussion that it undoubtedly merits."

Professor G. C. Foster, of the Andersonian University, said he had had an opportunity of examining, in company with the President, some parts of the engine referred to in the foregoing remarks. So far as he was yet able to judge, he was of opinion that the corrosion that had taken place, and the deposits formed, on the different parts of the engine were precisely such as must result if the steam were accompanied by a small quantity of hydrochloric acid. If it could be proved that this acid was present, he believed that all the appearances observed admitted of easy explanation. The only source of hydrochloric acid to which, under the circumstances, they could look, was the sea water evaporated in the boiler; but this source, he thought, was amply sufficient. Sea water contained a comparatively large proportion of chlorides—among them a very perceptible quantity of chloride of magnesium; and it was well known to every chemist that it was impossible to evaporate a solution of this salt to dryness without decomposing it almost entirely into magnesia and hydrochloric (or muriatic) acid. It was true that the sea water in the boiler of a marine engine was not boiled down to dryness: on the contrary, it was purposely kept in a comparatively dilute state by the process of continual supply and discharge adopted to prevent incrustation. But although this applied to the mass of the water in the boiler, a considerable quantity of the water thrown up against the hot sides, above the water line, must be evaporated to complete dryness; and in boilers in which the steam was intentionally superheated, the spray thrown up by the ebullition came into a drying atmosphere of unsaturated steam gas. In this atmosphere the water of each globule of spray would evaporate, leaving the salts which it held in solution in an extremely finely divided state, in which any portion of chloride of magnesium that might have escaped decomposition during the evaporation, would be almost certain to be completely converted into magnesia and hydrochloric acid by the superheated steam which surrounded it. Indeed, calling to mind Mr Tilghman's experiments on the decomposing powers of superheated steam, it was a question whether the alkaline chlorides of the sea water would not also be similarly decomposed to some extent. Hence, unless the laws of chemistry were different inside a steam boiler from what they were elsewhere, it seemed a necessary consequence of those laws that the steam of a boiler fed with sea water must, at least if superheated, contain a greater or less quantity of hydrochloric acid; this quantity naturally varying to a great extent with the degree of superheating, the position of the superheater, the amount of priming in the boiler, and perhaps other circumstances. This conclusion was confirmed by the experiments of M. Cousté, who had stated that when sea water was evaporated until it began to form a deposit, the first deposit produced consisted of magnesia—a result that was difficult to understand, unless it were supposed to be a consequence of the decomposition of chloride of magnesium during the evaporation. If the hydrochloric acid produced in the manner already explained passed out of the boiler with the steam, it would inevitably produce such effects as those which Mr Napier had described. In presence of oxygen, resulting from the air dissolved in the water supplied to the boiler and driven out on ebullition, it would first attack the copper steam pipe, forming chloride of copper; this would be carried forward by the steam until it came in contact with the iron slide valves and valve cases, corroding the iron by imparting to it its chlorine, and coating it with copper at the same time. The valves, valve cases, and the inside of the cylinder were, in fact, as Mr Napier expressed it, literally electroplated with copper; and at the bottom of the valve box, where probably water holding chloride of copper in solution had lodged, there was a tenacious coating of metallic copper of considerable thickness, exactly resembling electrotype copper. The chloride of iron, formed by the action of the chloride of copper on the iron, would be decomposed in its turn by the overheated steam; oxide of iron would be thus formed, and hydrochloric acid would be regenerated, and would pass on to corrode a further portion of the metal. Thus, in presence of overheated steam, a very small absolute quantity of hydrochloric acid might suffice to produce the total amount of corrosion observed.

Mr T. DAVISON said, that so far as the benefits from superheating were illustrated by the paper read on 17th February, he feared they could not be depended upon, the data being so very incomplete that it was difficult to separate the effects due to the change in the paddles from that arising from the altered condition of the steam, and the altered operation of the engines, and it was a pity they had not more information on the subject. He had made a calculation showing that but a very small portion of the economy in the case of the *Berlin* might be due to the superheating. He had supposed that the new boilers were as effective in generating steam as the old ones, in proportion to the quantity of fuel burned; that before the alterations the steam was cut off at two-thirds of the stroke, being about the usual practice in such engines; and that afterwards the steam was used expansively to the degree it would admit of. The calculation was then as follows:—30 lbs. absolute pressure of steam in boilers would give 28 lbs. in cylinders; this cut off at ·666 would average 26 lbs. throughout the stroke; deducting 5 lbs. back pressure, the remainder, 21 lbs., would be the average effective pressure; this multiplied by 17·25, the average revolutions, gave 362 as the representative value in foot-pounds per minute of steam so used. After the alterations, the saving was found to be 35·8 per cent.; and supposing that the new boilers produced this proportion less steam, if they reduced ·666 by 35·8 per cent., they had 428 as the proportion of the cylinder that would be filled with steam at the same speed of engines; but that must be still further reduced in the proportion of 17·25 to 26·25, in order to obtain ·278, the proportion of the cylinder that would be filled with steam at the increased speed, as the rate of expansion after the alterations. The calculation of power after the alterations would be as follows:—29 lbs. absolute pressure of steam in boilers would give 27 lbs. in cylinders; this cut off at ·278 would average 17 lbs. throughout the stroke; deducting 4 lbs. back pressure (as owing to the increased speed of air pump there would no doubt be a better vacuum than before the alterations), the remainder, 13 lbs., would be the average effective pressure; and this multiplied by 26·5, the average revolutions, gave 344 as the representative value in foot-pounds per minute of the steam so used. Comparing this with 362, the representative of the power before the alterations, he found a loss of only 5 per cent.; but as there was a loss of speed of 3·3 per cent., equivalent to a loss of power of at least 10 per cent., it left a balance of 5 per cent. in favour of the new arrangement. It was therefore evident that all the economy attained might be attributed to the increased rate of expansion alone, without making any allowance for the benefit of feathering wheels or superheating beyond perhaps what was sufficient to prevent condensation in the cylinders. In the calculation he had assumed that the engines were properly fitted to take advantage of their altered circumstances, and that when no mention was made in the data respecting any point, it had remained the same. It would therefore seem a great error to attribute the economy to the superheating of the steam. Making the same calculation in the case of the *Concordia*, he found that 550 represented the power before alterations, and 500 after, showing a loss of 10 per cent., so that the result in this case due to increased expansion would not be so good as in that of the *Berlin*; but it was probable that this vessel gained much more from the change in wheels, as the proportion in her case of the old to the new was so very different from that of the *Berlin*; at any rate, to attribute all the economy to superheating would be an erroneous view of the case.

Mr W. Beardmore, in answer to questions, said that there was no alteration in the valve of the *Berlin*, but they had wiredrawn the steam. In regard to the *Berlin*, he might state that her paddle wheels were decreased in diameter, and so they obtained an increase in speed; whilst to get sufficient boiler power they were obliged to work the steam expansively by wiredrawing. The first steamboat they altered was the *Magician*. She had feathering wheels, and they merely put a superheater in, and slightly reduced the steam pipe in order to wiredraw the steam. She was originally rather hard for steam, but she became very easy in this respect, and they got an increase in the number of revolutions, with 25 per cent. decrease in the consumption of coal. There was no alteration made in the *Metropolitan's* engines, and there was a saving of 24 per cent. of feul. Nor was there any alteration made in the *Caledonia*, so that the saving of 25 per cent. of coal in her case must have been due to superheating. The *Seine* had feathering wheels, and there was no alteration made in her arrangement, although there was a saving of 27 per cent. The *Berlin* showed a saving of 35 per cent., and a slight decrease of speed; but after her alterations she carried 120 tons more cargo, because of the greater saving in room by the new boilers; and she being a vessel that was always filled, it was a great advantage to her owners. The *Concordia* showed a saving of 41·5 per cent. of fuel, which was partly due to the introduction of feathering wheels and partly to superheating. None of those boats were fitted with expansion valves. It was very well known that if steam were expanded beyond half-stroke without superheating, no benefit resulted. Theoretically it was so, but not practically. The grates were diminished by 25 per cent. In the instance of the *Berlin* the original common valve cut off at about five-eighths of the stroke, and was never altered.

Mr J. BROWNLEE said he understood Mr Beardmore to say that he had found no benefit from expansion. Mr Napier had some years since said there, that in engines without the cylinder steam casing, and without superheating, he had never found any advantage in expanding the steam beyond *twice* the initial volume. This statement accorded with his own experience; but the economy which he had realized by expanding to that extent had always been most decided. In the session before last, Dr Rankine brought forward a paper on the liquefaction of steam within the cylinder, deduced from experiments made in the United States of America. In those experiments it appeared that when expanded to $1\frac{4}{10}$ times the initial volume, nearly 16 per cent. of the whole steam admitted was liquefied while entering the cylinder, When expanded to $2\frac{1}{10}$ times the initial volume, $70\frac{1}{2}$ per cent. only of the steam which left the boiler continued in the state of vapour within the cylinder at the instant of cutting off, the residue ($29\frac{1}{2}$ per cent.) having been liquefied during admission; and when expanded to three times the initial volume, the walls of the cylinder became so much colder than the entering steam that not more than 58 per cent. of the steam which left the boiler operated in propelling the piston, the residue (42 per cent.) having condensed upon the colder surface of metal during admission. Now, if they supposed as much as 29 per cent. of the steam to have been similarly liquefied in the trials of Mr Beardmore before superheating, the saving realized by the application of his superheaters was not more than might have been anticipated, without demanding any extent of superheating beyond that which might be found just sufficient to prevent that liquefaction.

Mr A. GILCHRIST said the *Berlin* was originally particularly short of steam, and her builders put a piece on the ends of the valve, and they could not get it upon the inner port, but they put half an inch on the outer end of the valve, but that did not improve matters very much; and then they put three-quarters of an inch, and slightly reduced the travel of the valve. He understood that no alteration had since been made, in which case she must be cutting off at about half-stroke. Regarding the deposit in the vessel referred to by the President, he might state that he had found the same deposit in the cylinders and the valves of certain other vessels which had annular superheaters.

Mr W. BEARDMORE remarked that they had fitted *thirty* ships with superheaters, and had experienced no difficulty at all. He thought the superheater itself would oxidize rather readily, but only where the steam impinged; but he met that difficulty by putting on cast-iron ferules. He never used copper now, for after employing a little of it he found it would not do.

Mr J. G. LAWRIE said that deposits of copper, such as were referred to in the President's remarks, were of very rare occurrence.

Mr W. BEARDMORE thought that if the steam did not impinge upon the copper there would not be much difficulty. He had only once experienced that difficulty, when he had met it by altering the steam pipe so as to do away with all sharp bends.

Mr J. G. LAWRIE remarked that on the principle Professor Foster had laid down, the deposit ought to occur in every case. Now, deposits did not occur in one out of every twenty vessels.

Mr W. M. NEILSON thought Professor Foster had said that it required a high temperature to decompose the chloride of magnesium.

Professor FOSTER replied that as long as the chloride of magnesium remained dissolved in the water, it was not decomposed to any appreciable extent; but where superheating occurred, an evaporation to dryness took place, which must cause decomposition. But whether the acid got into the cylinder in every case in which it was produced, required further and closer investigation to decide.

Mr J. G. LAWRIE merely wished to point out that the deposit was not found in all cases.

Mr A. BROWN remarked that in the case of a paddle steamer still running, the slide valve was placed at an angle, and the upper corner got much corroded by seven or eight months' working. He also thought some other things affected the consumption of fuel besides superheating. He had had to do with a vessel which was unable at the first trial to keep steam up when running full speed. After putting one-fourth more lap on the induction side of her valves, and shifting the steam pipe to a more roomy part of her boilers, a greater command of steam and a better vacuum were obtained, and the engines made two revolutions more per minute. He was also of opinion that altering the wheels from common to feathering floats affected the consumption.

Mr J. DOWNIE thought that it might be interesting if Professor Foster could inform them of the temperature at which the acid was set at liberty.

Professor FOSTER answered that whenever evaporation to dryness occurred, even at 212° Fahrenheit, it would take place, and it increased with the temperature; but what was the lowest temperature at which it occurred he could not say.

Mr T. DAVISON thought that where boilers were subject to prime, and superheaters were used, there would be more of the salts thrown up into the steam space and against the highly heated plates of the boiler and superheater, and consequently give off a very large quantity of the acid; and as all boilers did not prime, that might be a reason for there being so much difference in the amount of corrosion. Hitherto, surface condensers had been sometimes blamed for this corrosion, and he was glad that some other cause had been found for it.

Dr MACHATTIE said that he quite concurred with the remarks made by Professor Foster as to the evolution of hydrochloric acid from the chloride of magnesium of sea water, when that salt was brought in contact with a highly heated surface; but he did not think that this would in all cases account for the destruction of boilers and steam pipes. Where boilers were charged with sea water, and the loss by evaporation was replaced by fresh water or condensed steam, the amount of chloride of magnesium (even on the very improbable supposition that it would all be decomposed) would not, in his opinion, yield sufficient hydrochloric acid to destroy a large quantity of iron; and he therefore thought that some other action assisted at least in the destruction of the metals. He further stated that his experience of boiler deposits containing copper was limited to one case. This deposit, which was found by him on the old boiler of a steamship about six years ago, contained a compound of copper mixed with carbonate of lime, and he considered the presence of carbonate of lime in it incompatible with the supposition that the copper was dissolved or corroded by hydrochloric acid. Judging from the local nature of the corrosion in the boiler to which their attention had been drawn that night, and considering that the part destroyed was probably at times raised to a red heat, he was inclined to think that the iron had been decomposing water, and had in that way become oxidized. He agreed with Professor Foster that the copper deposit on the cylinder clearly indicated the decomposition of a compound of copper by the iron of the parts coated. As to the corrosion of the copper pipes, he believed that in the presence of water and common salt an oxychloride of copper might be produced, which opinion was confirmed by the fact that Professor Foster had found an analogous compound, the oxychloride of zinc, on the brass throttle valve of a steam engine. In reply to a question by Mr Davison, as to whether a high temperature was always necessary to the continued oxidation of iron, Dr Machattie stated that rusting or oxidation took place at the ordinary temperature of the air, and, if once begun, would go on continuously in the presence of water, and especially of salt water. But, he further remarked, the oxide formed at a red heat was the magnetic or black oxide of iron, and was different from the red oxide or rust formed at lower temperatures; and, on account of such distinctions in the products of corrosion under various conditions, he thought that an examination of such products or deposits would, in most cases, clearly indicate the circumstances in which they had been produced, and the causes of their formation.

Professor Foster said he thoroughly agreed with Dr Machattie's opinion, that the only way of definitely deciding how the deposits were formed was by examining them chemically. He had had very little opportunity of doing so himself; but in the case of the deposit scraped off a brass throttle valve of an engine, he had found chlorine and zinc—in fact, the deposit seemed to be mostly oxychloride of zinc, the zinc having dissolved out from the brass, leaving the copper with its red colour below.

Mr W. M. Neilson suggested whether it would not be well to get some of the deposits analysed.

The meeting generally approved of the suggestion, and Dr Machattie was requested to undertake the duty.

On the Incrustations of Marine Boilers. By Mr James R. Napier.

In the Transactions of this Institution, 1859-60, will be found a paper which I wrote, chiefly for the purpose of showing that regenerators, as ordinarily constructed, were much too small for the object intended. But I have there also stated (page 46) that "when these regenerators are made with a sufficient amount of surface, so that abundance of water can be supplied to and discharged from the boilers with little loss of heat, then there will be *no incrustations*, &c." In the last paragraph of the paper I have, with more caution, said "that this amount of discharge and surface, *it is expected*, will prevent incrustation, and save nine-tenths of the heat at present lost by the ordinary method of blowing off."

The object of the present communication is to show that the practice here recommended leads to results the very opposite of what was expected. Believing, as I then did, in the ordinary theory of blowing off from the boiler before the water became saturated with salts, that an abundant feed and blow-off would prevent the lime depositing, and therefore prevent the incrustations; and being desirous of saving the heat which would otherwise be lost by the great amount of blow-off which I believed to be necessary, I had a regenerator made for the S.S. *Lancefield* with about 10 times the surface which it had been customary to give to such apparatus; but the results, as stated at a recent meeting, were so much at variance with my understanding of the ordinary theory, that I think a statement of the facts will help others to a clearer knowledge of the matter.

The vessel, then, sailed from Glasgow about noon every Thursday for the Hebrides, lay in one of the lochs there from Saturday evening till Monday morning, and arrived again in Glasgow on Wednesday, to re-commence on Thursday a similar voyage. The steam was up or at hand all the voyage; about fifteen stops, of two or three hours each, were made each week, during which time the boiler was supplied with feed by a Giffard's injector, but little or no blow-off. While steaming, however, the quantity of water continually discharged through the regenerator was so great that the glass hydrometer used for ascertaining the density showed very little difference between the sea and the boiler water. The boiler was worked in this manner for about four weeks, and then examined; when, instead of being found, as I expected, clean, with little or no scale or deposit, the coating was much thicker than usual, but soft, very much like newly made mortar, not difficult, before getting dried, to scrape off all accessible places, but which when dry was nearly as difficult of removal as the ordinary compact scale.

During one of the voyages, when I was personally directing the experiment, and had for some time been keeping the greatest amount of feed on the boiler which the engine could supply, I observed the water in gauge glass get muddy, but did not then discover the cause. About two years before this I found the same soft limy deposit in the S.S. *Islesman's* boiler, when trying similar experiments on the same station; but as I had disregarded the *Islesman's* experience, and did not then know the experience of others, the *Lancefield's* regenerator was continued, but with lesser quantities of feed and discharge, for about six months, when, the tubes of the apparatus giving way, it was discontinued. I was fortunately saved further trouble, and the expense of repairing it, by discovering, in the *Annales des Mines* for 1854, an interesting paper by M. Cousté "On the Incrustations of Boilers." He there shows that the sulphate of lime can be deposited by heat alone, without any evaporation, and that, at a temperature of 124° Cent., or two atmospheres of pressure, sea water in its natural state is very near the point of saturation. As the *Lancefield's* boiler was loaded to nearly 40 lbs. of absolute pressure, and worked generally at about two atmospheres, or 255° Fahr., or about the point of saturation of the lime, it is clear that the greater the amount of sea water supplied to the boiler, the greater would be the quantity of lime deposited in it. And although there was a constant discharge from the surface by a conical tube, only some of the deposited matter—that which had not attached itself to the boiler—could be so discharged. If this be not the true explanation of the great deposit in the *Lancefield's* boiler, of the difficulty of working boilers with sea water at higher pressures, and of the ordinary experience that boilers are cleaner when worked at a greater density, it will remain for others to explain it,

M. Cousté's experiments, however, appear to me to be conclusive. He suggests a method of getting quit of the lime by filtration at a high temperature. The following extract from his paper shows the conclusions he arrived at from his experiments:—

1. "The sulphate of lime is less soluble in hot than in cold fresh or sea water.

"For temperatures above 100° Cent. the solubility of the sulphate of lime in sea water diminishes nearly in proportion to the increase of temperature; and, consequently, this solubility diminishes very rapidly with the corresponding increase of pressure.

"The following Table indicates this solubility for different temperatures, as well as the degrees of concentration at which the saturation of sulphate of lime has place:—

"*Solubility of Sulphate of Lime at different Temperatures above 103° Cent.*

Degrees of the Areometer corresponding to the Saturation.	Temperatures.	Pressures in Atmospheres.	Solubility or Proportion of Sulphate of Lime in 100 of Water at Saturation.	Degrees of Areometer.	Temperatures.	Pressures.	Solubility.
	Degrees.	Atmos.			Degrees.	Atmos.	
12½	103·00	1	0·500	6	118·50		0·226
12	103·80		0·477	5	121·20		0·183
11	105·15		0·432	4	124·00	2	0·140
10	108·60	1¼	0·395	3	127·60		0·097
9	111·00		0·355	2	130·00	2¼	0·060
8	113·20		0·310	1	133·30		0·023
7	115·80	1½	0·267				

"This table expresses that, for example, sea water boiling at atmospheric pressure, or 103°, will arrive at saturation of sulphate of lime when it will have acquired the concentration of 12·5° of Beaumé, and then it will contain 0·500 per cent. of this salt; at 1·25 atmospheres, or 108·6° of temperature, the water will be saturated with sulphate of lime, when the areometer marks ten, it will then contain 0·395 per cent. of sulphate of lime; at two atmospheres, or 124° of temperature, sea water in its natural state, and before it has experienced any concentration, is very near the point where the saturation takes place—for the natural water marks from 3 to 3·5°, —and in this case the saturation takes place at 4° of concentration.

2. "Sulphate of lime becomes wholly insoluble either in sea water or in soft water at temperatures comprised between 140° and 150° Centigrade; and if we expose at these temperatures water containing some of this salt in solution, it is entirely precipitated in the form of little crystals, or of very thin pellicles according as the salt is more or less abundant in the solution. The sulphate thus precipitated is redissolved after the cooling, but as much more slowly as the temperature at which it is deposited is elevated. That which is deposited at 150° takes many days to redissolve."

In the discussion which followed the reading of the paper,

Mr Elder said he had had a good deal to do with the working of boilers at from 30 lbs. to 35 lbs. pressure without surface condensers, and in some cases he had seen very extraordinary deposits. One naturally expected to find most deposit in the section of a boiler where there was most salt and lime; but in a boiler divided into eighteen parts he had found, to his surprise, that although in the last section there were two and a half times more salt in the water than in that of the first section, yet he could ascertain little difference in the quantity of deposit of lime in any section. He had therefore come to the same conclusion as the President, that the deposit depended upon the temperature of the water, and not upon the quantity of lime in it. The great difficulty they had to contend with in preventing deposit was that of keeping the circulation in such a state as that the currents would prevent the deposit, for it was found that where there was a current in a boiler the lime did not deposit to any extent. There was certainly no evidence to show that the lime deposited more on account of the presence of a greater quantity of it. The Americans ran with a pressure of 40 lbs. at sea, and they did not appear to suffer much from deposit. They seemed to overcome the deposit of lime by cleaning the boiler whenever they got into port. He was aware of boilers working at 30 lbs. for six or seven years, and the deposit was not greater with that than at lower pressures. He was quite satisfied, with the President, that the lime deposited with pure sea water, and with sea water having twice or thrice the usual quantity of salt in it, was the same.

Mr LAWRIE remarked that apparently it was Mr Napier's opinion that beyond a certain pressure the deposit of sulphate of lime was not aggravated by an increased pressure.

Mr ELDER observed that though the lime separated from the water, yet it did not necessarily settle down unless it got into eddies. Where the heating surface was, it had no great tendency to deposit. It was found that the deposit occurred in places where there was no great current.

Mr LAWRIE said that they would naturally expect to find it down below the furnace. He asked whether it had been found in practice that there was a greater or less deposit in boilers working at 60 lbs. pressure than at 30 lbs.? He would infer from the discussion that the deposit of sulphate of lime was not greater at the higher pressure.

Mr ELDER had observed boilers working with salt water for three or four months at 45 lbs. pressure, and he could not say there was much difference between the deposit at that pressure and at 25 lbs. He believed, however, there was a greater tendency for the lime to separate from the water, but it did not necessarily settle down over the heating surface of the boiler.

Mr LAWRIE said that the gunboats, of which the late Mr Hughes had great experience, worked at a pressure of 60 lbs., and no extreme difficulties had been experienced in them.

Professor THOMSON suggested that the water might be filtered in a tube 10 or 12 feet long, in which it could be heated up to 150° Cent., but this would probably take a good deal of power.

Mr ELDER remarked that nearly every engineer knew of examples of furnace crowns and furnace sides of steam boilers with salt water tumbling in on account of the deposit of lime or salt on those parts; and it was always considered to be the result of too little blowing off, any such accident being prevented by sufficient blowing off. Were there not other deposits formed at a greater degree of saturation? Suppose they had a quadruple strength of salt in the boiler, was the salt deposited of an injurious kind when it got to a certain density? When did the injurious deposit begin? He believed that when water got to those densities, the lime and the salt formed a crust, and became a non-conductor, and the surface got nearly red-hot, and tumbled in. Now, if the lime came out at a temperature of 220°, one would suppose that it would do the same at 230° or 240°. He would have expected that the furnace of the *Lancefield* would have fallen in.

Mr JAS. R. NAPIER answered that the sides of most furnaces bulged between the stays, but he did not know the cause of it.

Mr LAWRIE remarked that there seemed to be one very important fact ascertained—that the extensive use of refrigerators could not be attended with the good that was expected from them.

Mr JAS. R. NAPIER explained the construction of the *Lancefield's* regenerator, and, in reply to inquiries, stated that it was about 12 feet high, 20 inches in diameter, and fitted with iron tubes of about ½-inch bore. The tubes gave way at the bottom, near the feed inlet. It was very efficient while it lasted. Where there was less water discharged there would be less heat to be saved. Still, the regenerator would always be useful in saving a great portion of the heat that would otherwise be lost.

Mr ELDER had observed that the regenerators in the *Shamrock* and *Thistle* wore away rapidly at the ends of the tubes, which were of brass, where the current of water impinged against them, which he believed arose from the mechanical friction caused by the velocity of the water. He would have expected that iron tubes would have gone much more quickly; for in the cases he had mentioned there was no appearance of galvanic action.

Mr LAWRIE said the old refrigerators did not wear away quickly, although the water struck against their brass ends.

Mr THOMAS RUSSELL had seen regenerator tubes worn away both from mechanical action and other causes, such as by rust; whilst he also knew that they worked about ten years in the West India boats, and yet seemed pretty perfect after that, and certainly not worn out; so much so, that, when they got new boilers, they repaired their regenerators, and continued to work them for years after that. He did not know whether they were still working them.

Description of a Hydraulic Engine for working Organ Bellows.

SEE PLATE VII.

Read 16th March, 1864.

In Plate VII., Fig. 1 is a side elevation, and Fig. 2 is a vertical section, at right angles to Fig. 1, of a small hydraulic engine constructed a number of years ago by Mr Elder, sen., for Mr Robert Napier, and in use at his residence, West Shandon, for working the bellows of an organ. Upon a quadrangular cast-iron base piece, A, formed with connections for the inlet pipe, B, and outlet pipe, C, and with suitable internal passages, there is fitted a valve casing, D, and upon this are erected two vertical brass cylinders, E, F, which are single-acting, being fitted with pistons, G, H, packed with cupped leathers. The piston rods, I, J, are connected to levers, K, L, from which the motion is transmitted to the bellows. A light brass framing supports the levers, K, L, and the upper ends of the piston-rod guides. The inlet and outlet to each cylinder are regulated by two three-way cocks, M, N, fitted in the valve box, D; and the spindles of the cocks are fitted externally with balance discs and with levers, which levers are connected by links, P, to levers on two rocking shafts, Q, above. One of the rocking shafts, Q, is tubular, and the other passes through it, the two working independently of each other. The rocking shaft acting on the cock, M, of one cylinder, E, is fitted with an arm, R, disposed so as to be acted upon by pins on the piston rod, J, of the other cylinder, F; and a similar arm, S, acted on by pins on the other piston rod, I, actuates the cock of the cylinder, F. In Fig. 2 the cylinder, E, is shown full, whilst the cylinder, F, is emptying. On the piston, H, reaching the bottom of its stroke, it would cause the cock, M, to discharge from the other cylinder, E, and on the piston, G, reaching the bottom of its stroke, the cock, N, would be turned to admit water into the cylinder, F; then, on this becoming full, the cock, M, would be turned to admit water to the cylinder, E, and on its being filled, the cock, N, would be turned to discharge again from the cylinder, F—the positions in the figure being thus resumed. In this way the action is continuous so long as the throttle valve, T, does not become closed by the distended state of the reservoir compartment of the bellows, to which compartment it is connected by a rod.

On Renewing the Substructures of Railway Bridges and Viaducts without Stopping the Traffic. By Mr J. DOWNIE.

SEE PLATE VIII.

Read 13th April, 1864.

ONE of the most difficult problems in our railway engineering of the present day is the *renewal* of part of the so-called "permanent way," especially in such structures as are made the subject of this short paper; and as many of the bridges and viaducts of our railways have been constructed of timber, &c., it is simply a question of time as to the *necessity* for the renewal of all such with materials of a more substantial character, to suit the existing and future requirements of our increasing traffic in that now all-important branch of our carrying trade.

Unfortunately, each case is surrounded with local difficulties of its own, besides the inseparable difficulties common to all; and on the subject of renewal being approached, when action *must* be taken, it is then found to be no easy matter to provide, not only for the public safety *without* detention to the passenger and freight trains, but to carry out the necessary operations with safety to life and limb of those engaged in the construction of such important works. As time is, and must always be, the all-important element in carrying out *successfully* the designs that are put in the hands of the contractors who undertake this class of work, it may not be altogether uninteresting to the meeting to have a short account given of the salient features of some very interesting examples of railway bridge building and renewals that have been recently completed.

At the time of the original construction of such works, stone work would have increased very much their first cost, as compared with timber, &c.; but it is to be questioned whether, with the cost of these *necessary* renewals *added*, it would not have been *true* economy to have made all such in masonry.

As it is, the conditions imposed, and the necessities of the traffic, render such a material as stone almost inadmissible for such renewals, and the engineer is in a manner forced to choose the next best lasting material for the purposes of his designs—viz., iron or steel.

Figs. 1 and 2, Plate VIII., exhibit the viaduct over the valley of the Nethan, on the Lesmahagow Branch of the Caledonian Railway. This was originally a timber structure, on the laminated arch principle, as shown in Fig. 2; and being a "single line" railway, the difficulties in the way of keeping the traffic open with such a ricketty roadway of partially rotten timber, and at same time raising in the *same* foundation line the necessary intermediate iron piers, &c. (to a height of about 145 feet above the bed of the stream), for the new iron roadway, was a work of no ordinary anxiety to the engineer, especially as the usual scaffolding or staging was in this case discarded in the erection of the new work.

To effect this a line of rails were laid on balks of timber, secured to the longitudinal stringers that ran across the ends of the transverse beams of the old roadway; and on these rails traversing "Goliath cranes," high enough to allow the engines, &c., to run under them, spanned across and overhung the timber structure—so that the materials for the new piers were lifted out of the railway trucks by the travelling crab winches overhead, and dropped down by the friction brakes to the workmen suspended underneath from the old superstructure on an arrangement of "flying stages," with the means of hoisting or lowering themselves to any level to suit the progress of the work. The new bridge, Fig. 1, exhibits the introduction of the "Crumlin-viaduct" principle of piers alternating with the existing stone piers, and is a very beautiful example of *safely* utilizing an expensive part of such a structure, designed originally for the adaptation of a totally different material.

A slight examination will show that the piers of the masonry here are much too thin at top to sustain the strain of heavy lattice girders, such as those used at the Clyde Viaduct, referred to in a subsequent part of this paper; and the wisdom of reducing the spans 50 per cent., while, at same time, a much stronger fabric is got with less weight of materials, is very apparent, and clearly a great gain every way.

Figs. 5, 6, and 7 are sections, showing the mode of joining the iron work of the piers and their bracings, and it is submitted to the meeting as an improvement on the method used at "Crumlin," and some other viaducts constructed on the same principle. In point of fact, it would have been very difficult to have erected this structure with the same degree of accuracy and safety without this dovetail arrangement for the bracings of each stage of the cast-iron work, coupled with the bored-out thimbles or collars fitting the turned ends of the columns, thus avoiding bolts, which on principle are bad in such a structure, simply because they shake loose with the passage of the trains, and can never be depended on like a turned and bored fit of some 2 feet in depth, where no such fastenings are required, and where you have the strain transmitted from top to bottom of the entire piers, metal to metal, in a direct line.

During the construction of this new substructure, the traffic of the line was regularly maintained, not only while the piers were being erected, but while *all* the main girders were being placed in position, and this was effected so far in consequence of the rails being raised some nine feet two inches, or so, above their former level, so as to get rid in a great measure of the inclined planes, 1 in 125 and 1 in 66, at either end of the viaduct; and while the earthwork necessary for this purpose was being executed, the superstructure of iron work, consisting of the usual transverse girders and longitudinal beams, as shown on cross section, Fig. 3, and in side view in Fig. 4, were put on, and all finished off satisfactorily, without accident of any kind. Had the *same* level of rails been maintained, no stoppage whatever would have been necessary.

I have dwelt thus long on this example of renewal, principally in consequence of the traffic being conducted entirely on a "*single* line" of rails, and also because it possesses several novel features that might be interesting to the members of the Institution.

Where a *double* line of rails exist, such as at the Calder, Esk, and Gartsherrie Viaducts, on the Caledonian Railway main line, and the Tay Viaduct on the Perth and Dundee line, all of which have been recently renewed in stone and iron, there is much less difficulty, because only one-half of the old roadway requires to be broken up, the train shunted over on the untouched portion, and all brought slowly and safely along in charge of the "Pilot," whose duty it is to travel on *each* engine, and thus prevent the remotest chance of accident by collision or otherwise.

Even with the best possible precautions as to the safety of the public and those engaged in these *necessary* renewals, it does not lessen the anxiety or risk of those concerned in conducting such operations; and it argues a great deal in favour of the use of iron or steel in such works, that nearly all the materials necessary can be prepared in the workshop, and brought to the site of the bridge or viaduct ready for fixing, with *practically no* loss of time or detention to the traffic, enormous as it has now become on all our main lines of railway.

Fig. 9 represents a viaduct designed for a French railway, combining piers of masonry about 150 feet high, having on top iron piers, on the Crumlin plan, about 100 feet high; these latter carrying bowstring and lattice girders of about 150 feet span. This has not yet been executed, but it shows how a deep ravine may be crossed with great economy of materials.

The model before the meeting, and Fig. 10 of Plate VIII., represent the "Clyde Viaduct," erected last year on the Douglas Branch of the Caledonian Railway.

This is *not* a renewal, but is brought before the Institution at this time because it is referred to in contrast with another design in a previous part of this paper, and were it postponed till next session, it might not then be convenient to have the model in illustration of it.

It is an excellent specimen of the application of the "bowstring and lattice" principle to the main girders that carry the roadway, and reflects great credit on Mr George Graham, the engineer who designed it, and whom we have the honour to rank among our members.

It has a singularly light and airy appearance, and shows at a glance that no materials have been thrown away upon it; while its strength and rigidity is very ample for the work, as was proved by the fact that, with a test of some 350 tons of rolling stock, consisting of the heaviest goods engines, coupled up and driven full tilt along the viaduct, the deflection on these main girders was only ⅜ths of an inch at centre, with a clear span of 115 feet between supports.

This bridge is carried on cast-iron cylinders sunk in the sandy bed of the river, and filled up some little height above flood level with concrete, leaving upwards of 40 feet of the upper portion of the cylinders without any filling. This is an interesting and instructive feature in Mr Graham's design, seeing it has added to the stability of the structure, and quite met his previous anticipations in this respect. Certainly, it has reduced the cost more than £1000 on the item of concrete over the viaduct—a result, I doubt not, interesting to the shareholders from a pecuniary point of view, as well as to us as engineers from a practical one; and I think it is well to bring out such facts in bold relief before our Institution, so that they may not only be known, but much more generally followed, where economy and efficiency are thus found combined.

Although this subject may be most interesting to perhaps only *one* section of our members—viz., railway engineers—I may be excused for bringing it forward, when it is considered, that although we are not all *directly* connected *with* railways, yet we all travel very frequently *by* them, and it is important to know that every improvement and safeguard that engineering ingenuity can reach is being daily applied to render the public comfort and safety in railway transit more complete.

The discussion on this paper took place at the adjourned meeting on 27th April, 1864, when

Mr D. M'Call said the subject of Mr Downie's paper was a most interesting one to railway engineers; but, unfortunately for the title of the paper, Mr Downie had scarcely given them a single instance of the renewal of railway bridges without stopping the traffic. The Clyde Viaduct was a new bridge altogether; and the Nethan Viaduct was not renewed without stopping the traffic.

Mr J. Downie said that the paper described how the Nethan Viaduct was renewed, and with a very short stoppage to the traffic. The great difficulty was felt in consequence of the Nethan being a single line, and having the rails raised above their former level, although there was no difficulty in constructing the new viaduct on the old foundation. It might be interesting if they were informed why the old bridge was made at the bottom of two inclines. As regarded a double line, it was easy to renew it by turning the traffic over to the one line, as described in the paper, while the other was being relaid.

Mr D. M'CALL answered that the Lesmahagow Railway was got up at a very depressed period in the history of railways; and the Nethan viaduct was made only 140 feet high, so as to reduce the cost. The viaduct must be at the bottom of two inclines, as the railway descended for a long distance on each side towards the great valley of the Nethan, and it depended on the height of the bridge, what extent of level line there was between the inclines. At first there were 150 yards level; there were now more, as the viaduct had been raised a few feet. That viaduct of 140 feet high and 300 yards long cost only £12,000 originally; but he believed that the renewal and strengthening by means of the new piers, although advantage was taken of the old stone piers, cost considerably more.

Mr R. FAULDS believed the original bridge was almost tumbling before it was finished.

Mr D. M'CALL said Mr Faulds was mistaken: the spaces of 100 and 120 feet were of very fair timber work; but laminated timber arches were not rigid enough for the heavy engines now used. The piers were of excellent ashlar masonry, and were still in the present bridge.

Mr R. FAULDS said wooden bridges were not so durable as iron or stone. In this case, however, he begged leave to take exception to the quality of the work. Laminated wood bridges required extra care in putting together.

Mr D. M'CALL believed it would have stood a much longer time.

Mr G. GRAHAM said that this viaduct was got up immediately after the great railway mania, when for four or five years no railway was constructed but with very great difficulty, and generally only with the assistance of the gentlemen in the district. This caused those lines to be made very much as the landowners wished; and hence the place that had been chosen for that viaduct, which was certainly not a very good site. He had reason to think that it had been made in a cheap way, because no more money could be got, and was not so substantial as was considered necessary now; but the proprietors were quite satisfied with their bargain.

Mr D. ROWAN objected to fault-finding in a general way, and would like to hear defined what were the faulty parts of the original viaduct—wheth t was in the design, or in the use of wood, or in defective workm hip.

Mr 1 FAULDS did not mean to find fault with the design; but every one knew that unless timber work was well seasoned before being erected, it would warp and give way very speedily.

Mr A. SMITH had been disappointed with the paper. From its title he had expected to get some information regarding the renewing of railway bridges without stopping the traffic; but he had not at all been enlightened on the subject. He thought that at present there were great facilities for renewing railway bridges, in the fact that they had the railway to carry materials, which it would have been impossible to have conveyed to the spot otherwise.

In reply to Mr J. Milne, Mr G. GRAHAM said the Nethan viaduct had stood about seven years from the opening of the branch.

Mr D. M'CALL remarked that it was commenced in 1853, and was used for locomotive traffic for a considerable time before the railway was opened throughout.

Mr T. DAVISON remarked that they heard a good deal about the decline of wooden bridges; but he would like to know if there were any data for the age of iron bridges. Was any means taken to prevent the decay of the cast-iron cylinders on which the bridges rested? He had observed that about the water line some of them seemed rusting away; and to prevent this, they were being protected with wood in the Thames. From all appearances, they would not have a long life.

Mr D. M'CALL questioned whether stone piers would not have been both better and cheaper in the Clyde Viaduct. Salt water affected cast-iron very injuriously, and doubtless the iron cylinder at the surface of fresh water would be seriously acted upon, unless properly protected.

Mr J. DOWNIE, in reply to the general discussion, remarked that he thought the very beautiful method which had been adopted for renewing the Nethan bridge deserved to be brought under their notice. Of course, difficulty with renewals only occurred on single lines, and those it was almost impossible to renew without a slight stoppage of the traffic. As regarded the title of his paper, he would remark that the term *Substructure* could not mean the *rails* or mere *roadway*, which, in the case of the Nethan viaduct, obviously could *not* be renewed without a slight stoppage.

Mr S. J. V. DAY instanced a railway in Wales where a single line had been renewed without stopping the traffic, and explained on the black board how this had been done.

Mr G. GRAHAM saw no difficulty in renewing a single line without stoppage of traffic, if the new bridge was on the same level as the old.

Mr J. DOWNIE remarked that that was the difficulty that met them in the Nethan bridge, which was raised 9½ feet. Otherwise, no doubt, the bridge could have been built on the same foundations, without cessation of traffic, even for the few days that it did take place.

On Valves and Valve Gearing for Steam Engines. By Mr W. Inglis.

SEE PLATE IX.

Read 13th April, 1864.

The valves generally used for the distribution of steam in the steam engine may be divided into two classes—viz., sliding valves and lifting valves. To the latter class belong the double-beat balance valves. Among the former may be classed all valves which open and close the ports by sliding over the valve faces.

It is essentially necessary in any arrangement of valves that they should admit and release the steam to the cylinder at the proper times, and that any escape of steam should be prevented when the ports are closed. Another point of great importance is, that the valves should be capable of being moved easily, and that the amount of power required for working them should be as small as possible. In the common arrangement of slide valves, the pressure tending to press the valves to the face is always so great that a very considerable power is required to move them; and notwithstanding that various means have been designed to relieve the valves of this pressure, yet practically the difficulty can be only partially overcome. The friction caused by this pressure not only renders the moving of the valves difficult, and induces rapid wear on the valve faces and connections, but, what is perhaps more important, it limits to a great extent the size of the ports in large engines.

In this paper the writer's principal object is to describe arrangements of double-beat valves and American Corliss valves which he has designed for several steam engines. Both these systems of valves possess the important peculiarity of requiring much less power to work them than ordinary slide valves. Double-beat valves can be so nearly balanced as to permit of their being moved with great ease, and in this respect perhaps cannot be surpassed. One disadvantage, however, which prevents their being adopted for quick-working engines, is, that they are not at all suited for high speeds, on account of the noise and concussion caused by the valves falling into their seats when worked quickly. The system of valves known as Corliss valves consists of a series of cylindrical slides, which receive a rocking motion from central valve spindles, the spindles being worked by levers fitted on their ends. The valves are placed near the ends of the cylinder, each cylinder having two induction and two eduction valves.

As in the arrangement of double-beat valves, the steam and exhaust valves are separate; but in the Corliss system there are also separate ports or passages for the admission and eduction of the steam. Another peculiarity of the Corliss system is the method of giving a very quick motion to the valves when being opened or closed; but when the ports are nearly full open, the valves move very slowly, as they also do when the ports are closed. This is usually accomplished by an arrangement of levers set on a central disc plate, and fitted in such positions that, when one steam valve is receiving its motion, and while the lever working it is at its most effective point for making the valve travel quickly, the lever giving motion to the opposite steam valve will be at or near its dead point.

The same relative motions are imparted to the exhaust valves. The steam valves are opened against the resistance of springs. The valves can be made to cut off the steam at any point up to half-stroke by being liberated from the valve rods, when they are instantly closed by the action of the springs.

The arrangement of double-beat valves is almost invariably used on the engines of American river steamers. In these boats frequent stoppages have to be made, and the engines require to be moved quickly by hand. A good arrangement of gear for working these valves has been designed by Mr Gilbert, of Montreal. The gear is a modification of the variety known as the long toe cut-off, the steam and exhaust valves being worked by separate eccentrics. The point at which steam can be cut off from the cylinder is not variable, without altering the position of the long toes or wipers on the rocking shaft, as well as the eccentric. For this reason the gear is usually set to cut off the steam at a fixed point of the stroke. The usual proportion of valve opening is $\frac{1}{10}$th the area of cylinder; but this depends somewhat on the speed at which the engines are intended to work: with a speed of piston of 600 feet per minute, about one-eighth the area of cylinder is allowed for the valve opening. These valves, even when applied to the largest engines, can be worked by hand with an ordinary starting bar, and it requires but a very slight exertion of one man to move them. The valves and seats, when made wholly of cast-iron, are found to answer well in practice. In some cases, however, brass is used for the valves and seats.

It is necessary, when the valves are of brass, that the connection between the top and bottom discs should be of cast-iron; otherwise, on account of the difference of expansion between brass and iron, the valves would not fit down on their seats when heated by the steam. Double-beat valves, either of iron or brass, are always more or less affected by the difference in the expansion of the valves and casing. The best way to insure their being tight is to grind them up in their places when the chests are heated by steam.

The engine shown in Plate IX., Figs. 1 and 2, was designed by the writer for driving a paddle steamer having feathering wheels, and was fitted with the arrangement of Corliss valves, as shown. Being a beam engine, it was designed somewhat after the usual style of American engines—the frame of wrought-iron plates—and the valves and gearing are the only parts which differ materially from the usual arrangements. The engine was constructed at Montreal, Canada, in 1861. In Fig. 1 the cylinder, air pump, &c., are shown in section; and Fig. 2 is a side view of the cylinder, showing the arrangement of the valve gearing. In this engine the valves and passages for admitting steam to the cylinder are separate and distinct from the exhausting valves and passages, the cylinder being provided with two steam valves and two exhaust valves. In Fig. 2 the disc plate is shown, with the valve rods connected, for working the valves. The hand wheel marked A is for regulating the point at which the steam valves are liberated from the rods, and the steam cut off. The point at which steam will be cut off from the cylinder can be varied in this way from about half-stroke down to a point when no steam is admitted. At whatever point the steam may be cut off, the exhaust valves open to the full extent of the port, their motion not being affected by the closing of the steam valves. The cylinder of this engine is 60 inches in diameter × 8-feet stroke. The engine makes about 32 revolutions per minute with 40 pounds steam, developing over 1500 indicated horses power. The steam ports are 50″ × 4″, and the exhaust ports 50″ × 6″. The boat being a river steamer requiring to stop frequently, it was necessary that the engineer should be able to move the valves quickly, and have them fully under control for stopping, reversing, &c. No engine of such a large size as this one had previously been fitted with this system of valves; and it was expected that, as the valves were large, a man would be unable to work them with a starting bar. The writer therefore designed the small cylinder shown in Fig. 2, to be worked by water from the boilers, for giving motion to the valves when the eccentric rod was disconnected; but when the engine was completed it was found that, with a starting bar about 5 feet long inserted in the wrist plate, one man was quite able to move the valves; and this plan has been adhered to in preference to the small cylinder. The valves are found to wear well, remain tight, and give perfect satisfaction.

Fig. 3 is a side elevation of a horizontal condensing engine, with a cylinder 24 inches diameter and 3 feet 6 inches stroke. This and a non-condensing engine, with a 24-inch cylinder and 4-feet stroke, were designed by the writer to drive the machinery in paper mills near Edinburgh, and have been constructed by Mr Robert Douglas, Kirkcaldy. They are fitted with the American Corliss valves, with the writer's patented improvements in the springs and gear. The governor on these engines, instead of acting on a throttle valve to regulate the speed, is connected so to vary the expansion. The steam is thus always admitted at full pressure on the piston, and cut off from the cylinder at points of the stroke varying according to the amount of resistance the engine has to overcome.

In all cases where the power required is variable, and where a governor has to be used, it must be apparent that the method of regulating the speed of the engine, by varying the point of cut-off, is far superior to the method more usually adopted of effecting the regulation by a throttle valve. By having the point of suppression under the control of the governor, the full benefit of expansion is obtained at all times.

The Corliss valves are particularly suited for horizontal engines, on account of the facility afforded for the escape of water from the cylinders. The exhaust valves being situated at the lowest point, the water escapes at once when the ports are opened at each stroke.

The discussion on this paper took place at the adjourned meeting on 27th April, 1864, when,

In answer to questions, Mr Wm. Inglis said that the Corliss valves described in the paper had iron facings, and they wore very well. In the engine shown in Figs. 1 and 2 they had worked perfectly, without difficulty, for three years. He had seen cylindrical valves running ten years without being scraped up more than once during that time. The engine referred to had a 32-inch cylinder, and it ran in fresh water. The friction upon the face was very little. He had not made any particular calculation for the engine shown, to compare the space between the port and the valve, in the present arrangement, and with double-beat valves; but he had no doubt it would compare very favourably in this respect. The largest engine he had seen fitted with this valve was one with a 36-inch or 38-inch cylinder. He had not applied the valves to engines larger than the one with a 60-inch cylinder. This engine worked at about thirty-two revolutions per minute. When the engine was projected there was a question whether the double-beat valves would work well at that speed. In some of the engines he had seen running about twenty-six revolutions per minute on the river Hudson, the long toe used to descend more quickly than the valve would follow by gravitation, and the valves were noisy unless springs were used. This was one of the reasons for putting the Corliss valves into that engine. The arrangement with cylindrical valves was better than flat slides, with which they could not get the motion so handily. The valves had a very quick motion when opening and closing, and a very slow motion in the interval. He did not know that there was any particular virtue in the round valve, except that it made a neater mechanical arrangement, with less friction on the faces. He had drawn out a design with slide valves; but the round valve was deemed to be decidedly better, as there was no way to make the others equal in mechanical arrangement. There was very little difficulty felt in facing them up; but it was not often required, as the friction was very little, and not nearly so great as with the ordinary slide valve, from the great pressure that was upon it. The valves were very well suited for horizontal engines. Every time the port was open there was free egress for the water, the steam valves being on the top, and the exhaust valves at the bottom.

Mr J. Brownlee said it was an obvious improvement to have the exhaust valves at the bottom rather than at the top; but it did not apply to this valve alone. Did Mr Inglis never find any difficulty in keeping double-beat valves tight?

Mr W. Inglis replied that it depended on how they were finished. If they were ground, when they were expanded by heat there would not be much fear of leakage.

Mr T. Davison remarked that a good deal depended upon the shape and the material of which double-beat valves were made.

Mr J. Brownlee observed that the difficulty of making the two valves fit their seats accurately was obviated in a kind of valve applied to steam hammers by Mr Paton. He sketched the valve on the board, showing how the pressure on a single valve was equilibrated by counter pressure on a piston attached to the valve, and working in a cylindrical chamber. He asked whether the arrangement of the improved valves was such as enabled them to alter the cut-off?

Mr W. Inglis replied that, by turning a hand wheel, the point of cut-off was varied from giving no steam at all up to half-stroke.

Mr T. Davison said another recommendation of the valve was the ease of working in case of a break down. The steam-ship *Atlantic* had broken down 700 miles from land, and the engineers worked it by hand to shore, making eleven or twelve revolutions per minute.

Mr W. Inglis had known of an instance in which the valves had been hand-worked for thirty miles. The exhaust port was about six inches wide, and the valve was eight. There was a lap of an inch at each end. In regard to its economical value, he might state that he knew of an engine which had run five years without facing; and the engine he had already referred to had run three years without any injury to the valve facings. In engines worked night and day there was no difficulty experienced with them. He then showed, in answer to Mr Downie, how the governor attachment was made to give the precise amount of steam at any particular part of the stroke in the horizontal arrangement, which was by merely shifting the point of a lever; this was his own patented arrangement. Engines fitted with those valves were economical in the consumption of coal; but he would not state precisely to what extent, as he had not made any very accurate experiments. He had replaced a common slide valve with those in a 37-inch cylinder, with 8-feet stroke, and the saving of fuel in three months paid for the cylinder. In some of the mills in Providence he had been informed that the consumption of coal with those valves was only 2½ lbs. per horse power per hour, with non-condensing engines, carrying about 50 lbs. or 60 lbs. of steam. There was one remarkable case in which Mr Corliss sold an engine of this arrangement under a stipulation as to the saving of coal, which resulted in his being paid 19,000 dollars instead of 10,000 dollars for the engine.

Mr J. Brownlee said that the saving of fuel could not always be attributed to the improvements supposed to be introduced, as that saving often arose in a great measure from the superior working condition of the engine. He had frequently seen about half the fuel saved by simply facing the valves, re-fitting the piston, and putting the different parts in good working order. The fuel consumed by one engine compared with another, of which nothing was known, was therefore no criterion. The question of economy or real efficiency of the engine could be decided only by determining the weight of water evaporated, and the work which that steam performed.

Mr J. Downie approved highly of the plan of proportioning the steam by the action of the governor. He had seen various plans, but none that appeared so simple as that of Mr Inglis.

INSTITUTION OF ENGINEERS IN SCOTLAND.

SEVENTH SESSION, 1863-64.

MINUTES OF PROCEEDINGS.

The First Meeting of the Session was held in the Hall, Anderson's University, Glasgow, on Wednesday, 28th October, 1863, James R. Napier, Esq., President in the Chair.

Four new Honorary Members and Four new Members were proposed.

The Report of the Council, issued with the Notices calling the Meeting, was held as read, and was approved of.

William Johnstone, Esq., President for the Fifth Session, 1861-62, presented the Gold Medal of the Institution for the Best Paper read during that Session, to the successful Competitor,

Dr W. J. Macquorn Rankine,

for his Paper *On the Liquefaction of Steam in the Cylinder of an Engine working Expansively*, read 5th February, 1862.

The President, James R. Napier, Esq., delivered an Introductory Address.

A Paper was read *On the Expansive Energy of Heated Water*, by Dr W. J. Macquorn Rankine. The Discussion of this Paper was postponed.

A Paper was read *On Turned and Bored Joints for Gas and Water Main Pipes*, by Mr John Downie. A Discussion followed the reading of this Paper.

Report of the Council, October, 1863.

During the recess the Council have held various meetings, and made the following arrangements :—

In terms of the minute of last General Meeting regarding the appointment of Secretary, they resolved that on or before 1st February, 1864, an advertisement be inserted in the newspapers, inviting parties to offer themselves as Candidates for the Secretaryship of the Institution.

The following appointments have been made in terms of the Regulations :—

Library Committee.

W. J. M. Rankine, LL.D., Librarian and Convener.
R. Bruce Bell.
James G. Lawrie.

Sub-Librarian.

James M'Lagan, 204 George Street.

Editing Committee.

W. J. M. Rankine, LL.D.
R. Bruce Bell.
James G. Lawrie.
The Secretary, Convener.

Committee on Accounts.

A. Smith.
J. M. Gale.
J. Brownlee.
The Treasurer, Convener.

The Regulations appearing to require some modifications, Messrs Napier, Rankine, Smith, and Johnstone, have been appointed to revise them. Members of the Institution having any changes to suggest, are requested to communicate their views to this Committee. The alterations proposed will be submitted to the Institution at an early date.

Books have been presented to the Institution from—

Messrs David Kirkaldy,
„ C. W. & F. Siemens,
„ J. F. Spencer,
General Arthur Morin,

and letters of thanks sent to the donors.

The Library Committee have added several works to the Library, a List of which, with the donations referred to above, accompanies this Report.

The Editing Committee have made an alteration in the binding of the Transactions, which the Council hope will give satisfaction. They also contemplate an improved arrangement of the printed papers and business of the Institution, with the view of rendering the Transactions more valuable.

Subscriptions have been received "for the purpose of founding a Prize "Medal for the promotion and encouragement of improvements in Iron "Shipbuilding, Marine-Engine Making, and all Engineering Works "connected with Steam Marine—to be given annually by the Institution "of Engineers in Scotland for the best communications and greatest "improvements in connection with the construction, the economy, and "the safety of such important works."

Subscriptions have also been received "for the purpose of founding a "Prize Medal for the promotion and encouragement of improvements "in the construction, practice, and economy of Railway Works—to be "given annually by the Institution of Engineers in Scotland, for the "best communications and the greatest improvements relating to such "important undertakings."

In accordance with the above, two Prize Medals will be given for communications brought forward during the present Session.

The Council expect to bring before the Institution communications on the following subjects:—

"On the Expansive Energy of Heated Water." By Professor RANKINE.
"On the Jointing of Water Pipes." By Mr JOHN DOWNIE.
"On the Glasgow Corporation Water Works." By Mr J. M. GALE.
"On a Cotton Press, and on Hydraulic Presses." By Mr DAVID MORE.
"Experiments with a Rotatory Steam Engine." By Mr JAMES PLATT.
"On Gas Furnaces." By Mr SIEMENS.
"On Breakwaters." By Mr JOHN MOFFAT.
"Experiments with Frith's Coal-Cutting Machine." By Mr DALGLISH.
"On the Means of Preventing the Liquefaction of Steam in Steam Engine Cylinders." By Mr BEARDMORE.
"On Raising Sunken Vessels." By Mr BELL.
"On a Blowing Fan for Drying Malt." By Mr JAMES R. NAPIER.
"On Pistons of Locomotives." By Mr PATRICK STIRLING.

Members are requested to send their communications to the Secretary, or to any Member of Council, as early as possible, to enable the Council to make suitable arrangements.

It has been arranged to hold the Ordinary General Meetings during the present Session in the Hall, Anderson's University, 204 George Street, as formerly. The First Meeting will take place on Wednesday, 28th October, at 8 p.m.

At the end of the Session 1861-62, the Institution comprised the following :—

6 Honorary Members, 163 Members, 4 Associates, 12 Graduates.

During the past Session, 1862-63, there were less by retirement or death—

1 Honorary Member, 4 Members, 2 Graduates.

whilst during the same period there joined the Institution—

12 Members, 1 Associate, 3 Graduates.

making a total, at the commencement of the present Session, of—

5 Honorary Members, 171 Members, 5 Associates, 13 Graduates.

The Council, desirous of increasing the stability and influence of the Institution, would urge the importance of introducing new and suitable Members.

The Second Meeting of the Session was held in the Hall, Anderson's University, Glasgow, on Wednesday, 25th November, 1863, James R. Napier, Esq., President, in the Chair.

The following were elected Honorary Members :—

General Arthur Morin.
Joseph Whitworth, Esq.
Nicholas Wood, Esq.
Archibald Smith, Esq.

The following were elected Members :—

Mr F. WISE, London.
Mr R. DOUGLAS, Kirkcaldy.
Mr A. WALKER, Stranraer.
Mr W. ROBERTSON, Glasgow.

A new Member was proposed.

A discussion took place on the Paper by Dr W. J. M. RANKINE, read on 28th October, *On the Expansive Energy of Heated Water.*

Parts I., II., and V. were read, of a Paper *On the Glasgow Water Works*, by Mr J. M. GALE. The discussion thereon was commenced and adjourned.

The President exhibited *Captain J. R. Ward's Life Belt*, and *Messrs Wright & Co.'s Silver Tube Pressure Gauges for Steam and Water.*

Mr GALE showed, in motion, and explained *Schiele's Turbine for Small Powers.*

Donations received :—

Admiralty Manual : Deviations of the Compass, 2nd Edition, 1863. From Archibald Smith, Esq., F.R.S.

Proceedings of the Institution of Mechanical Engineers, 7th May, 1863. From the Institution.

The THIRD MEETING of the Session was held in the Hall, Anderson's University, Glasgow, on Wednesday, 23rd December, 1863, JAMES R. NAPIER, Esq., President, in the Chair.

The following was elected a Member :—

Mr SAMUEL FERNIE, Nottingham.

Seven new Members were proposed.

Parts III. and IV. were read of a Paper *On the Glasgow Water Works*, by Mr J. M. GALE. A discussion followed the reading of the Paper.

Mr J. M. GALE again showed, in motion, and explained *Schiele's Turbine for Small Powers;* and some discussion took place thereon.

Mr G. RUSSELL exhibited and explained *Gamble's Salinometer for Marine Boilers;* and some discussion took place respecting Salinometers.

Donations received:—

Ueber den Unterschied zwischen activem und gewöhnlichem Sauerstoffe. From the Author, Prof. R. Clausius, Hon. Memb., I.E.S.

Proceedings of the Scottish Shipbuilders' Association, 5th October, 2nd November, 1863. From the Association.

A SPECIAL MEETING was held in the Hall, Anderson's University, on Tuesday, 12th January, 1864, JAMES R. NAPIER, Esq., President, in the Chair.

A number of alterations in the Regulations were discussed and agreed to. These alterations are embodied in the Regulations as printed in the present volume.

The FOURTH MEETING of the Session was held in the Institution Hall, 204 George Street, Glasgow, on Wednesday, 20th January, 1864, JAMES R. NAPIER, Esq., President, in the Chair.

The following were elected Members :—

Mr W. Beardmore, Glasgow.
Mr W. R. Copland, Paisley.
Mr W. Moore, Glasgow.
Mr J. Donald, Paisley.
Mr R. Wilson, Paisley.
Mr J. Binnie, Glasgow.
Mr C. Gunn, Glasgow.

The President stated that, in terms of the Minute of 26th November, 1862, a Prize Medal was to be awarded by the Council for the best paper read during the preceding Session, 1862-63; that the Council had decided to make the award in accordance with the opinion of a majority of the Members; and that, considering the terms of the Minute referred to, they had decided that the following were "papers" entitled to compete :—Mr Russell's paper, p. 52; Mr Warner's, p. 55; Mr Napier's, p. 63; Mr Napier's, p. 66; and Mr Downie's, p. 77,—all in Vol. VI. of the Transactions. It was necessary, however, that the Meeting should accept this decision or amend it before taking the votes.

After some discussion it was agreed, on the motion of Mr R. G. Ross, seconded by Mr W. M. Neilson, that Mr Kirkaldy's communication, at page 27, should be allowed to compete.

The votes were then taken, when fifteen voted in favour of Mr Kirkaldy's communication, and six in all voted otherwise.

Mr W. M. Neilson introduced the subject of a proposed visit to Glasgow of the Institution of Mechanical Engineers, with the view of ascertaining the feeling of Members present towards the proposal; and in the course of his remarks read a letter he had received from the Secretary of that Institution. After some discussion, Mr D. Rowan proposed that—"The Secretary be instructed to intimate to the Institution of Mechanical Engineers that their Secretary's letter had been considered, and that they might rely on receiving a cordial welcome from this Institution." This motion was seconded by Mr Neilson. It was then moved as an amendment by Mr J. M. Gale, and seconded by Mr A. Smith :—"That before communicating with the Institution of Mechanical Engineers in the manner proposed, the matter be remitted to the Committee already appointed, with instructions to report to an early Meeting of Council." On the votes being taken they were equal, but the Chairman gave the casting vote to the amendment, which was declared carried.

The following Papers were read :—*On Cotton and other Presses*, by Mr D. More; and *On Trials of the Speed of Steam Vessels in a Tideway*, by Dr W. J. M. Rankine.

Discussions followed the reading of both papers, that on the latter being adjourned.

Boyd's Mechanism for forming Imitation Selvages in weaving fabrics to be divided was exhibited, as applied to a small but completely fitted working model of a loom.

Donations received :—

Proceedings of the Institution of Mechanical Engineers, 4th and 5th August, 1863. Part I. From the Institution.

Ueber einen Grundsatz der mechanischen Wärmetheorie. By R. Clausius. From the Author.

The FIFTH MEETING of the Session was held in the Institution Hall, 204 George Street, Glasgow, on Wednesday, 17th February, 1864, JAMES R. NAPIER, Esq., President, in the Chair during the first part of the proceedings, and J. G. LAWRIE, Esq., Vice-President, subsequently.

The following were elected members :—

Mr HUGH MUIR, Engineer, 12 Walworth Terrace, Glasgow.
Mr WILLIAM PRENTICE, Engineer, 115 Dumbarton Road, Glasgow.
Mr W. R. M. THOMSON, Engineer, 268 Bath Street, Glasgow.
Mr JAMES COPLAND, Engineer, 15 Rose Street, Garnethill, Glasgow.
Mr PETER MORISON, Engineer, Shaws' Water Works, Greenock.
Mr ST. J. V. DAY, Civil Engineer, 166 Buchanan Street, Glasgow.
Mr THOMAS KENNEDY, Water Meter-Maker, Kilmarnock.
Mr G. M. NEILSON, Engineer, Hyde Park Street, Glasgow.
Mr STEPHEN ALLEY, Engineer, 11 Carnarvon Street, Glasgow.
Mr JAMES GOODWIN, Founder, Ardrossan.
Mr NEIL M'HAFFIE, Founder, 8 Broad Street, Mile-End, Glasgow.
Mr HENRY DUBS, Engineer, 2 Wellesley Place, Glasgow.
Mr C. R. LAWSON, Engineer, Mountblue Works, Glasgow.

The following was elected a Graduate:—

Mr C. H. L. Fitzwilliams, Graduate Mechanical Engineer, 479 St. Vincent Street.

Prize Medal for Session 1862-63:—The following Notice by the Council was read. "The Council have great pleasure in awarding the "Prize Medal for Session 1862-63 to Mr David Kirkaldy for his com-"munication, reported at page 27 of Vol. VI. of the Transactions of the "Institution, in accordance with the votes taken at the Meeting on "20th January, 1864; believing that, although the communication may "not be considered to be a 'Paper' in the strict sense of the term, the "award will nevertheless be acquiesced in."

An adjourned discussion took place on Dr Rankine's Paper, read 20th January, *on Trials of the Speed of Steam Vessels in a Tideway.*

A Paper was read *On the Effects of Superheated Steam and Oscillating Paddles on the Speed and Economy of Steamers.* A Discussion followed and was adjourned.

A Paper was read *On the Incrustations of Marine Boilers*, by Mr James R. Napier, and was followed by a Discussion.

Donations received:—

Transactions of the Royal Scottish Society of Arts, Vol. VI., Part III. From the Society.

On the Relative Deflection of Lattice and Plate Girders. By B. B. Stoney, B.A., M.R.I.A., C.E. From the Author.

The Sixth Meeting of the Session was held in the Institution Hall, 204 George Street, Glasgow, on Wednesday, 16th March, 1864, W. Simons, Esq., Vice-President, in the Chair.

A note from the President was read, excusing his absence.

The following was elected a Member:—

Mr W. Renny Watson, Engineer, 1 Royal Bank Place, Glasgow.

Messrs D. More and W. Ramsay were appointed Auditors, in accordance with Regulation 17.

A discussion, continued from 17th February, took place on the Paper *On the Effects of Superheated Steam and Oscillating Paddles on the Speed and Economy of Steamers.*

Mr D. MORE described a screw bolt contrived by Mr ROBERT ELDER, on the principle of a lewis, for inserting in a hole in a ship's bottom from the inside and under water, or in other situations accessible on one side only.

A Paper was read on "The Distribution in the City," being Part VI. of a Paper on *The Glasgow Water Works*, by Mr J. M. GALE. A Discussion followed.

Drawings were exhibited and explained of Elder's, Joy's, and Kennedy's Hydraulic Engines for working Organ Bellows, &c. Elder's engine is described and illustrated in the accompanying report. Joy's is described in the *Proceedings of the Institution of Mechanical Engineers* for 25th June, 1857, and Kennedy's is a simple adaptation of his Water Meter, described in the *Practical Mechanics' Journal* for 1st December, 1855.

Donations received :—

Proceedings of the Scottish Shipbuilders' Association, 7th December, 1863.

Proceedings of the Institution of Mechanical Engineers, 4th and 5th August, 1863. Part II.

The SEVENTH MEETING of the Session, being the Annual General Meeting for the Election of Office-Bearers, was held in the Institution Hall, 204 George Street, Glasgow, on Wednesday, 13th April, 1864, R. BRUCE BELL, Esq., Vice-President, in the Chair.

The following were elected Members :—

Mr JAMES M'LEISH, Engineer, 54 St. Enoch Square, Glasgow.
Mr WILLIAM JOHNSON, Civil Engineer, 166 Buchanan Street, Glasgow.
Mr THOMAS R. HORTON, Mechanical Engineer, 15 Scotia Street, Glasgow.

The Treasurer's Annual Financial Statement was held as read, and was approved of. It is given at pages 132, 133.

OFFICE-BEARERS were elected in place of those retiring at the end of the present Session; the following being

COUNCIL FOR THE EIGHTH SESSION, 1864-65:—

President.

JAMES R. NAPIER.

Vice-Presidents.

J. G. LAWRIE. | J. M. GALE. | J. BROWNLEE.

Councillors.

W. M. NEILSON.
R. B. BELL.
D. ROWAN.
D. MORE.
A. DUNCAN.
J. DOWNIE.
B. CONNER.
W. J. M. RANKINE.
W. JOHNSTONE.
P. STIRLING.

Treasurer.

D. M'CALL.

Mr J. F. SPENCER exhibited a number of Surface-condenser Tubes which had been in use for three years, and explained that a case of corrosion, noticed in his absence at a previous meeting, was due to special causes, and was entirely exceptional.

The following Papers were read:—*On Valves and Valve Gearing for Steam Engines*, by Mr WILLIAM INGLIS; and *On Renewing the Substructures of Railway Bridges and Viaducts without Stopping the Traffic*, by Mr JOHN DOWNIE.

The Meeting was adjourned to the 27th April, for the purpose of discussing the Papers read.

TREASURER'S STATEMENT—SESSION 1863-64.

Dr.

1863. April 15th.	To Balance in Bank, ...		£578 7 9	
	,, ,, in hand, ...		1 13 8	
				£580 1 5
April, 1863, to Mar., 1864.	To Subscriptions— From 135 Members,	@ 30s,	£202 10 0	
	,, 4 New Members	@ 50s,	10 0 0	
	,, 5 do.	@ 40s,	10 0 0	
	,, 11 do.	@ 30s,	16 10 0	
	,, 4 Associates	@ 20s,	4 0 0	
	,, 1 New do.	@ 40s,	2 0 0	
	,, 6 Graduates	@ 15s,	4 10 0	
	,, 1 New do.	@ 10s,	0 10 0	
				250 0 0
	To Arrears of Subscriptions— From 21 Members, 1862-63,	@ 30s,	31 10 0	
	,, 2 New do.	@ 50s,	5 0 0	
	,, 1 Graduate	@ 15s,	0 15 0	
	,, 3 Members, 1861-62,	@ 30s,	4 10 0	
	,, 1 New do.	@ 50s,	2 10 0	
	,, 1 Graduate	@ 15s,	0 15 0	
	,, 1 Member, 1860-61,	@ 42s,	2 2 0	
				47 2 0
1864. March 3rd.	To Interest of London and North-Western Railway Preference Stock, ...			3 16 5
April 4th.	,, Bank Interest, ...			8 13 8
	,, Balance due to Treasurer, ...			2 6 3
				£891 19 9

Cr.

1864. April 4th.	By Secretary's Salary, ...	£100 0 0
	,, Fees to Officer, Sub-Librarian, and Janitor, 1862-63.	11 0 0
	,, Rent of Hall, 1862-63, ...	15 0 0
	,, Cost of 300 Copies of the Transactions, Vol. VI., and of Circulars, Stationery, &c., 1862-63, ...	71 1 3
	,, Postage, Porterage, &c., ...	9 12 6
	,, Reporter, 1862-63, ...	8 8 0
	,, Books and Library Expenses, ...	66 12 3
	,, Commission for Collecting Subscriptions,	3 10 6
	,, Advertisements for Secretary, ...	0 18 0
	,, Cost of Medal Die, ...	13 13 0
	,, Cost of Preference Stock, London and North-Western Railway, ...	363 13 5
	,, Letter of Credit for same, ...	0 6 11
	,, Balance in Union Bank, ...	228 3 11
		£891 19 9

Glasgow, *5th April, 1864*.—We have examined the foregoing Statement, and compared it with the relative Vouchers, and find the whole correct—the Balance being, in Preference Stock of the London and North-Western Railway, Three hundred and sixty-three pounds Thirteen shillings and Fivepence; in the Union Bank, Two hundred and twenty-eight pounds Three shillings and Elevenpence; and due to the Treasurer, Two pounds Six shillings and Threepence; leaving at the credit of the Institution, Five hundred and eighty-nine pounds Eleven shillings and one Penny.

(Signed) D. MORE, W. RAMSAY, } *Auditors.*

PRIZE MEDAL FUND.

Dr.

1863. April 15th.	To Balance in Union Bank, ...	£317	14	11
1864. April 4th.	,, Subscriptions, ...	40	0	0
	,, Interest on Railway Preference Stock, ...	3	9	2
	,, Bank Interest, ...	4	3	3
		£365	7	4

Cr.

1863. Oct.	By Gold Medal for 1861-62, ...		£10	5	6
	,, Preference Railway Stock, ...	£330 0 0			
1864. April 4th.	,, Balance in Union Bank, ...	21 12 8			
	,, ,, in Treasurer's hands,	3 9 2			
			355	1	10
			£365	7	4

Glasgow, *5th April, 1864*.—We have examined the foregoing Statement relative to the Prize Medal Fund, compared it with the Vouchers, and find the same correct—the Balance being, in Preference Stock of the London and North-Western Railway, Three hundred and thirty pounds; in Union Bank, Twenty-one pounds Twelve shillings and Eightpence; and in Treasurer's hands, Three pounds Nine shillings and Twopence;—in all, Three hundred and fifty-five pounds One shilling and Tenpence.

(Signed) D. MORE, W. RAMSAY, } *Auditors.*

CAPITAL ACCOUNT.

London and North-Western Railway Preference Stock, ...	£363 13 5	
In Union Bank, ...	228 3 11	
	£591 17 4	
Deduct Amount due Treasurer, ...	2 6 3	
		£589 11 1

MEDAL FUND.

London and North-Western Railway Preference Stock, ...	£330 0 0	
In Union Bank, ...	21 12 8	
Balance in Treasurer's hands, ...	3 9 2	
		355 1 10
		£944 12 11

An Adjourned Meeting, being the Eighth Meeting of the Session, was held in the Institution Hall, 204 George Street, Glasgow, on Wednesday, 27th April, 1864, J. G. Lawrie, Esq., Vice-President, in the Chair.

The Chairman presented the Prize Medal for Session 1862-63 to Mr David Kirkaldy, for his communication *On Experiments on Wrought Iron and Steel*; making the following remarks:—

"These prize medals have hitherto been awarded by the votes of the Members of the Institution, and seeing that we meet here on a footing of equality—that we do not know and do not acknowledge any difference of wealth or social position—that we recognize no distinctions but those of superior intelligence, it is most honourable and most meritorious for any of us to receive at the hands of his fellows one of these prize medals. While, however, it is honourable for the successful competitor to receive the medal, it is no less satisfactory to the Institution that, by the means which have been adopted for awarding these prizes, they have been bestowed in wisdom and with propriety. For my own part, through a considerable experience in matters of this kind, I have never known an instance in which prizes that have been awarded by general voting have been conferred otherwise than with fairness and justice. The merits of Mr Kirkaldy's work this Institution is peculiarly fitted to judge and appreciate. We see the ability displayed in the investigations: we know the immense labour and untiring perseverance which it requires. Mr Kirkaldy has not confined his investigations to an inquiry into the strength of different qualities of iron and steel, but has extended them to an examination of the origin of the differences of strength arising from the conformation of the material; he has elaborated most carefully the apparent difference of strength due to the contraction of the breaking section; he has measured the amount of extension or stretching—which, in a sense, is a measure of malleability,—caused by the breaking loads in the different materials tested; he has traced out the effect of both cold and hot rolling and tensile extension on the strength of materials; he has investigated the different and relative properties of iron and steel—which are due to quality of material, to original manufacture, to the treatment of the material by workmanship after manufacture, to the kind of use to which the material is applied; and he has not omitted the effect of the climate in which the material is used. To recount all the judicious inquiries which Mr Kirkaldy's work embraces would be to read the book itself, with which all of you are already familiar, and to detain you with a narration which is much better left in

Mr Kirkaldy's own words. I now, therefore, on the part of the Institution, have great pleasure in presenting to Mr Kirkaldy this honourable and well-merited prize."

Discussions took place on Mr WILLIAM INGLIS' Paper, read 13th April, *On Valves and Valve Gearing for Steam Engines;* and on Mr JOHN DOWNIE's Paper, also read 13th April, *On Renewing the Substructures of Railway Bridges and Viaducts without Stopping the Traffic.*

This terminated the business of the Session.

On 1st June, 1864, the Council appointed MR J. P. SMITH, 42 BATH STREET, GLASGOW, to be Secretary to the Institution from 1st July, 1864.

List of Honorary Members, Members, Associates, and Graduates of the INSTITUTION OF ENGINEERS IN SCOTLAND, *at the Termination of the Seventh Session*, April, 1864.

HONORARY MEMBERS.

JAMES PRESCOTT JOULE, LL.D., F.R.S.

CHARLES PIAZZI SMYTH, F.R.SS.L. & E., Astronomer-Royal for Scotland.

WILLIAM FAIRBAIRN, C.E., LL.D., 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.

General ARTHUR MORIN.

JOSEPH WHITWORTH, C.E.

NICHOLAS WOOD.

ARCHIBALD SMITH, M.A, F.R.S.

MEMBERS.

James	Aiken, jun.,	Cranstonhill Foundry, Glasgow.
William	Aiton,	Engineer and Contractor, Partick.
William	Alexander,	Government Inspector of Mines, Glasgow.
Alexander	Allan,	Scottish Central Railway, Perth.
Thomas	Allan,	Springbank Foundry, Garscube Road, Glasgow.
Stephen	Alley,	17 North Claremont Street, Glasgow.
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.
William	Beardmore,	The Forge, Parkhead, Glasgow.
R. Bruce	Bell,	4 Bothwell Street, Glasgow.
James	Binnie,	26 Berkeley Terrace, 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.
W. S.	Brown,	Edinburgh and Glasgow Railway, Cowlairs.
James	Brownlee,	City Saw Mills, Port-Dundas, Glasgow.
James C.	Bunten,	Anderston Foundry, Glasgow.

James T.	Caird,	Greenock.
Duncan	Cameron,	Springfield Iron Works, M'Neil St., Glasgow
James	Campbell,	Elliot Works, Finnieston, Glasgow.
Peter	Carmichael,	Dens Works, Dundee.
John	Carrick,	City Architect, Glasgow.
Robert	Cassels,	23 St. Enoch Square, Glasgow.
Daniel K	Clark,	11 Adam Street, Adelphi, London.
James	Clinkskill,	3 Rose Street, Garnethill, Glasgow.
Benjamin	Conner,	Caledonian Railway, Glasgow.
Robert	Cook,	100 Commerce Street, Glasgow.
William R.	Copland,	Burgh Engineer, Paisley.
James	Copeland,	15 Rose Street, Garnethill, Glasgow.
William	Cowan,	Gt. North of Scotland Railway, Aberdeen.
Archibald	Craig,	Gateside, Paisley.
George	Crawhall,	Elliot Works, Finnieston, Glasgow.
Thomas	Davison,	Belfast.
St. J. V.	Day,	166 Buchanan Street, Glasgow.
William S.	Dixon,	1 Dixon Street, Glasgow.
James	Donald,	Abbey Works, Paisley.
John	Donald,	21 Robertson Street, Glasgow.
Robert	Douglas,	Dunnikier Foundry, Kirkcaldy.
John	Downie,	13 Clarendon Place, Glasgow.
Henry	Dubs,	2 Wellesley Place, Glasgow
Andrew	Duncan,	16 Robertson Street, Glasgow.
George B.	Edington,	7 Buckingham Terrace, Glasgow.
John	Elder,	12 Centre Street, Glasgow.
Robert	Faulds,	6 Parson Street, Glasgow.
James	Ferguson,	Auchinheath, Lesmahagow.
Samuel	Fernie,	Bloomsgrove Works, Nottingham.
William	Ferrie,	Monkland Iron Works, Calderbank.
J. R.	Forman,	133 West Regent Street, Glasgow.
William	Forrest,	9 Canal Street, Glasgow.
Robert	Forrester, jun.,	Ardeer Iron Works, Stevenston, Ayrshire.
Alexander	Fullerton,	Vulcan Works, Paisley.
John B.	Fyfe,	Canal House, Ardrishaig.
James M.	Gale,	Engineer to the Glasgow Corporation Water Works.
Andrew	Galloway,	16 Clyde Place, Glasgow.
John	Galloway,	Kilmarnock.
Archibald	Gilchrist,	33 St. Vincent Crescent, Glasgow.
David C.	Glen,	Greenhead Works, Glasgow.
James	Goodwin,	Ardrossan.
Henry	Gourlay,	Dundee Foundry, Dundee.
George	Graham,	Caledonian Railway, Glasgow.
Walter	Grant,	9 Dorset Street, Glasgow.

Archibald	Gray,	Middleton, near Dalry.
James	Gray,	New Cumnock, Ayrshire
Matthew	Gray,	Gourock.
Thomas C.	Gregory,	149 West George Street, Glasgow.
Charles	Gunn,	102 to 114 Union Street, Glasgow.
George	Harvey,	Albion Machine Works, Glasgow.
James	Henderson,	7 Exchange Place, Glasgow.
James M'L.	Henderson,	Renfrew.
John	Hendrie,	Kirkwood, Coatbridge.
Thomas R.	Horton,	15 Scotia Street, Glasgow.
James	Howden,	128 West Street, Tradeston, Glasgow.
Edmund	Hunt,	28 St. Enoch Square, Glasgow.
James	Hunter,	Newmains, near Motherwell.
John	Hunter,	Dalmellington Iron Works, near Ayr.
John	Inglis,	60 Warroch Street, Glasgow.
John	Inglis, jun.,	60 Warroch Street, Glasgow.
William	Johnson,	166 Buchanan Street, Glasgow.
Ronald	Johnstone,	138 West George Street, Glasgow.
William	Johnstone,	Glasgow and South-Western Railway.
Angus	Kennedy,	132 St. Vincent Street, Glasgow.
Thomas	Kennedy,	Kilmarnock.
David	Kirkaldy,	28 Bartholomew Road, North, Kentish Town, London, N.W.
David	Laidlaw,	Alliance Foundry, Glasgow.
Robert	Laidlaw,	Alliance Foundry, Glasgow.
John W.	Law,	7 Park Circus, Glasgow.
James G.	Lawrie,	Whiteinch.
C. R.	Lawson,	Mountain-Blue Works, Camlachie.
John	Lawson,	Mountain-Blue Works, Camlachie.
James G.	Leadbetter,	13 Gordon Street, Glasgow.
H. C.	Lobnitz,	Renfrew.
John	M'Andrew,	27 North St. Mungo Street, Glasgow.
David	M'Call,	133 West Regent Street, Glasgow.
Thomas	M'Culloch,	Vulcan Foundry, Kilmarnock.
James J.	M'Dermont,	Winton Buildings, Ayr.
John	Macdonald,	87 Union Street, Glasgow.
Walter	Macfarlane,	Saracen Foundry, Glasgow.
James	M'Gregor,	Partick.
Neil	M'Haffie,	8 Broad Street, Mile-end, Glasgow.
James	M'Ilwham,	Anderston Foundry, Glasgow.
John	Mackenzie,	Dundyvan, Coatbridge.
Robert	Maclaren,	Eglinton Foundry, Glasgow.
James	M'Leish,	54 St. Enoch Square, Glasgow.

Walter	MacLellan,	127 Trongate, Glasgow.
Hugh H.	Maclure,	65 Sauchiehall Street, Glasgow.
John	M'Michael,	55 Drygate, Glasgow.
John	M'Nab,	Dumbreck Priory, Paisley Road, Glasgow.
William	Macnab,	Shaws Water Foundry, Greenock.
Andrew	M'Onie,	Scotland Street Engine Works, Glasgow.
Daniel	Miller,	4 Bothwell Street, Glasgow.
James	Milne,	16 Windsor Ter., St. George's Rd., Glasgow.
James B.	Mirrlees,	Scotland Street Iron Works, Glasgow.
John M.	Mitchell,	83 Jamaica Street, Glasgow.
John	Moffat,	Ardrossan.
William	Moore,	4 West Regent Street, Glasgow.
Ralph	Moore,	Jane Bank Villa, Cambuslang.
David	More,	33 Montrose Street, Glasgow.
Peter	Morison,	Shaws Water Works, Greenock.
Hugh	Muir,	12 Walworth Terrace, Glasgow.
Matthew A.	Muir,	Anderston Foundry, Glasgow.
James	Murdoch,	Lancefield Forge, Glasgow.
James R.	Napier,	22 Blythswood Square, Glasgow.
John	Napier,	Lancefield Foundry, Glasgow.
Robert	Napier,	West Shandon.
G. M.	Neilson.	Hyde Park Street, Glasgow.
Walter	Neilson,	172 West George Street, Glasgow.
Walter M.	Neilson,	Hyde Park Foundry, Glasgow.
William	Neilson,	Mossend Iron Works, Bellshill.
John	Norman,	Pulteney Street Engine Works, Glasgow.
John W.	Ormiston,	Shotts Iron Works, Motherwell.
John	Paton,	Govan Foundry, Glasgow.
R. F.	Pearce,	Clyde Foundry, Glasgow.
William	Prentice,	115 Dumbarton Road, Glasgow.
William	Ramsay,	37 West George Street, Glasgow.
Charles	Randolph,	12 Centre Street, Glasgow.
W. J. Macquorn	Rankine,	59 St. Vincent Street, Glasgow.
William	Reid,	76 Hill Street, Garnethill, Glasgow
David	Ritchie,	Glasgow.
James	Robertson,	Alliance Foundry, Glasgow.
William	Robertson,	116 St. Vincent Street, Glasgow.
Hazelton R.	Robson,	2 Tulliallan Place, Paisley Road, Glasgow.
Neil	Robson,	127 St. Vincent Street, Glasgow.
Robert	Robson,	133 West Regent Street, Glasgow.
Richard G.	Ross,	Greenhead Engine Works, Glasgow.
David	Rowan,	Cranstonhill Foundry, Glasgow.
John M.	Rowan,	Atlas Works, Glasgow.
George	Russell,	16 St. Enoch Square, Glasgow.
James	Russell,	16 St. Enoch Square, Glasgow.

Thomas	Russell,	Clydebank Foundry, Glasgow.
John	Scott, yngst.,	Greenock.
Thomas	Shanks,	Johnstone.
Thomas	Sherriff,	12 Monteith Row, Glasgow.
William	Simons,	London Works, Renfrew.
Alexander	Simpson,	175 Hope Street, Glasgow.
George	Simpson,	172 West George Street, Glasgow.
Alexander	Smith,	Eglinton Engine Works, Glasgow.
David	Smith,	37 West George Street, Glasgow.
David	Smith,	St. James' Foundry, Glasgow.
George	Smith,	Sun Foundry, Port-Dundas Road, Glasgow.
Hugh	Smith,	3 Rutland Place, Govan Road, Glasgow.
James	Smith, jun.,	54 St. Vincent Street, Glasgow.
John	Smith,	Garscube Road Engine Works, Glasgow.
William	Smith,	Eglinton Engine Works, Glasgow.
John F.	Spencer,	St. Nicholas Buildings, Newcastle-upon-Tyne.
Robert	Steel, jun.,	Greenock.
Andrew M.	Stewart,	Founder, Irvine.
David Y.	Stewart,	St. Rollox, Glasgow.
Patrick	Stirling,	Glasgow & S.-Western Railway, Kilmarnock.
A. Morton	Strathern,	103 Burnside Street, New City Rd., Glasgow.
Peter	Sturrock,	Kilmarnock.
William	Tait,	Scotland Street Iron Works, Glasgow.
W. R. M.	Thomson,	268 Bath Street, Glasgow.
Thomas C.	Thorburn,	Town Surveyor's Office, Birkenhead.
David	Tod,	Meadowside Works, Partick.
William	Tod,	Clyde Foundry, Glasgow.
John	Tulloch,	Dumbarton.
George	Urie,	101 Commerce Street, Glasgow.
Matthew	Waddell,	Cleland, near Motherwell.
Alexander	Walker,	Portpatrick Railway, Stranraer.
William	Wallace,	Liverpool.
W. Renney	Watson,	1 Royal Bank Place, Glasgow.
William	Weir,	Eglinton Iron Works, Kilwinning.
Alexander	Whitelaw,	Gartsherrie House, Coatbridge.
Isaac	Whitesmith,	29 Govan Street, Glasgow.
John	Wilkie,	33 Renfield Street, Glasgow.
James E.	Wilson,	Clutha Iron Works, Glasgow.
Peter	Wilson,	96 Stirling Road, Glasgow.
Robert	Wilson,	Abbey Works, Paisley.
Thomas	Wingate, jun.,	Whiteinch.
Francis	Wise,	Chandos Chambers, Adelphi, London.
Robert	Young,	Caledonian and Dumbarton Railway, Bowling.
John	Yule,	111 Rutherglen Loan, Glasgow.

ASSOCIATES.

A. Orr	Ewing,	2 West Regent Street, Glasgow.
Robert	Gardner,	2 West Regent Street, Glasgow.
William	Hall,	Bellevue, Irvine.
George T.	Hendry,	8 Dixon Street, Glasgow.
James	Young,	Limefield, West Calder.

GRADUATES.

Thomas	Black.	Charles B.	King.
Constancio	Costa.	Thomas	Roberts.
C. H. L.	Fitzwilliams.	W. C. T.	Sloan.
Guilherme	Fox, jun.	Cornelius	Thompson.
William	Inglis.		

REGULATIONS

OF THE

INSTITUTION OF ENGINEERS

IN SCOTLAND.

As Amended at a Special General Meeting of the Institution, 12th January, 1864.

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, appointed by the Council, who shall receive such salary as the Institution shall fix, but who shall not be a Member of the Institution.

Section IV.—DUTIES OF OFFICE-BEARERS.

11. The Office-bearers shall assume office immediately after the close of the Session in 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. He shall be a Member, *ex officio*, of all Committees of Council.

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, except books, papers, drawings, models, and specimens of materials; 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; write the correspondence of the Institution and Council; read minutes and notices at Meetings; report discussions; collect subscriptions; perform whatever other duties are indicated in the Regulations of the Institution as appertaining to his department; and, if desired by the Council, prepare and revise papers for reading and publication, and read papers and communications at the Meetings.

Section V.—AUDIT OF ACCOUNTS.

17. Two Auditors, who shall be Members of the Institution, but not Office-Bearers, shall be chosen at an Ordinary Meeting preceding the Annual General Meeting of each Session, to examine the accounts and statements produced by the Treasurer; and the Annual Financial Statement, with their Audit, shall be printed in the notice calling the Annual General Meeting, and shall be read at that Meeting.

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, after which notices of motion may be given. The paper or papers for the evening shall then 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 four 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 circulars stating the business so far as known.

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, in accordance with instructions from the Council. Each paper shall have prefixed to it the date at which it shall have been received by the Secretary.

28. Explanatory notes communicated after the reading or discussing of papers may be printed in the Transactions, if the Council see fit, but not without having prefixed the dates at which they shall have been received by the Secretary.

29. The copyright of any paper read at a Meeting of the Institution, with its illustrations, 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.

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 they shall be sold to the public at such prices as the Council shall fix. Authors of papers shall be entitled to twelve separate copies of their papers as printed in the Transactions.

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 name of the Candidate shall be inserted in the notice calling the first ensuing Ordinary Meeting of the Institution; and the Candidate shall be balloted for at that Meeting, 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 an Ordinary Meeting of the Institution. The person shall be balloted for at the following Ordinary 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 of the General Meeting; 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 required in order to supply vacancies (except the Secretary) shall be severally elected by ballot at an Annual General Meeting, such Meeting being the last Ordinary Meeting held in each month of April.

36. The Members of Council shall each hold his office for not more than two years; and every retiring Office-Bearer shall be ineligible to the office from which he retires until after being a year out of it; excepting the Treasurer, who may be re-elected any number of times without interval.

37. Of the three Vice-Presidents, two shall retire the year the President continues in office, but only one the year the President retires; and of the ten Councillors, five shall retire each year, the other five retaining office without re-election. The retiring Members shall be those who have been longest in the offices; or, in case of one or more having to be selected from two or more who are equal in this respect, then the selection shall fall on the one or more having the fewest votes when originally elected.

38. A vacancy occurring during any Session, in consequence of the resignation 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.

39. The Subscriptions noted in the following Table shall be payable on election and at the first Meeting of each Session, by every Member, Associate, and Graduate respectively:—

	Member.	Associate.	Graduate.
	£ s.	£ s.	£ s.
If Elected in October or November ...	2 10	2 0	1 0
If Elected in December or January ...	2 0	1 10	0 15
If Elected during the remainder of the Session	1 10	1 5	0 10
And every October thereafter	1 10	1 0	0 15

40. Honorary Members shall pay no contributions.

41. No Member nor Associate whose contribution is in arrear shall be entitled to vote.

42. 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.

43. 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 BY-LAWS.

44. 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.

45. 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 four days' notice, and detailing the alteration or addition proposed to be made.

46. Motions not relating to the Regulations may be made at any Meeting of the Institution, but not without notice of each such motion having been either inserted in the notice calling the Meeting, or given in writing and read at the Meeting next preceding.

47. The Council shall have power to make or alter By-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.

Section X.—MANAGEMENT OF THE LIBRARY.

48. The Council at their first Meeting each Session shall appoint three of their number to form a Library Committee, one of the three to be Librarian and Convener of the Committee.

49. The Library Committee, subject to the sanction of the Council, shall expend in Books and Library Expenses the sums placed at their disposal, make By-Laws for the management of the Library, and appoint Assistants.

50. The Library Committee shall report periodically to the Council, detailing the state of the Library affairs.

51. The Library Committee shall take charge of all the Books, Papers, Drawings, Models, and Specimens of Materials belonging to the Institution; and they shall annually make an examination of the Property under their charge, and report to the Council at the Meeting next preceding the day of the Annual General Meeting.

LIBRARY BY-LAWS AS TO USE OF BOOKS.

Sanctioned by the Council, 31st December, 1862, and Amended, 12th January, 1864.

1. Except when closed by special order of the Council, the Library shall be open for consulting, borrowing, and returning books, every law-

ful day except Saturday, from 10 A.M. until 4 P.M., and from 6 P.M. until 8 P.M.; and on Saturdays from 10 A.M. until 2 P.M.

2. Books shall not be lent to any persons except Members, Associates, or Graduates of the Institution; but a person entitled to borrow books may send a messenger with a signed order.

3. The books marked with an asterisk in the Catalogue shall be kept for consultation in the Library only, and shall not be lent.

4. The Librarian or Assistant Librarian shall keep a register, in which he shall enter the titles of the book or books lent, the date of lending, the name of the borrower, and the date of the return of the book or books to the Library.

5. The borrower of the book or books, or, in his absence, the bearer of his order, shall sign his initials to the entry of such borrowing in the Librarian's Register.

6. The Librarian or Assistant Librarian shall sign his initials to the date of the return ot the book or books.

7. Should books be returned in a damaged condition, the Librarian or Assistant Librarian shall immediately make an entry of the fact in the Register, and report the same to the Library Committee without delay; and he shall give notice in writing of such entry, and report to the person from whom he last received the book, within three clear days of the receipt of the book, exclusive of the day of receiving the book and the day of giving such notice.

8. No person shall be entitled to borrow, or have in his possession at one time, more than two complete works belonging to the Library, or two volumes of any periodical.

9. No borrower shall retain a book longer than thirteen clear days, exclusive of the days of borrowing and returning, under a penalty of twopence per volume for each day in excess; and written notice shall be sent to the borrower one day after the time has expired; but neither the sending nor the omission to send such notice shall relieve the borrower from the obligation to pay the fine and return the book. In no case shall any book be kept longer than twenty clear days.

10. In the event of two or more persons applying for the same book at the same time, the applicants shall draw lots for priority.

11. The foregoing Rules may be amended at any time by authority of the Council.

INDEX.

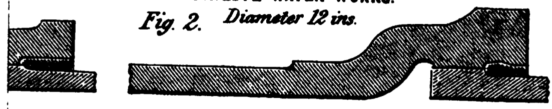
William Munro, General Printer, 80 Gordon Street, Glasgow.

Mr. DOWNIE'S PAPER.

PLATE I

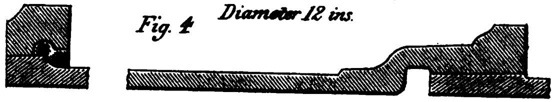
TRIESTE WATER WORKS.

Fig. 2. *Diameter 12 ins.*



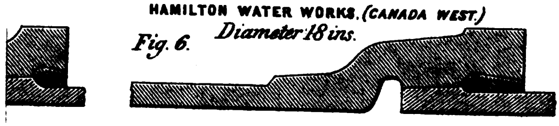
BUENOS AYRES GAS WORKS.

Fig. 4 *Diameter 12 ins.*



HAMILTON WATER WORKS. (CANADA WEST.)

Fig. 6. *Diameter 18 ins.*



HOBART TOWN WATER WORKS.

Fig. 8. *Diameter 10 ins.*

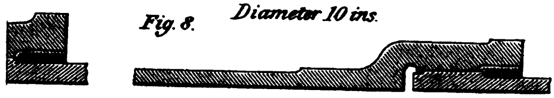
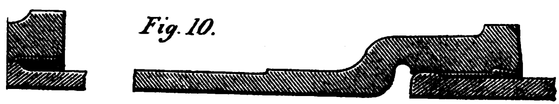


Fig. 10.



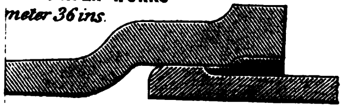
LIVERPOOL WATER WORKS.

Diameter 36 ins.

Fig. 12.

OOL WATER WORKS

meter 36 ins.



UNIVERSAL JOINT.

Diameter 5 ins.

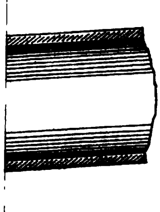
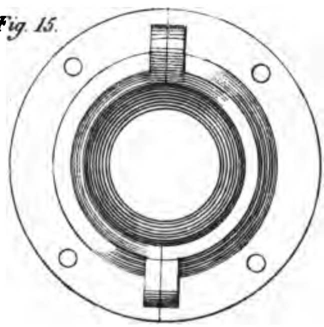


Fig. 15.



ale for Figs. 1 to 13.

9 — 1 FOOT.

ale for Figs. 14, 15.

1 — 2 FEET

5.

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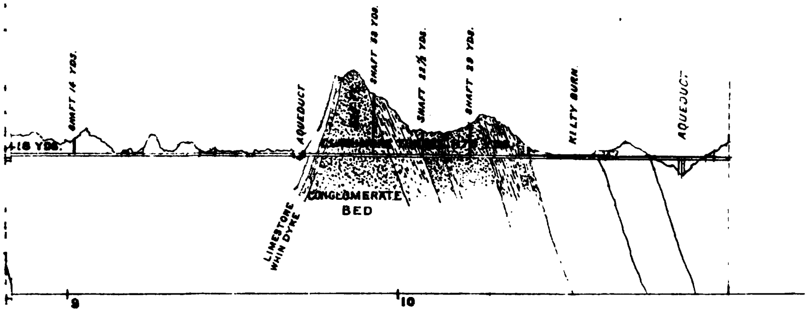


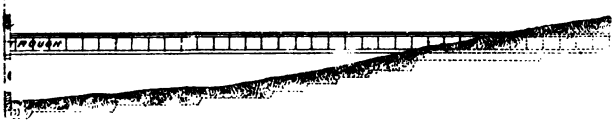


Fig. 10. CROSS SECTION OF WROUGHT IRON TUBES.

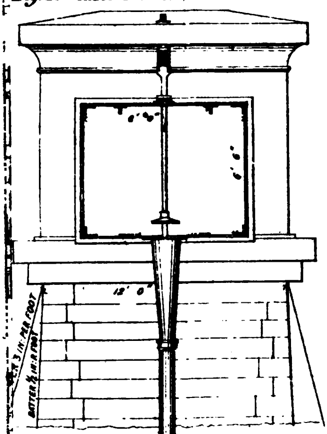
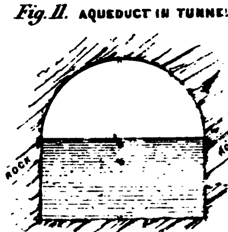


Fig. 11. AQUEDUCT IN TUNNEL



RON AQUEDUCT OVER STREAM AT 3 MILES 17 CHAINS.

Fig. 7. CROSS SECTION

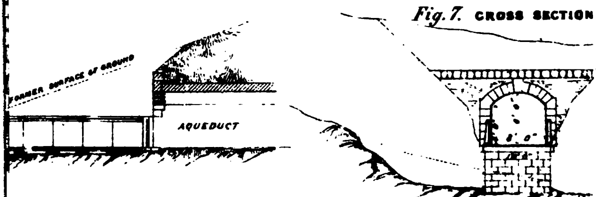


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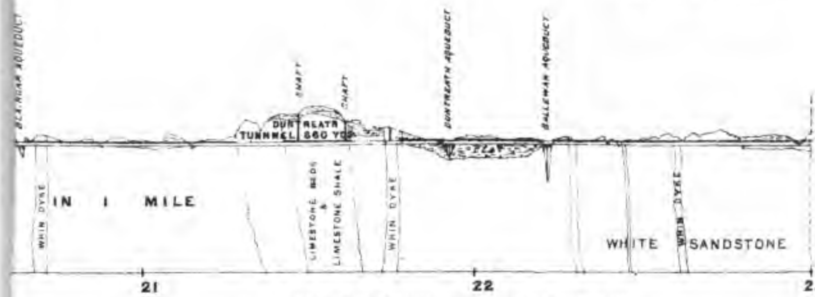
PLATE III



CULVERT CARRYING STREAMS UNDER AQUEDUCT.

Fig. 27. HALF LONG: SECTION. HALF ELEVATION.

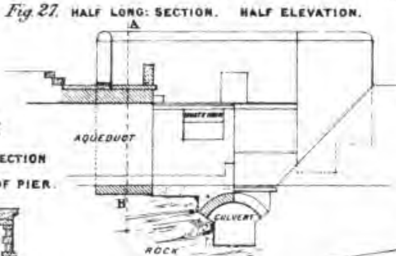


Fig. 29. SECTION THROUGH CULVERT.

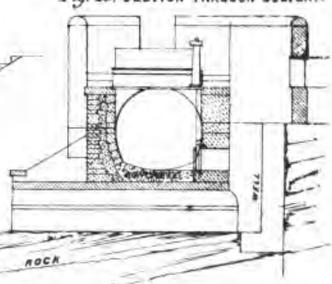


Fig. 26.
...VERSE SECTION
... CENTRE OF PIER.

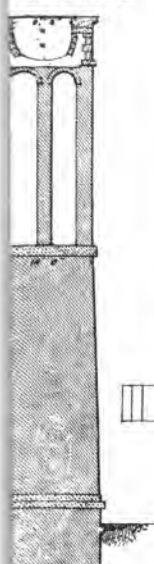


Fig. 28. PLAN.

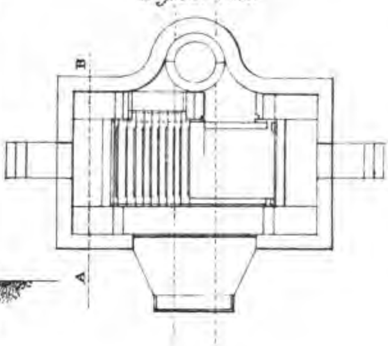
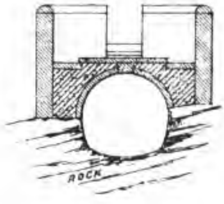


Fig. 30.
TRANSVERSE SECTION AT A.B



Scale for Figs. 21 to 26.

Scale for Figs. 12 to 20 & 27 to 30.

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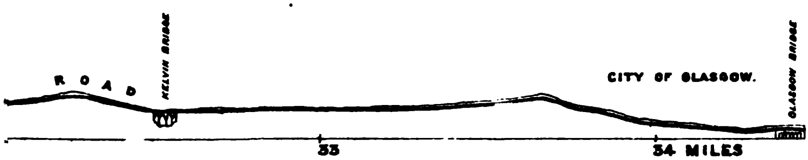
PLATE IV



36 INCH STOP VALVE.

Fig. 42. PLAN.

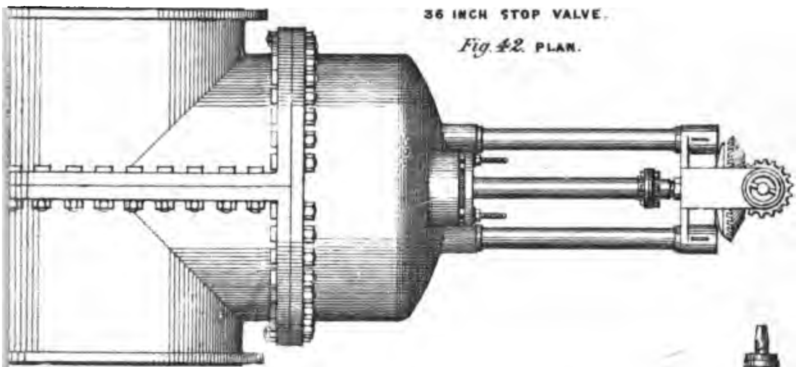
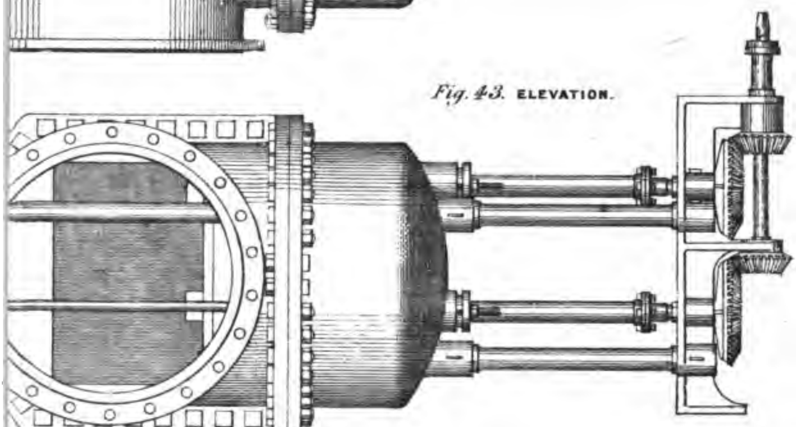


Fig. 43. ELEVATION.



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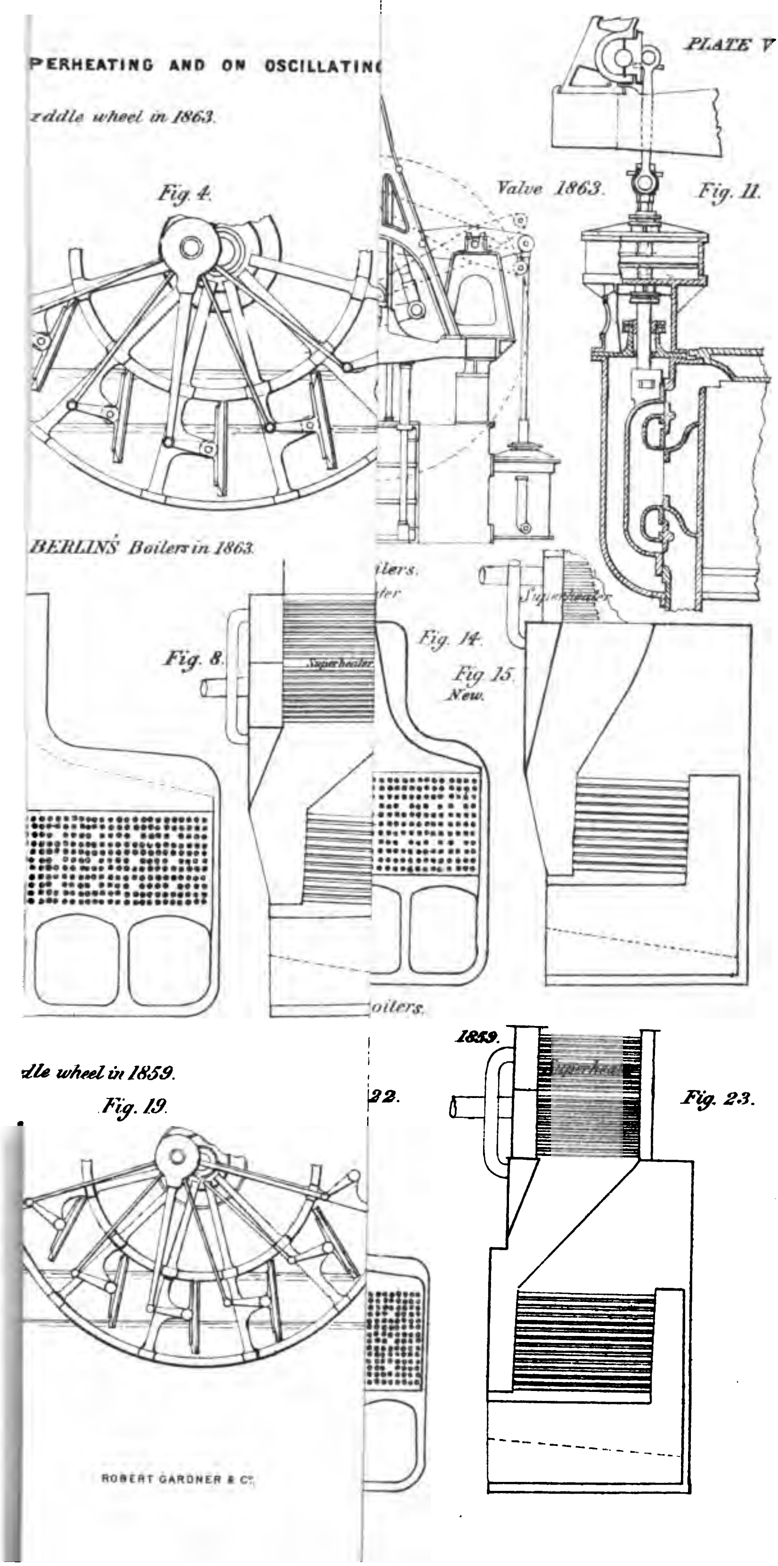
PERHEATING AND ON OSCILLATING
PLATE V
ıddle wheel in 1863.
Fig. 4.
Valve 1863.
Fig. 11.
BERLIN'S Boilers in 1863.
ilers.
Superheater
Fig. 8.
Superheater
Fig. 14.
Fig. 15.
New.
oilers.
1859.
dle wheel in 1859.
Fig. 19.
22.
Superheater
Fig. 23.
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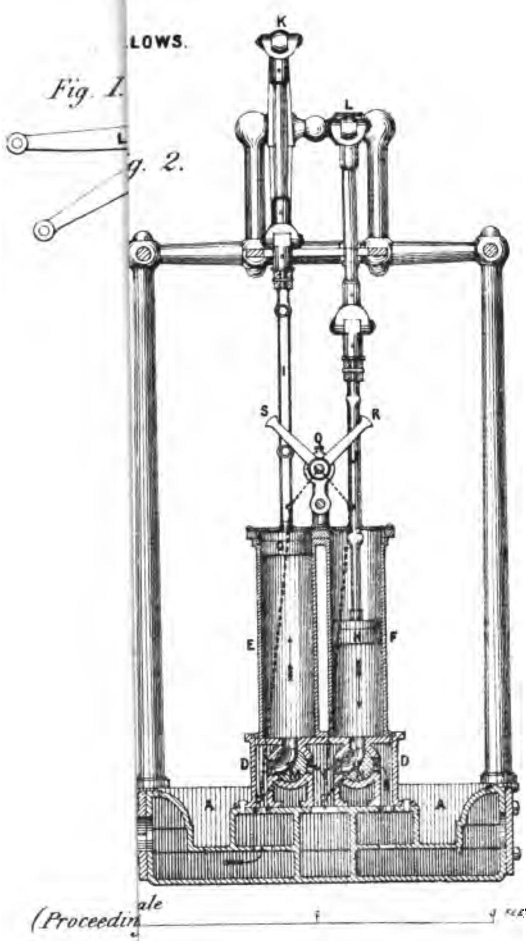
...LOWS.

PLATE VII

Fig. 1.

...g. 2.



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