II. — *On the Consumption of Coal in Furnaces, and the Rate of Evaporation from Engine Boilers. By* John Graham, Esq.

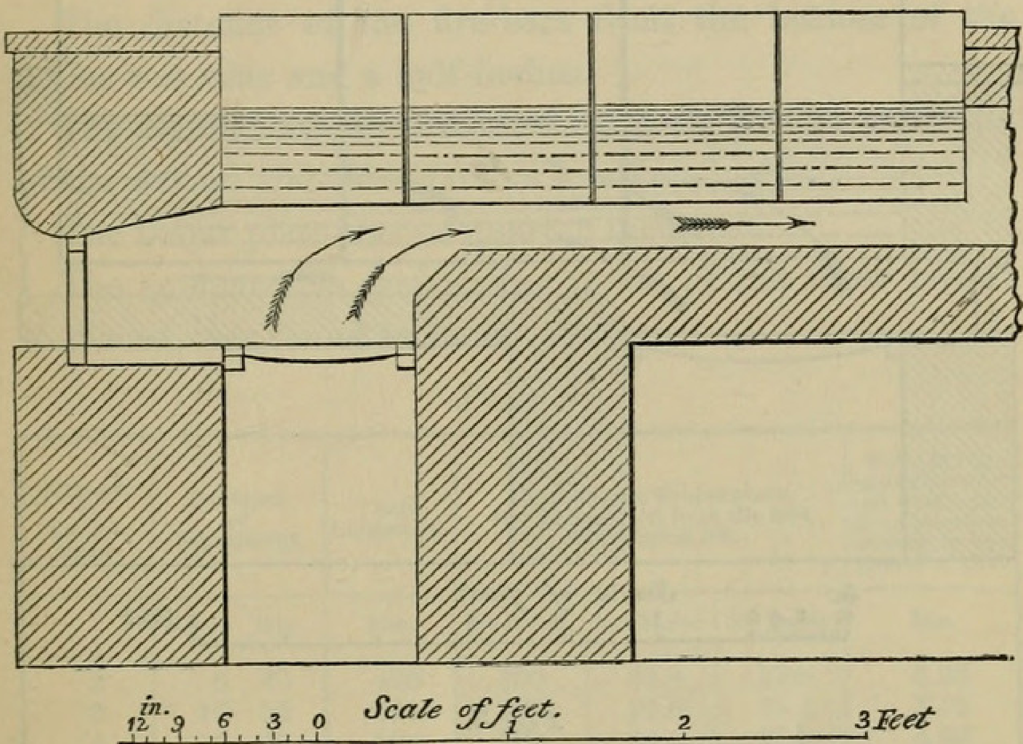
Read February 23rd, 1858.

The experiments to be detailed in the present paper were originally undertaken with a view to beneficial application, and were conducted, as they are now described, in as simple a manner as I was capable of doing. I have been desirous to avoid all entanglements arising from the use of formulæ and the introduction of theoretical speculations; the great and important field of practical knowledge to which the enquiry belongs being as yet, in my humble opinion, too little explored to admit of much generalizing; and I have aspired only to lay down a road into the region, hard and dry, on the basis of sure experiment.

I. Series of Experiments.

The experiments which I shall first describe were made with the view to ascertain the comparative evaporative power of equal but differently placed areas of heating surface, for the purpose of deciding whether we should look most, as regards the saving of coals, to the improvement of the fire-place, or the extension of evaporating flue surface. The results obtained were in accordance with general observation. Four open tin pans, each twelve inches square, were carefully fitted up in brickwork, and arranged together side by side, as seen in *Fig.* 1, the flame-bed or flue being made to communicate with the main flue of a factory, to insure the draught being under control.

Fig. 1.



The evaporation from the pan first in order represents the direct heating effect of the fire; the evaporation from the second may be supposed to represent the heating effect of an equal surface of blaze; the evaporation from the third and fourth the effect of heated air only.

With a moderately strong draught the average rate of evaporation from the four open pans was as follows:

From the first pan,	100	67.6
From the second „	27	18.2
From the third „	13	8.8
From the fourth „	8	5.4
		100.0

Care should be taken to compare in each case the *scale* attached to the drawing.

II. Series of Experiments (small boilers).

Fig. 2.

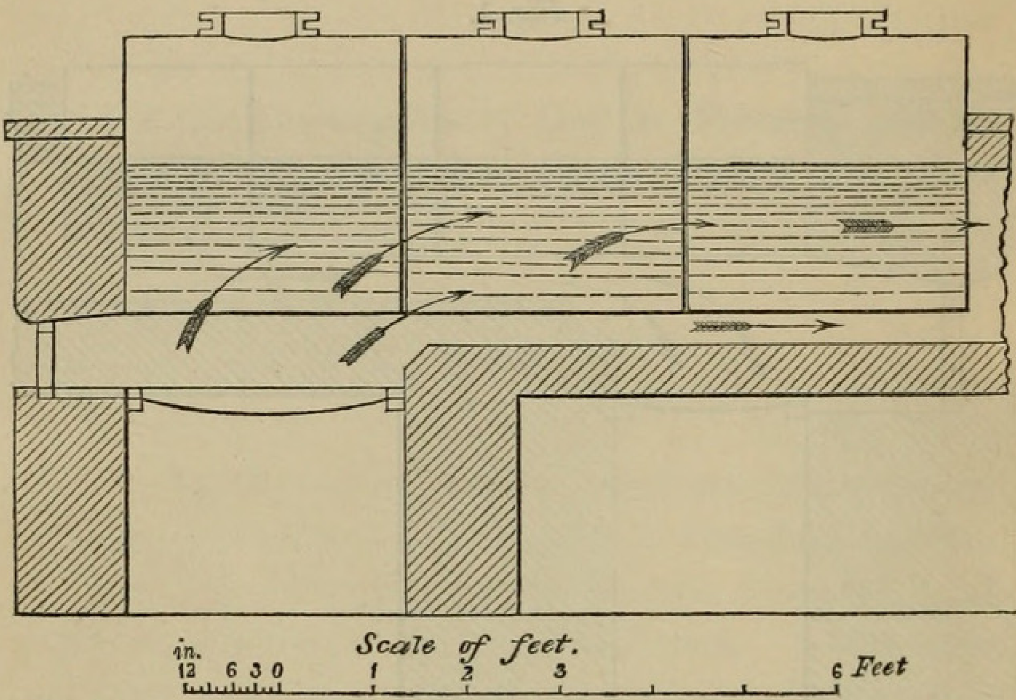
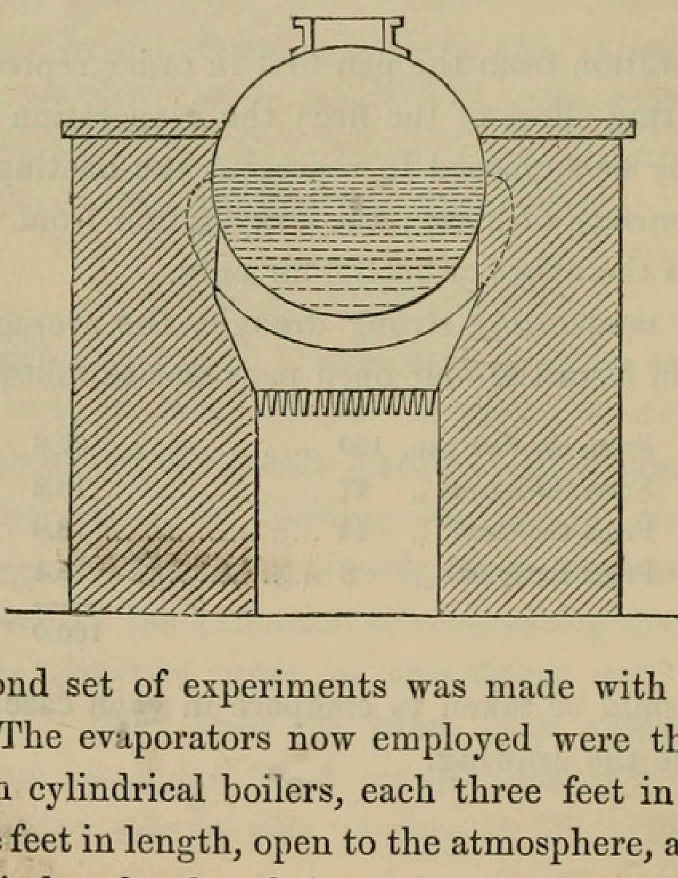


Fig. 3.



A second set of experiments was made with a similar object. The evaporators now employed were three separate plain cylindrical boilers, each three feet in diameter and three feet in length, open to the atmosphere, and placed close behind each other, being well set in brickwork.

The fire-place under the first boiler was two feet wide by three deep.

The fire-bars were half an inch thick, with half inch spaces.

The distance of the fire-bars from the bottom of the boiler was nine and a half inches.

The distance of the flame-bed from the bottom and sides of the second and third boilers was four inches.

The boiler plate was of quarter inch iron.

The comparative evaporating power of the three boilers so placed, was found to be as follows:

Table A.

Number of Experi-ment.	Duration of Experiment.	Coals Consumed.	Comparative Evaporation, the Evaporation from the first Boiler being 100.			Total Water heated from 60°, and evaporated from the three Boilers by one pound of Coal.
	Hours Min.	Lbs.	1st Boiler.	2nd Boiler.	3rd Boiler.	Lbs.
1	*					
2	6 30	420	100	22.8	13.8	5.26
3	10 55	811	100	27.8	15.1	5.19
4	6 30	694	100	39.4	20.3	4.68
5	9 10	480	100	33.5	16.4	3.98
6	6 50	500	100	32.9	12.8	4.42
7	8 15	473	100	29.0	12.0	4.87
8	9 25	473½	100	28.6	9.7	3.83
9	5 15	489½	100	37.0	16.0	4.63
10	7 00	484	100	36.0	13.0	4.02
11	5 25	486	100	50.7	24.0	4.64
12	7 45	487	100	44.4	22.9	4.59
11	83 00	5798	1.100	382.1	176.0	50.11
Average	7 22	527	100	34.7	16.0	4.55

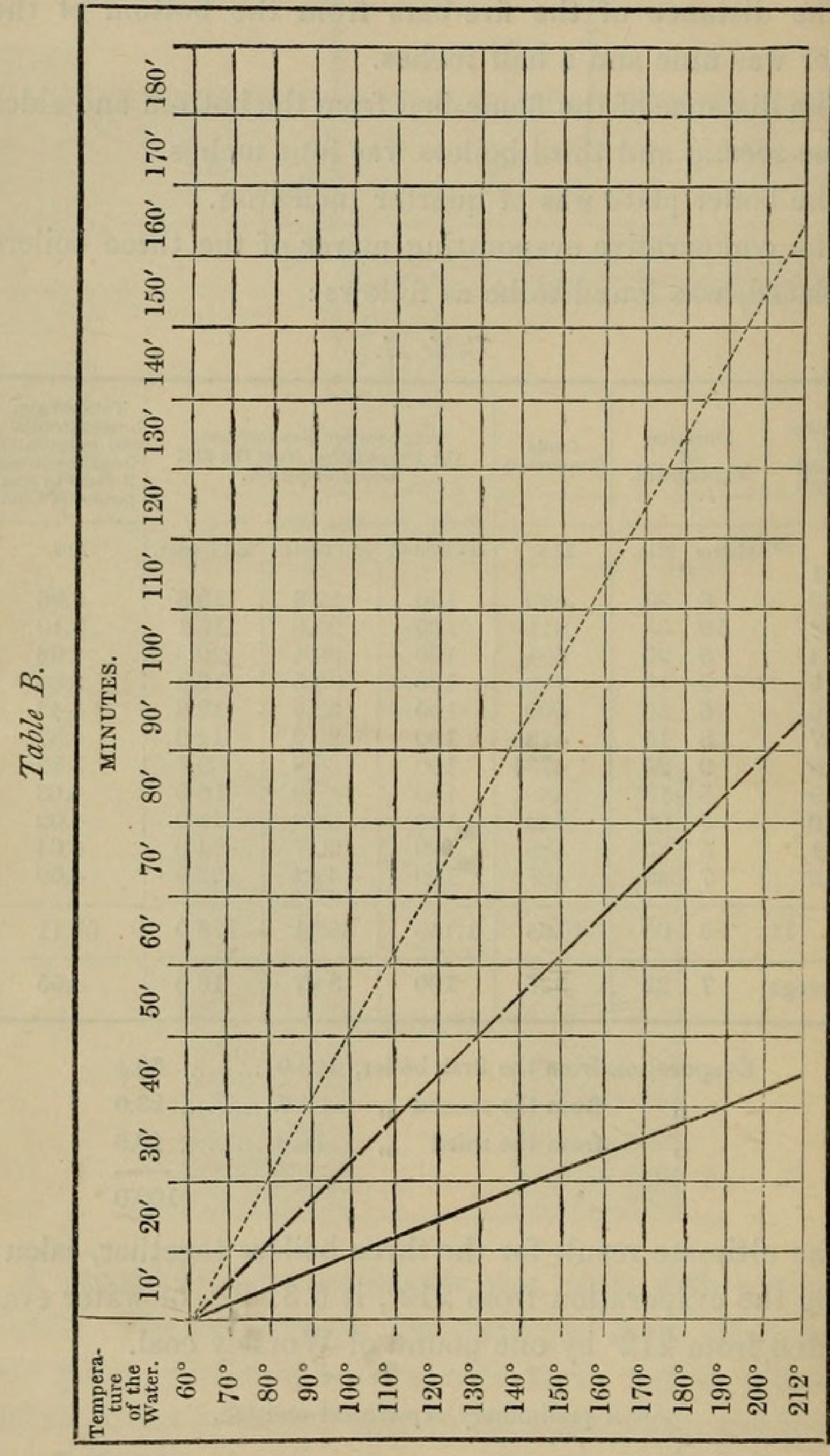
Evaporation from the first boiler,	100.0	....	66.4
„ from the second „	34.7	....	23.0
„ from the third „	16.0	....	19.6
			100.0

The ultimate result for the three boilers together, calculating the evaporation from 212°, is 5.31 ℔s. of water evaporated from 212° by one pound of Worsley coal.

* A preliminary experiment omitted.

The rate of heating the water in the series of three boilers, placed as described, was also observed:

The results are expressed by the lines in the following diagram, *Table B*, showing the average rate at which the



three small boilers placed in series were heated from 65° to 212°; the rate of the first boiler being represented by the line ———, the rate of the second boiler by – – – – –, and the rate of the third by ·············:

To be heated from 65° to 212°, the first boiler required 40 minutes, the second boiler required 92 minutes, the third boiler required 161 minutes; or the heat acquired in equal times by the three boilers in series was by the first boiler 100°, by the second boiler 43.5°, by the third boiler 24.9°.

By comparing the amount evaporated from the third boiler, *Table A,* with its comparative rate of heating as above, it will be seen that flue space acts much more usefully in heating cold water up to 212° than in boiling it off, namely in the proportion of 24.9 to 16, the third boiler in both cases being considered as flue surface only.

The progressive manner in which heat is communicated, when the temperature of the body to be heated is not greatly under that of the heating body, is illustrated practically for steam as the vehicle of the heat by the following Table. The apparatus used was a square wooden cistern with an iron bottom, double-cased for the purpose of admitting steam. The cistern being filled with water at 60°, steam of the temperature of 218° was admitted.

Table C.

Time in Minutes.	Temperature of Water in Cistern.	Increase of Temperature.
0′	60°	0°
10′	100°	40°
20′	134°	34°
30′	158°	24°
40′	174°	16°
50′	183°	9°
60′	192°	9°
70′	198°	6°
80′	201°	3°
90′	206°	5°
100′	210°	4°

In experiments of this nature it is difficult to raise the water in the cistern beyond 210°. The increasing heating activity of the steam towards the end, as shown by the above Table, may possibly be accounted for by the increased motion in the water as it came near the boiling point.

Although the experiments were carefully performed with these small boilers, the results present a want of harmony among themselves, as regards the amount of water evaporated, and are not in accordance with the results obtained with other boilers, also of small dimensions. The effects produced by disturbing causes seem to be much more considerable when the boilers are small. At the risk of being tedious, I subjoin a notice of such disturbing causes as were recognized during the performance of the small boiler experiments (*Table A.*) Some of these influences appear of an unimportant character, and really are so in large experiments; but it would appear that slight disturbing causes may with small boilers produce greater deviations than is generally believed. It will also be observed that uniformity is not always attained even when the disturbing causes, so far as known, appear to be nearly equal. And lastly, that such causes appear occasionally to give the opposite result with small boilers from what they give with boilers with larger fire-places.

This discrepancy in results obtained in the "small way," as compared with those obtained on the "large scale," is well known to men of practical skill, and constitutes our chief difficulty in subduing science to our requirements. The case, for example, of dyeing "patches," as compared with dyeing "pieces," may be mentioned as one where disturbing causes rise to an extreme.

Disturbing causes recognized during the performance of small boiler experiments in Table A.

The First Experiment was rejected in consequence of the brickwork setting of the furnace being cold and damp.

Second Experiment. — Barometer 29.4 inches; hydrometer dry bulb 69°, wet bulb 67°; weather cloudy, with showers; draught strong; fired every 15 minutes; feed water 70°.

Third Experiment. — Barometer 30 inches; hydrometer 72° dry, 70° wet; weather dry and clear; draught good; fired every 10 minutes; feed water 70°.

Fourth Experiment. — Barometer 29.8 inches; hydrometer 70° dry and 64° wet; heavy rain; draught good; fired every 40 minutes; the fire-place was nearly filled each time with coals; feed water 70°.

Fifth Experiment. — Barometer 29.9 inches; hydrometer 66° dry and 60° wet; draught good; fired every 15 minutes; the burning fuel was kept about 3 inches deep only. In consequence of the coals being of the usual irregular size, some parts of the bars became bare occasionally. Feed water 70°.

Sixth Experiment.—Draught strong; thickness of fire 4 inches; feed water 60°. In other respects the same as fifth experiment.

Seventh Experiment.—Draught slow; thickness of fire 3 inches; feed water 60°. In other respects the same as fifth experiment.

Eighth Experiment.—Draught slower still; thickness of fire 3 inches; feed water 65°. In other respects the same as fifth experiment.

Ninth Experiment. — A repetition of the sixth experiment.

Tenth Experiment. — A repetition of the seventh experiment.

Eleventh Experiment.—Draught good; thickness of fire 5 inches. The coals in this experiment were fed upon the inner end of the fire-bars by a hole in the side of the brickwork, the red hot coals being pushed forward towards the front by the rake.

Twelfth Experiment.—A repetition of the eleventh experiment, but with a slower draught and a thinner fire.

III. Series of Experiments (small boilers.)

Fig. 4.

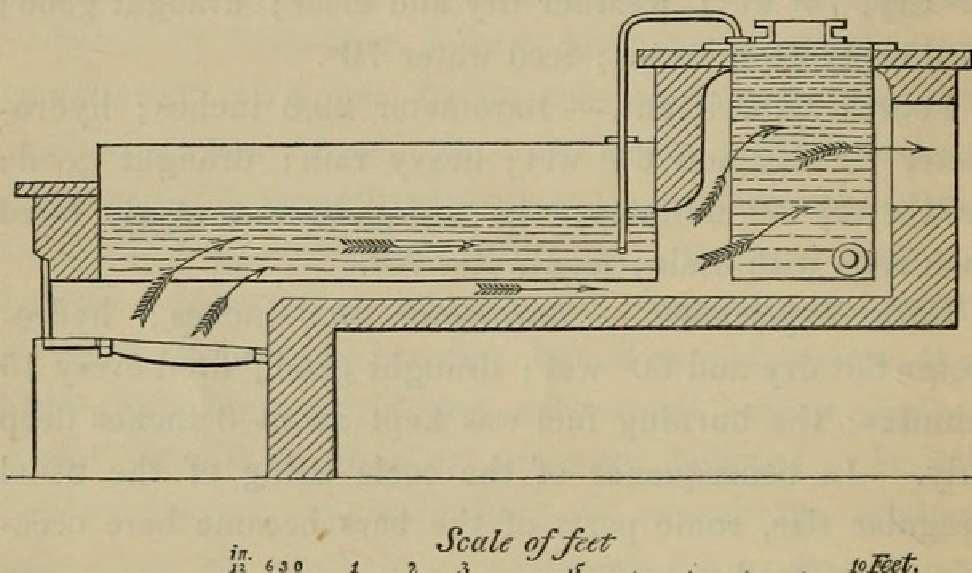
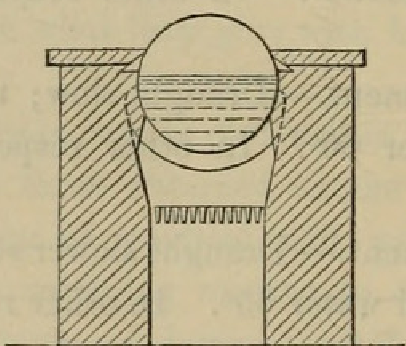


Fig. 5.



The next set of experiments was also made to ascertain the value of flue space, but more attention was now given to the capacity of the hot air after it had passed from under the boiler to heat a separate boiler. The boiler used in this case was similar in construction and setting to the previous three small boilers, but was 10 feet long. The supplementary boiler was 4 feet 6 inches long, standing on end as seen in the drawing. It was worked for a lengthened period to heat the feed water made to pass through it, with the constant result that the feed water was heated variously from 170° to 180°.

The draught went directly under the main boiler, and was made to impinge against the side of the supplementary boiler and to pass round it and under it. Where the draught so impinged, the surface remained free from soot.

The average result was as follows, allowing in the calculations one increment of heat to raise the temperature of the water from 60° to 212°, and five increments to boil it off:

Heat acquired by principal or working boiler,	100...	87
„ supplementary „	15...	13
		100

It appears from a careful set of experiments made in this neighbourhood, under the inspection of another observer, that when means are employed to keep the supplementary heating surface free from soot, a still more favourable result is obtained, viz:

Heat acquired by water in working boilers,	100	78.7
„ by water in heating pipes,	27.4....	21.3
		100.0

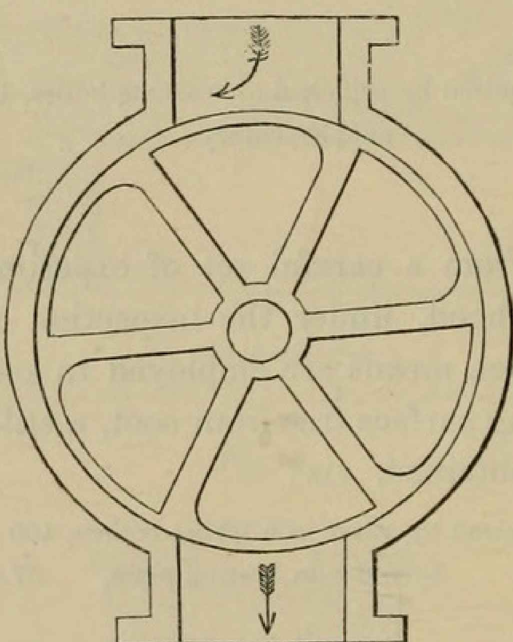
In the last experiments upwards of one-third of a mile of 4-inch piping was in use, which received the escaped heat from six large boilers, each 42 feet long. Six boilers, assisted by the supplementary heating surface, were found in practice to do the work which had previously required eight boilers, without such assistance. It should be noticed that in neither case was the principal boiler giving more than 7.5 pounds of water for the pound of coal consumed. I have no results to show what the effect might be if the supplementary heating apparatus had been applied to a boiler capable of yielding itself a larger result.

IV. Series of Experiments.

The next set of experiments was made for the purpose of ascertaining the evaporative power of engine boilers of various shapes and of large dimensions.

In order to do this I found it necessary to contrive a simple water meter capable of registering the supply of water to the boiler with accuracy. This machine is exhibited in the accompanying figure.

Fig. 6. *Water Meter.*



This meter worked with perfect accuracy for several years, as was ascertained by occasionally checking its registered indications by means of a water cistern of known capacity attached. The registering apparatus was similar in construction to that used in gas meters, and was attached to one end of the axle. The interior part of this apparatus, which conveyed the water into the boiler, was not unlike a large "greasing tap." It was driven by a fast and loose pulley, the direction of which was entrusted to the stoker, while the levels of the water in the boiler, and other circumstances at the beginning and end of each experiment were registered by another person. The drawing scarcely gives a proper idea of the mode by which the water was conveyed round and into the boiler.

I shall now give an account of the results obtained by me with the four different shapes of boilers in most common use in this neighbourhood. I should remark that before beginning to register results, the boilers in each case were re-set, and placed, by careful and continuous experiments, into what was found, to the best of my judgment, to be their condition for giving the best working result. The boilers were, further, always amply protected by coverings from loss of heat by radiation. The experiments of the present series were each of twelve hours duration. They commenced at 6 a.m. and terminated at 6 p.m., except those performed on Saturdays, which lasted from 6 a.m. to 1 p.m. It was also the practice to commence and end with the steam at, as nearly as possible, 7 lbs. of pressure.

As each experiment of importance was carried on day by day for four or six weeks, and often repeated under varying circumstances at different times of the year, also with various boilers, with coals of various kinds, and different stokers, the experiments altogether occupied the better part of several years. At first the disturbing circumstances were found very perplexing, as they led to variations in the results which at the time could not be explained; but in proportion as these circumstances became known and were reduced in number, it became possible to proceed with more satisfaction and precision. The coals used in these experiments were the usual Worsley qualities, except in the case of the experiments made with the cylindrical boiler, described under the head IX. Series of Experiments, where Dukinfield coal was used. I had, however, previously and have since ascertained that the Dukinfield and Worsley coals gave the same result.

Command was always had of the draught. The temperature in the flue at the bottom of the chimney, during some periods of the day, was sufficient to melt lead but never zinc.

V. Series of Experiments.

Fig. 7.

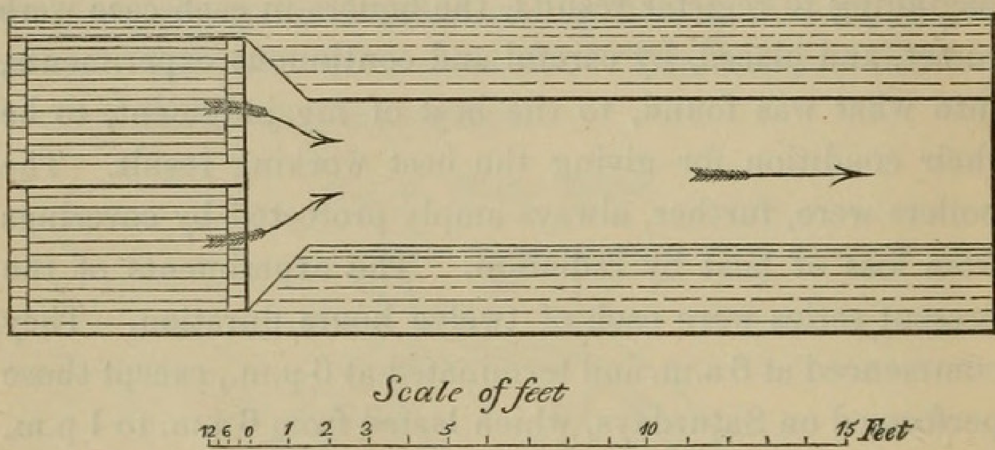
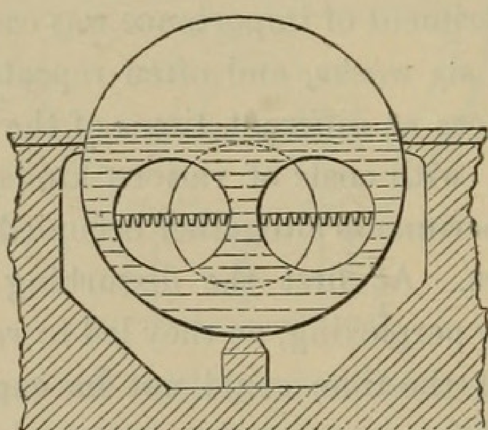


Fig. 8.



The boiler first experimented with was of the shape shown in the annexed drawing, and commonly called in this neighbourhood the "breeches boiler." It has two interior fire-places which join behind the bridges and form one direct flue through the interior of the boiler. It was 23 feet 3 inches long, 8 feet in diameter.

Fire-places each 3 feet by 6 feet, giving 18 square feet of fire surface.

Internal flue 3 feet 9 inches in diameter.

Fire-bars half inch thick with half inch spaces.

The boiler plate $\frac{3}{8}^{ths}$ of an inch in thickness.

The experiments made with this boiler were continued under different circumstances and at various times of the year, and the average result obtained, working under the best conditions I could command, was 5.90 lbs. of water evaporated from the temperature of 84° by one pound of coal consumed.

Or if we add one-sixth to this result as equivalent to the heating of the feed water, the ultimate result will stand thus:

In the breeches boiler 6.88 lbs. of water are evaporated from 212° by one pound of coal.

In all the experiments made with this boiler, though my results were affected more or less by what was considered to be a slightly deficient draught, still each fire evaporated 24.429 lbs. of water from 60° in the course of twelve successive working hours, and generally throughout the series it was found that this boiler was more affected by disturbing causes than the boilers of other shapes, possibly in consequence of the comparatively small size of the fire-places.

The smallness of the yield from this boiler is a matter of surprise. I have, however, no reasonable grounds for suspecting the accuracy of my experiments, since they were so often repeated and under such varied circumstances.

VI. Series of Experiments.

I may add that in a short series of experiments made on two other boilers of an analogous construction, namely, with two fire-places and two internal flues passing from end to end, (a construction of boiler which greatly recommends itself for strength, durability, compactness, and simplicity of form,) working with an excellent draught, and under a pressure of 57 lbs. on the inch, I received a confirmation of the importance of disturbing causes. Both boilers were reported to me to be precisely the same, but that one yielded from the same weight of coals in the same time about one-third less steam than the other. However, it turned out that there were two slight differences.

The duration of the experiments, the quantity of coals consumed, and the draught, were the same for each boiler.

No. 1.	7ft. diameter, 34ft. long, plates $\frac{3}{8}$ths of an inch thick.			
No. 2.	Do.	do.	do.	
No. 1.	Surface of fire-bars, 2ft. 8in. by 5ft. 6in. = 14.6 sq. ft.			
No. 2.	Do.	3ft. by 6ft. = 18.0 sq. ft.		
No. 1.	Evaporated 6.36 lbs. of water per pound of coal.			
No. 2.	Do.	8.00 lbs.	do.	do.

No. 1 was then opened and found to be dirty and slightly scaled, No. 2 being clean. On No. 1 being thoroughly cleaned and again experimented upon a higher result was obtained, thus:

No. 1 evaporated 7.39 lbs. of water per pound of coal.

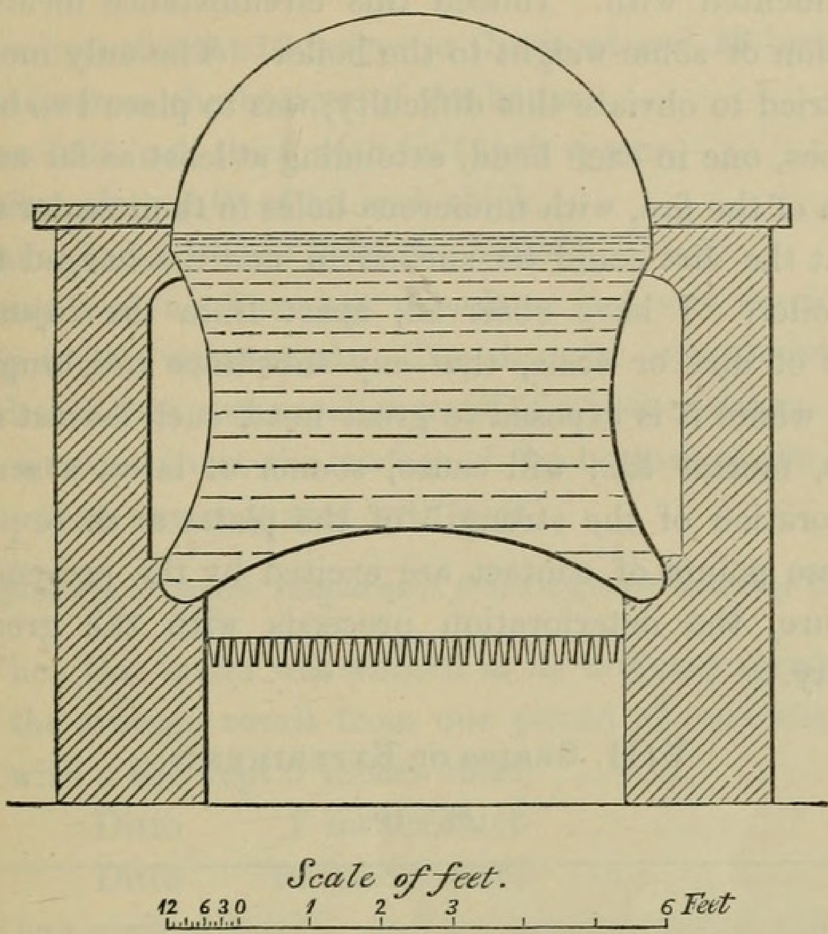
I could discover no other disturbing cause to account for the small yield from No. 1 beyond the comparative smallness of its fire-places, and accompaniment of dirt and slight scale. The evaporation is computed from water at the boil.

VII. Series of Experiments.

The boiler next experimented with was of the form as shown in the drawing usually called James Watt's "waggon-shaped boiler." It was 26 feet 6 inches long by 6 feet 6 inches in diameter.

Fire-place 5 feet 6 inches by 6 feet, equal to 33 square feet of fire surface.

Fig. 9.



Bars 16 inches from the top of the arch of the bottom of the boiler, half inch thick, with half inch spaces.

Plates $\frac{5}{16}$ths of an inch thick.

Depth of water over fire 4 feet.

A flue carried round the boiler, with capital draught.

A corresponding series of experiments being made with this boiler gave a different result from that obtained with the last boiler; 8.80 lbs. of water from the temperature of 60° were evaporated by one pound of coal consumed; or, if we add one-sixth as equivalent to the heating of the feed water, the result will stand thus:

In the waggon-shaped boiler 10.26 lbs. of water were evaporated from 212° by one pound of coal.

In consequence of the facility with which dirt settles in the lower bends of this boiler it is more liable to be burned at these parts than any of the boilers of other shapes I have experimented with. Indeed this circumstance forms an objection of some weight to the boiler. The only mode I have tried to obviate this difficulty, was to place two blow-off pipes, one in each bend, extending at least as far as the length of the fire, with numerous holes in their under sides so that the dirt could be sucked in and discharged from the boiler. I have observed, apart from the injurious effects of dirt or scale, that any substance touching the boiler where it is exposed to great heat, such as cast iron, bricks, mortar &c., will cause, sooner or later, a serious deterioration of the strength of the plates at these parts. If these points of contact are excited by the presence of moisture, the deterioration proceeds with the greatest rapidity.

VIII. Series of Experiments.

Fig. 10.

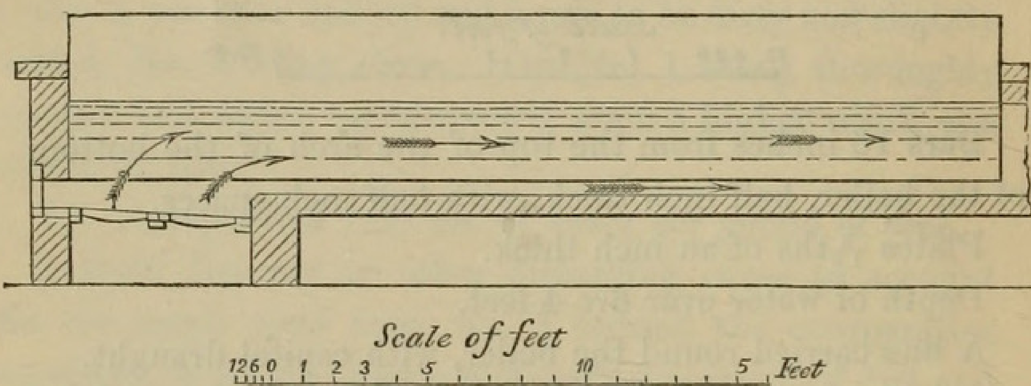
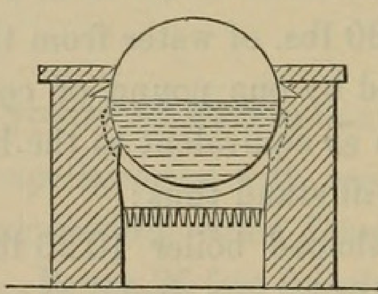


Fig. 11.



The third boiler experimented with was a plain cylinder, 33 feet long by 5 feet 6 inches in diameter.

Fire-place 4 feet 8 inches by 6 feet, equal to 28 square feet.

Fire-bars distant 12 inches at the front and 13 inches at the back from the bottom of the boiler.

Bars half inch thick with half inch spaces.

Boiler plate $\frac{5}{16}$ths of an inch thick.

Flame bed 5 inches from the boiler.

There was no flue, but the flame-bed was carried up nearly to the water-mark. The draught was thereby reduced to a thin and rapid current of 5 inches deep; under such circumstances the surface of the bottom of the boiler does not in any case coat with soot.

Quantity of water evaporated from a temperature of 60°.

	lbs.
When this boiler was worked at its ordinary speed, the average result from one pound of coal was, with a fire kept 5 inches thick	5.60
Ditto 7 inches thick	5.78
Ditto 10 inches thick	5.93
When worked briskly, and apparently pushed with a 7-inch fire	6.09
When in a dirty condition within, from a slight scale of sulphate of lime about the thickness of a sixpence or less, but in other respects under ordinary circumstances with a 7-inch fire	5.50
When made perfectly clean and keen internally by means of muriatic acid, with a 7-inch fire	6.45

This unusual activity produced by the muriatic acid continued only for a day or two. The boiler by that time, with the water used, became glazed or smoothed, and the keenness was destroyed.

This boiler at its ordinary speed evaporated, in 12 continuous working hours, 27,267 lbs. of water from the temperature of 60°, and when pushed 38,678 lbs.

The evaporating power of this boiler may therefore be considered as 6.09 lbs. of water evaporated by one pound of coal.

Or by adding one-sixth to that quantity for the heating of the feed water from 60° to 212°, the evaporating power will be 7.1 lbs of water evaporated by one pound of coal.

I have already stated that as these experiments proceeded, the deviations from uniformity became less perplexing, and when such deviations occurred they were more readily accounted for. The following short table is given to illustrate the degree of accordance of such observations.

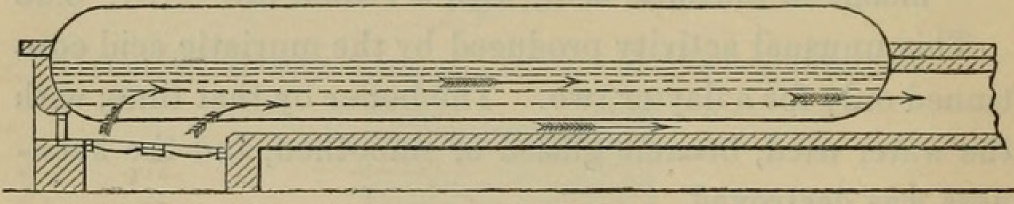
Table D.

Water evaporated from 60° per pound of coal burned.

By Thick Fires.		By Thin Fires.	
Lbs.	Observations.	Lbs.	Observations.
5.70	Monday.	5.63	
6.20		5.65	
5.97		5.74	
6.04		5.57	Saturday.
5.79		5.35	Monday.
5.90		5.57	
5.51	Monday.	5.36	Dirty coals.
5.93		5.64	
5.20	New fireman.		
6.00	Old fireman.		
&c.	&c.		

IX. Series of Experiments.

Fig. 12.

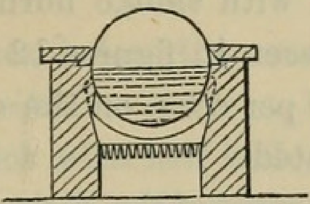


Scale of feet

12 0 1 2 3 5 10 20 25 Feet

The next boiler experimented with was also plain and cylindrical, 42 feet long and 6 feet in diameter.

Fig. 13.



Fire-place 5 feet 1 inch by 6 feet 11 inch = 35.1 square feet of fire surface.

Fire-bars placed 14 inches from the bottom of the boiler at the front, half inch thick with half inch spaces.

Boiler plate $\frac{5}{16}$ths of an inch thick.

Flame-bed, which was carried up to near the water mark, 6 inches from the bottom of boiler.

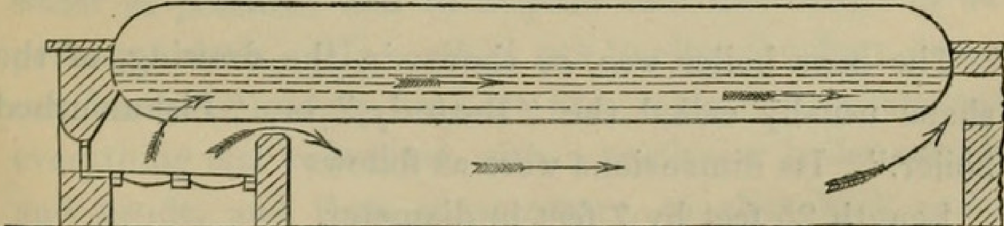
No return flue.

Water evaporated from 60° by one pound of coal.

	lbs.
When worked with the fire-bars 12 inches from the bottom of the boiler, the yield was	6.14
With an arrangement to cause the draught to impinge against the boiler bottom	6.30
By lowering the bars 2 inches, and under ordinary circumstances	6.46
By the introduction of a series of half-bridges, whereby the draught was dispersed and caused to impinge in all directions	6.69
By lowering the bars 11½ inches more (whole distance 25½ inches), under ordinary circumstances	5.11

This boiler had been fitted up previously to these experiments, and worked for some time as seen in *Fig.* 14.

Fig. 14.



It had been thus fitted to meet theoretical considerations in connection with smoke burning. When altered to the condition as seen in figures 12 and 13, a saving accrued of at least 30 per cent. on the consumption of coal, as practically estimated.

The evaporating power of the present boiler, which is of the same class as the last, but greater in diameter and longer, may be considered as 6.46 lbs. of water at 60° evaporated by one pound of coal.

Or adding one-sixth for the heating of the feed water from 60° to 212°, the power will be 7.54 lbs. of water evaporated by one pound of coal.

X. Series of Experiments.

Fig. 15.

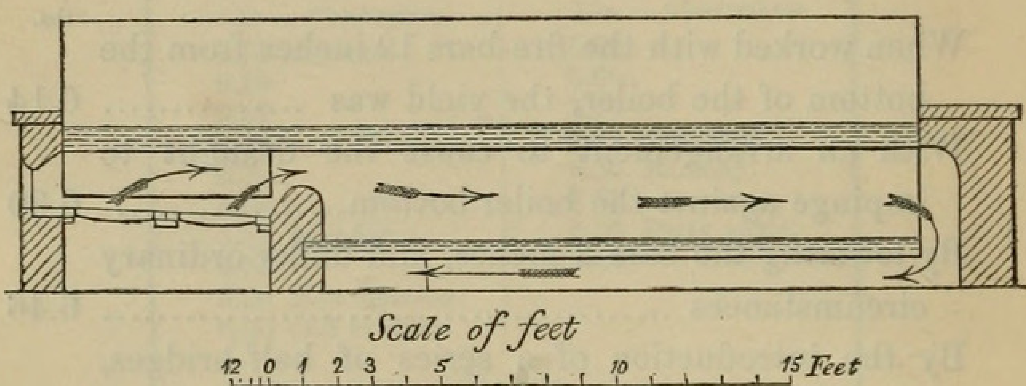


Fig. 16.

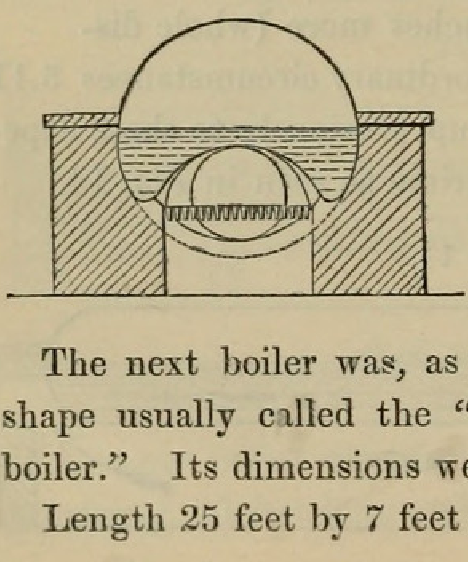
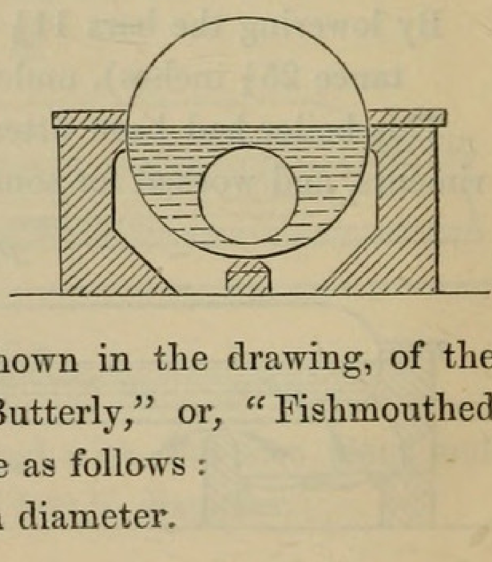


Fig. 17.



The next boiler was, as shown in the drawing, of the shape usually called the "Butterly," or, "Fishmouthed boiler." Its dimensions were as follows:

Length 25 feet by 7 feet in diameter.

Fire-place 4 feet 3 inches by 6 feet, equal to 25.4 square feet of fire surface.

Fire-bars 21 inches below the crown or arch forming the bottom of the boiler.

Bars half inch thick with half inch spaces.

Internal flue 29 inches in diameter.

Boiler plates $\frac{5}{16}$ths of an inch thick.

Flues were carried round the boiler.

When this boiler was worked at its usual speed and in ordinary circumstances the evaporating power was 8.33 lbs. of water evaporated from a temperature of 60°.

At its ordinary speed it evaporated 26,440 lbs. of water from the temperature of 60° in 12 successive working hours.

By adding to the above result one-sixth for the heating of the feed water from 60° to 212°, the evaporating power of the boiler will be 9.72 lbs. of water evaporated by one pound of coal.

This boiler became a general favourite, and was used with the smallest of the cylindrical boilers (*Fig.* 10) in most of my subsequent experiments.

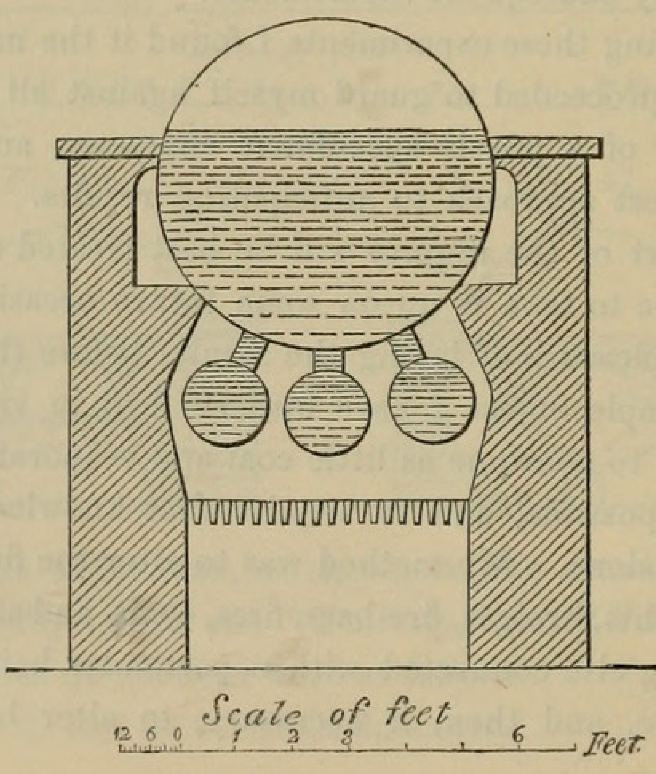
In making these experiments I found it the more necessary as I proceeded to guard myself against all bias from reasoning of a purely speculative character, and to avoid the smallest approach to anticipating results. The theoretical part of the inquiry will be best treated separately, and I hope to take it up on some future occasion and to have the pleasure of laying the results before the Society.

The simple object I have hitherto had in view was to learn how to consume as little coal and evaporate as much water as possible, and to acquire that knowledge by experiment alone. My method was to alter the flues, dampers, draughts, bridges, fire-bars, fires, coals, and stokers, and everything else connected with a particular boiler outside and inside, and then, if necessary, to alter back again, until it appeared that I had obtained the most favourable condition for work, of the boiler under trial. To do all this required time and a considerable expenditure, as may be readily supposed. But the economical results which followed in greatly reduced consumption of coals, less frequent repair of boilers, and increased safety to the people employed about them, were always a sufficient motive to urge on the experiments. I may be allowed to say that the useful result in my case from these and other collateral experiments was a reduction of about 67 per cent. on the cost for coals per piece printed.

XI. Series of Experiments.

Attempts have been made to improve the boiler by enlarging that portion of its surface which is exposed to the direct radiation of the fire. A boiler possessing a contrivance for that purpose came into notice a few years ago, and was strongly recommended on theoretical grounds, as it presented a very large absorbing surface as compared

Fig. 18.

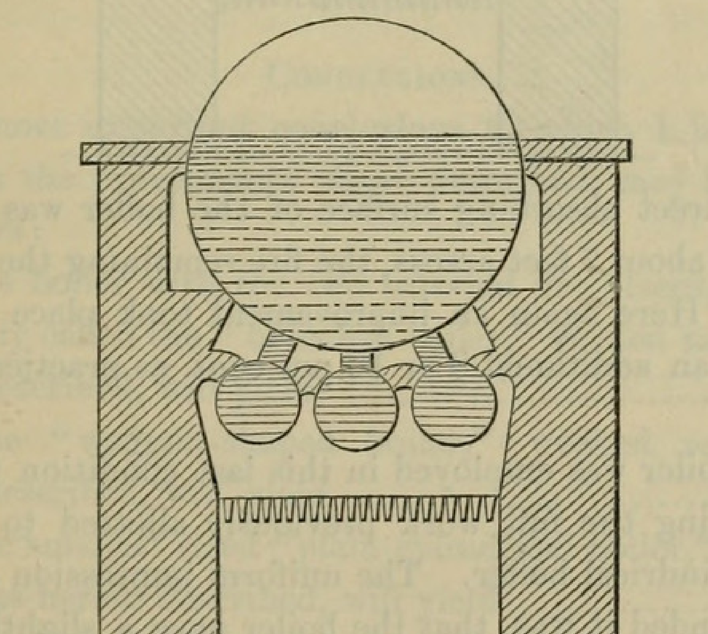


with the radiating fire surface. I was induced to have the cylindrical boiler, described under the VIII. head, altered to the new shape which is seen in *Fig.* 18.

Under the cylinder boiler of 5 feet 6 inches in diameter, three small cylinders, each of 1 foot 6 inches in diameter, extending the length of the main boiler, were placed, and filled with water from the upper boiler. A line carried across the fire-place measured 4 feet 8 inches, while a line carried in the same direction, but over the surface of the boiler bottom and its appendages, measured 17 feet 7 inches. When again used, the altered boiler proved unequal to the work of the original plain cylinder. It was found, indeed, when properly tested, to possess a remarkably low evaporating power, namely, from 5.5 to 5.8 lbs. of water at 212° per pound of coal.

The setting of the same boiler was then altered as seen in *Fig.* 19.

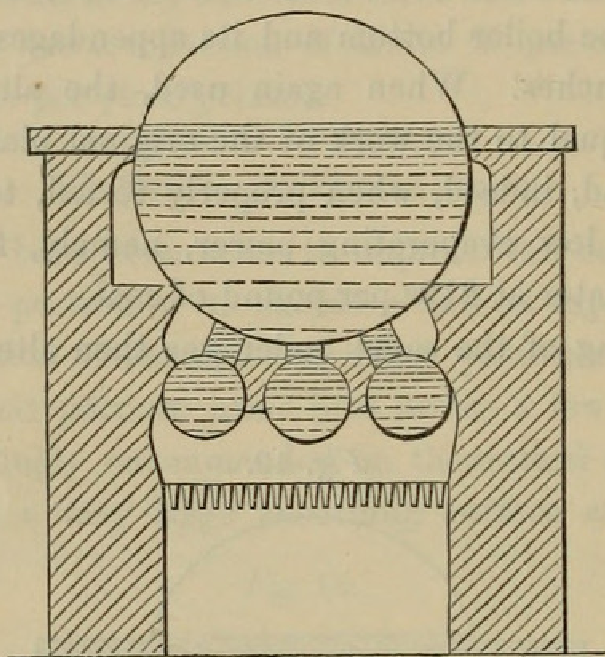
Fig. 19.



The lineal measurement of the absorbing surface was thus reduced to 10 feet 6 inches, while the line across the fire was the same as before. The new evaporating power was not numerically determined, but an improvement in the power of the boiler was most evident. It was now possible to go on with it at least, and the boiler was supposed at the time to have recovered about 20 per cent. in power.

This result, however, being still unsatisfactory, I had the boiler altered as shewn in *Fig.* 20.

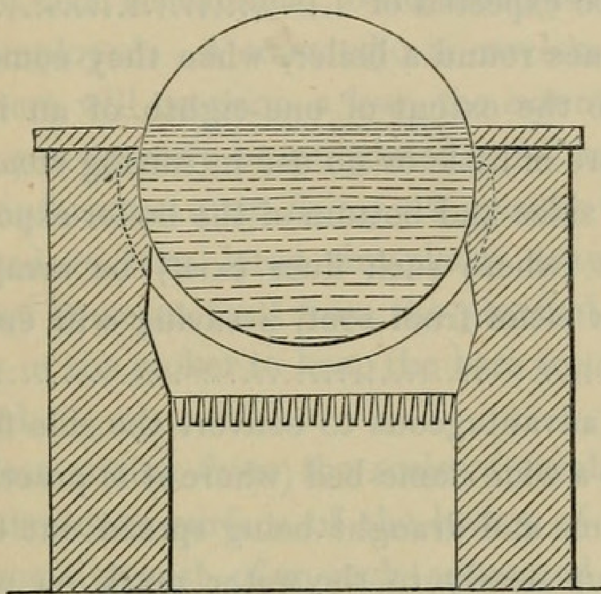
Fig. 20.



The direct absorbing surface of the boiler was now reduced to about 7 feet across, the fire remaining the same as before. Here again an improvement took place equal to at least an additional 8 or 10 per cent. as practically estimated.

The boiler was employed in this last condition for some time, doing the full work previously allotted to it as a plain cylindrical boiler. The uniform impression of those who attended it was, that the boiler gave a slightly better result in this condition than as a plain cylindrical boiler. There were, however, practical objections to the boiler in this form, the brickwork over the tubes was constantly shaking loose, and the tubes themselves became scaled and dirty and could not easily be cleaned. When, therefore, the tubes were burned out, which took place in their third year, I decided to remove them, and replaced the boiler in its original simple form as seen below, which it will be remembered gave the result of 7.1 pounds of water evaporated.

Fig. 21.



Conclusions.

The more important conclusions to which I have been led from the experiments above described, may be stated as follows:

	Of Water evaporated from 212°, by 1 lb. of coal.
1. The boiler with the two internal fire-places, commonly called the "breeches boiler," worked as herein described, will yield	6.88 lbs
2. The "waggon-shaped boiler," worked as herein described, will yield	10.26 lbs
3. The smallest sized "plain cylindrical boiler," worked as herein described, will yield	7.1 lbs
4. The large sized "plain cylindrical boiler," worked as herein described, will yield	7.54 lbs
5. The "Butterly boiler," worked as herein described, will yield, for one pound of coals consumed	9.72 lbs

6. A supplementary boiler, under the circumstances above described, gives a saving of .... 15 p c^t^

7. When numerous cast iron pipes are substituted for the supplementary boiler, and mechanical means are adopted to keep their surface clear of soot, a saving may, under the circumstances described, be expected of ... . 27.4 p c^t^

8. The flues round a boiler, when they come to be coated to the extent of one-eighth of an inch with soot, are of little or no use in raising steam.

9. If the sides and bottom of the boiler exposed in the flues (where such flues exist) be scraped once a week clean from soot, a saving will ensue of about .... 2 p c^t^

10. It is advantageous to convert the side flues at once into a wide flame-bed (where it is practicable), the flame and draught being spread out thin and going up nearly to the water mark on each side, and led straight on to the chimney. By such means the bottom of the boiler is preserved for its whole length free from soot, and there is an effective radiation from the hot bricks of the bed.

11. A very slight difference in the setting alone of the same boiler may readily produce a difference in the result amounting to .... 21 p c^t^

In extreme cases of bad setting, as may be seen at *Fig.* 14, of course a much larger loss than this may be looked for.

12. The difference between a boiler of one shape properly set, and another boiler of a different shape improperly set, but both clean and in good order, may readily amount to .... 42 p c^t^

In some cases even a greater difference is possible.

13. A difference in the mode of firing only may produce a difference in the result of .... 13 p c[t]

I refer here to a difference such as will be produced by withdrawing the regular and practised stoker, and substituting for him an equally intelligent and careful man, but who has not been accustomed to the boiler or the coal employed. A man who is careless or dishonest will occasion a loss, the extent of which can scarcely be calculated. All injurious influences upon firing are greatly aggravated in very large fire-places (say of six feet by seven feet) from the physical inability of the stoker to keep the bars equally covered.

14. The loss arising from the scale of sulphate of lime on the inner surface of the boiler, of not more than one-sixteenth of an inch, amounted to 14.7 p c[t]

15. Neither wet coals, nor coals which had been out of the pit for three years, nor wet weather, nor a variation of temperature of the atmosphere from 40° to 70°, produced any appreciable difference of result.

16. Windy weather invariably gave a high result.

17. A moderately thick and hot fire, with a rapid draught, uniformly gave the best result.

The coals used varying from the condition of dust to that of pieces four inches in diameter, it was found advantageous to keep the fire at a general thickness of from six to seven inches, in order to insure the bars being covered at all times; and as it is found, that in all boiler fires the coals are consumed more quickly at some parts of the bed than at others, such parts were supplied with extra quantities. This irregularity in the burning of boiler fires is one of the troublesome "disturbing causes" in boiler experiments, the more so that such quick burning localities shift slightly with variations of the wind and other changes. The fire-bars were always kept open, so that the ashpit was always bright and clear. The fire itself was "clinkered" at least once, and often twice in a day.

18. This law, as regards rapid combustion, was reversed on the small scale. In the usual evaporations commonly taking place in Print Works, where pans and open boilers are employed, varying in capacity from ten to three hundred gallons, the rate of evaporation per pound of coal is very low, varying from two to four and a half pounds of water evaporated from 212° for one pound of coal; and the law of evaporation from such vessels is about as follows: If the time is reduced to one half, the evaporation per pound of coal will be reduced also, to the extent of from 10 to 20 p c^t^.

19. The difference in the results obtained by a change in the coal used amounted to .... 11 p c^t^

20. The same coal reputed to be from the same pit varied in its evaporating power to the extent of 6 p c^t^

21. The higher the water stood in the boiler within certain unknown limits, the better was the result. In some experiments this advantage was in the proportion of 1 per cent. for every six inches of depth of water.

22. As regards the effect of pressure on evaporation, the general result of these experiments is in favour of the sup-

position that the rate of evaporation of water per pound of coals increases with and bears some ratio to the pressure under which the steam is generated. In connection with this idea I may mention a singular fact which may be supposed to give it support, or may, perhaps, find some other practical explanation. If a boiler be used exclusively for the purpose of heating water and liquors in a dyehouse, and be capable of working that dyehouse just sufficiently when the steam is at 10 lbs. pressure, it will be found unable to do so when the pressure falls to 7 lbs., and still less able to do its work when the pressure further falls to 2½ lbs. By repeated experiments on the large scale I find that the loss incurred by working steam at 2½ lbs. as compared with steam at 10 lbs., *an equal quantity of coals always being burned in the same time*, is as follows: —

Available power of the boiler to heat dye cisterns:

With the steam at	10 lbs. pressure	=100
„ „	7 lbs. pressure	= 92
„ „	2½ lbs. pressure	= 77

I have not experimented at higher or lower pressures than those stated.

23. While we may reasonably look for advantage from improvements in the construction of the fireplace, in the management of the fire itself, in the construction of the flame-bed and in adaptation of draught, in the form of the boiler, in the addition of separate supplementary heating surface, and in cleanliness, and by all these means effect a great saving in the consumption of coals, we cannot at the same time expect much saving from extension of flue space when allowed to coat with soot, nor from a greater length of boiler than four times the length of the fire-place.

24. With a view to the prevention of the "scaling" of boilers, or the coating with sulphate and carbonate of lime and mud, I have experimented with the following substances: caustic soda, quicklime, muriatic acid, soap liquor,

sawdust, spent madder, and logwood chips, with various degrees of advantage. Muriatic acid proved a most effective agent, indeed somewhat too much so. Although I never added more than two-thirds of the quantity of that acid necessary to saturate the lime known to be in the water as carbonate, yet the action continued not only to the point of the disappearance of the remaining third of the carbonate of lime, but went further. It had an action, also, on the oxide of iron surrounding the rivets, and existing between the edges of the plates; so that after six weeks, the usual duration of an experiment, it was found that the iron plates were not only clean and bright like silver, but also that the joints had been acted on to a considerable extent. The rust did not appear to be dissolved, but only loosened, nor did the metal of the plates appear to be corroded, for water from the boiler tested daily showed no iron.

The water used in these experiments was from the Lancashire "Red Rock," hard in quality, containing both sulphate and carbonate of lime, with a little iron. It required forty measures of Dr. Clarke's soap test liquor to soften it. The scale, when allowed to form, was composed in 100 parts of 22.5 carbonate of lime, and 77.5 sulphate of lime.

Two facts were noticed as regards the tendency of hard water to scale. First, that the *sulphate of lime* separates from the water only when in contact with solid objects, such as the bottom and sides of the boiler, or solid matters floating in the boiler, such as sawdust and logwood chips (hence their use); and that no precipitation takes place until the water has been concentrated by continued evaporation down to the condition of a saturated solution of sulphate of lime, or to that point which may be termed the "salting point." Secondly, *carbonate of lime* and mud are principally deposited in the midst of the water, and have but little disposition to adhere to the boiler, unless cemented by the sulphate of lime.

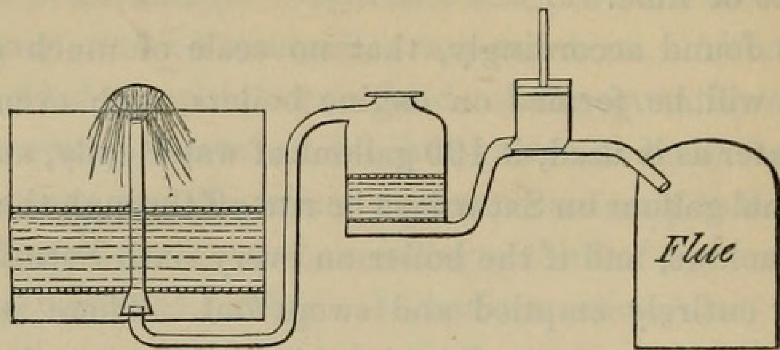
It is found accordingly, that no scale of much consequence will be formed on engine boilers, with even such hard water as is used, if 100 gallons of water daily, and 200 additional gallons on Saturdays be run off through the usual mud machine, and if the boiler on every sixth Saturday be further entirely emptied and swept out. There is little loss incurred by proceeding in this manner, as the chief discharge may take place at the close of each day, while a large profit accrues by the saving of coals and the increased durability of the boiler, with security from danger to all concerned with it.

25. In the five boilers most used in these experiments, the highest results were obtained when all the air required to consume the coals was introduced into the fire-place through the fire-bars. The introduction of additional air elsewhere uniformly occasioned loss, whether it was admitted by means of the furnace door during two minutes after firing, or for a longer or shorter period, or through a regulating slit above the furnace door, or through apertures of larger or less size and more or less numerous, in the sides of the furnace, in the front of the bridge, or on the top or back of the bridge.

26. Perfect combustion of black smoke was never arrived at, without the introduction of additional air. The consequent loss was a little over 1 per cent.

This loss, by the addition of air over the fire, will be understood when we consider the smallness of the weight of black smoke. The following experiments may convey some information on this point. I had in view the possibility of working bleaching keirs with hot air from the flue of the furnaces instead of steam. The apparatus used is shown in the drawing: —

Fig. 22.



I drew the hot air and smoke out of the main flue by means of a pump at a temperature of perhaps 600°, forced it through the intermediate washing vessel, in which was kept a small supply of water, and where mechanical means were adopted to subdivide the stream of air, and passed it on to the keir. The result of these experiments was a failure as regards the heating of the keir. I passed the hot air at a high velocity, namely, about 130 cubic feet per minute, and found that the heat communicated by the mass of air was barely sufficient to sustain the contents of the keir at a temperature not above 190° F., and that it took from six to eight hours to bring it up to that point. Incidentally, however, I had the means of estimating the weight of black smoke. The hot air and smoke used were from furnaces that produced dense black smoke after each fresh supply of coals. The washing apparatus intercepted the soot in such a perfect manner, that the water in the keir was not more than discoloured at the termination of the experiment. The black residuum in the washer, composed of dust and carbon, was carefully examined, but not analysed. I formed an opinion to the best of my judgment as to the amount of carbon, and as to its weight relative to the coal consumed in heating the air and smoke drawn by the pump, which was that the weight of black smoke does *not exceed* the one thousandth part of the coals consumed. The power of black smoke as it issues from the chimney-top to discolour the atmosphere is prodigious, but its weight is inconsiderable.

This discolouring power is rapidly abated and soon destroyed by the aggregation of the particles through electrical or other causes, and quick precipitation ensues, each particle being assisted in its descent by an associated burden of dust and other matters. The dense heavy cloud we see floating off to leeward of such large cities as Manchester, is not composed of black smoke; indeed, it may be questioned if, at the distance of half-a-mile from its source, and unless drifted like sand before the gale, there is then a single particle of black smoke in the atmosphere. Those who have "crofted pieces" under the current of their chimney can estimate the correctness of this remark as to the rapid precipitation of black smoke. The dust which descends, associated with the black smoke, has been invariably found to contain iron. This may be shown on the most minute scale by placing a particle of the soot between the wet folds of a pink piece dyed with madder at that point of the process when the piece has been washed out of the "tin." The chemical law of displacement in this experiment is beautifully shown by the iron taking the place of the alumina that formed the basis of the pink colour, and itself producing a black with the liberated alizarine. What we see floating in the atmosphere is dust associated with the volatile constituents of the coal which have been distilled off through imperfect combustion. It is scarcely in place in this paper to go further into this important subject; but I may remark that this rapid disappearance of black smoke by precipitation, more particularly in dry weather, is one of the marked tests of the proper action of the fires below, while if the smoke hangs lazily, keeps together, and is visibly black for a greater distance, we may be certain that something is going up the chimney as well as black smoke, and in serious quantities, which ought to have been burned in the fire itself. The presence of such volatilized oils appears to have the effect of sustaining the black smoke by hindering its aggregation and precipitation.