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"SOME NOTES ON WATER-TUBE STEAM BOILERS."

Read by MR. WILLIAM FYVIE, 1st July, 1903.

It is not without some little hesitation that I come before you with these few notes on "Water-Tube Boilers." This subject is of too much importance and far reaching in its various phases and ramifications for me to give it justice even in a very superficial way, but my object is to try and bring before you a few points, new or otherwise, or to bring under your notice a different view of an old face, and in a measure set the ball rolling, in the hope that it may be productive of useful discussion, during which the interchange of views and ideas among members will, I doubt not, advance the general knowledge on the subject, and no one is more anxious to pick up a few wrinkles than the writer.

In looking up some of my notes and scraps on this subject, I came across copies of results of tests on some boilers of this type, which I assisted to carry out about 20 years ago (but I am sorry to say the figures were not decipherable). Before this time and since then I have watched with considerable interest this type of boiler in its various forms very closely, and have seen it force its way successfully into use under all conditions where a steam generator is required, having had to do with their practical working more or less during the last 18 to 20 years. I have always had a great favour for this type of boiler, but I have had many disappointments with it, perhaps in those cases I expected too much.

It has been said somewhere that "It requires a considerable amount of ignorance to speak positively on such a subject." And I think this is fairly applicable in connection with watertube boilers. Many of my theories have fallen to pieces heretofore in connection with this matter, so that I hope I will not commit myself too far on this occasion.

I think it must be admitted by even the most enthusiastic water-tubist, that the old tank boiler is dying very hard, but the sign of the times is too evident that it is being superseded by the various modifications of the water-tube type. And at the present time this is one of the most important questions that is before the steam user and engineer. In those times of centralising our prime movers into large centres and distributing the energy by electrical transmission, when the older type of steam generators, which are built for pressures much below what is now considered good practice, must be replaced by a more up-to-date generator capable of carrying the higher pressure demanded; and when at no distant date our suburban

locomotives at least will be displaced by some central station prime mover, the engineer in many cases has no little hesitation in making up his mind which type to adopt, the higher class tank boiler or the water-tube. The main factors in favour of the water-tube when used for most land purposes are :---

First.—The very high pressures demanded in modern times (to produce the greatest amount of useful energy at the least possible cost) makes it a very difficult and costly matter to produce the tank boiler to withstand this great pressure, and at the same time resist the enormous unknown stresses that may and are set up in the structure due to difference in temperature of its various parts.

Second.—The possibility of serious disaster that may and does occur from time to time when one of those tank boilers let go, containing as they usually do a large volume of steam and water, at high pressure.

Third.—For marine purposes. In addition to those we have the objection of the much greater dead weight necessary to be carried, including boiler and water with the large fire-tube or Scotch marine boiler, thus reducing cargo capacity in proportion, which for land purposes is usually a matter of no importance.

Fourth.—For naval purposes. In addition to greater weight, a grave drawback to the large fire-tube boiler is the impossibility to get up steam quickly (which is one of the most essential features), and the risk of serious damage that may be done to this type of boiler, when it becomes necessary to attempt getting up steam quickly by forcing the fires.

Those are the four main features which tell against the tank type of boiler, whereas those objections are pretty well overcome in most boilers of the water-tube type.

First.—In the water-tube type they are divided up into numerous small sections, and of such a form that a comparatively thin section of metal is sufficient to resist the great pressures to which they are subject, and in most types those sections or elements are constructed in such a manner that considerable flexibility is permitted without straining the different parts to any serious or dangerous extent, thus what I have termed (in absence of a better expression) the "unknown stress." due to difference of temperature, is very much reduced, and in some designs of such little moment that they do not call for any practical consideration. In such cases the engineer or boilermaker has only to deal with the stresses which are fairly well defined, and can therefore be more effectually provided for; the factor of safety is usually very much higher in the water-tube type.

Second.—The possibility of serious disaster by explosion is more remote with most water-tube boilers, owing to the great pressure being, so to speak, put up into small packets, the total volume of water and steam being less, so that when any part or element does let go, the fracture invariably being small, and the area of opening restricted, the results are not usually of a serious nature, and this is proved by past experience; even in the earlier stages of their adoption down to the present time they have been remarkably free from accidents of a serious nature.

Third.—As regards total weight, this follows in a measure from the use of lighter materials of construction, but mainly by the reduction of cubic capacity and higher pressures permissible.

Fourth.—The feature of quick steam raising follows from the use of thin heating surfaces, smaller volume of water and steam, and a flexible structure that will withstand forcing to a considerable extent without permanent injury.

This is illustrated in a marked degree in boilers of Torpedo craft (which may be termed express boilers), the very high temperature generated in those furnaces when steaming to their full capacity, being such as would destroy any type of tank boiler furnace or combustion chamber in a short time where the thickness is §in. or more.

Now, the question which suggests itself to the practical man is: Why, with all those advantages (everyone of which is very important to have in a steam generator), has not the water-tube boiler long before this time entirely displaced the old type of tank boiler, more especially in the marine line, where the advantages above-mentioned are of much more value than on land, and if we keep outside the great navies of the world, and take the mercantile marine. and who are by far the largest users, where the commercial side is the allimportant one, the water-tube boiler is certainly very poorly represented, and in not a few cases where they have been adopted it has not been with the most satisfactory results?

Now, there must be some very good reason why they have not been more largely adopted up to the present time.

The question is, What is the reason? Each water-tube boiler advocate has overcome this in his own way, and to his own satisfaction, but the great majority of shipowners and many others ashore remain unconverted. It is far from my intention to attempt to explain this but there are one or two points I would like to bring under your notice, which I think have more or less influence on the question.

Mr. J. M. Rowan, of Glasgow, fitted water-tube boilers on a sea-going steamer, the "Thetis," in 1857, which worked more or less successfully for about a year. Another vessel, about

1869, was fitted with Rowan's water-tube boilers for a working pressure of 130 to 140 lbs., and worked more or less successfully for some years, so that the introduction of the water-tube boiler on board ship is not by any means a matter of recent date.

I think it is pretty well conceded all round that heretofore the water-tube boiler at sea, whether in the navy or mercantile marine, has not given the same all-round efficiency as the ordinary marine type of fire-tube boiler, therefore it is little comfort to the ship-owner to know that his boilers only weigh about half what the older type would do if he has to take three or four times this difference in weight of extra coal in the bunkers to complete the voyage, and this, I think, has been the general experience, so much so that all the large navies in the world have practically adopted the system of carrying sufficient old-type boilers for ordinary cruising purposes, and the balance $(\frac{2}{3}$ to $\frac{3}{4}$ of the total) of the water-tube type for anything like full speed work ; this, I understand, is wholly on the score of fuel economy, as the steaming time in the life of most naval vessels is at the cruising speed. In the mercantile marine we find little but the old type, where they are practically full speed all the time. (As the ship-owner says, there is no money-making when the propeller is stopped.)

This evidence I think pretty conclusive that there is a weak spot somewhere; it can hardly be said to be in lack of heating surface, or its inefficiency, as it is usually larger and much The weak spot, I think, is in the combustion of thinner. the fuel; with a great many water-tube boilers, the combustion is notoriously bad. The reason, I think, is not far to seek, as many of them have practically no combustion chamber at all worth the name, as we usually understand it; there is no room or space allowed for the mixing of the air and gases necessary to produce good combustion, as we have in the old marine, or even Cornish and Lancashire. The volatile and other hydro-carbons are distilled off from the fuel, and immediately come into contact with the comparatively cool surfaces of the tubes, where they are cooled down to a point that combustion is out of the question; they pass off without giving up their heat ((and not only this loss, but they produce much black smoke and soot, covering up the heating surfaces with a poor conductor of heat, thus reducing their efficiency, and adding considerably to the labour necessary for repeated cleanings), and it is no uncommon thing for the up-takes to be turned into combustion chambers, where two or more fires are connected to the same up-take. And this also holds good with many land boilers of the water-tube type. When you find the back flue behind the boiler with a temperature 1100deg. to 1200deg. F., under ordinary working conditions,

you may safely conclude that your back flue is a combustion chamber for the time being, and this is not by any means an exceptional occurrence.

I am not going to say that the total absence of smoke is a sure indication of efficient results, not by any means, as I have seen many practically smokeless chimneys where the results were notoriously inefficient.

In the mercantile marine, in most cases little regard is paid to the smoke (as they are not usually a nuisance to their neighbours), provided the results come out all right, but with the navy, the absence of smoke is one of the most important features, when we consider the vast sums of money spent every year by the British Navy to procure hand-picked Welsh coal for the primary purpose of efficiency and the prevention of smoke.

In comparing the modern marine boiler with the watertube, we can make comparison on a more equal footing, as they were both adapted for comparatively high-working pressures.

In the case of the old type of land boiler, it could hardly be said that we had reached anything like the working pressures, that the water-tube type are so well adapted for, and comparison is hardly on the same equal terms, the advantage in this case being decidedly in favor of the water-tube and in this connection I would like to point out that water-tube boilers have been much maligned, and very unjustly so. As an instance, we will suppose a Cornish or Lancashire boiler working at a pressure of 60 to 70 lbs. per square inch has been replaced by a water-tube boiler to work at, say, twice this pressure, 120 to 140 lbs. per square inch, and that the feed water contains a small quantity of scale-forming matter (nearly all natural waters contain more or less), under the new conditions the much higher temperature due to the greater pressure is naturally much more conducive to the formation of scale than the lower temperature that is obtained with the old boiler; it also follows that a much thinner accumulation of scale on the plate or tube will bring about loss of efficiency or injury to the parts, much more readily than when working at the lower temperature, and I regret to say this phase of the question has been lost sight of in most cases, to the detriment of the water-tube boiler.

The essential features that I consider necessary in a watertube boiler that has to work at high pressure and rapid steaming are as follows:—

1. Ample strength to resist the pressure for which it is to be used.

2. Flexibility to accommodate itself to sudden changes of temperature in its different elements, without stress or injury to any of its parts.

3. Good combustion must be obtained.

4. The heating surface sufficient, and so arranged that the greatest amount of heat will be taken up by the water in the boiler, from the hot furnace gases, and that free circulation will commence as soon as the fire is lighted and continue active.

5. Ample provision for inspection, cleaning and repairs, such repairs when necessary to be practically as good as when new.

6. The construction shall be such that the formation of "steam pockets," or "chambers," is practically impossible.

To overcome this, the following conditions are necessary : ---

(a) Circulation must be very active and continuous.

(b) The direction of the tubes, especially where greatest heat is applied, must be as near vertical as possible.

(c) That each tube or element ought to have a perfectly free inlet for water at its lower end, and a perfectly free outlet for steam and water at its upper end, equal to its own sectional area if possible.

(d) The proportion of length to diameter in the heating tubes ought not to be too great.

The formation of "steam pockets" or "chambers" (especially when steaming hard) is one of the most serious troubles in connection with many water-tube boilers; the temperature of a tube or part of a tube where a steam pocket has formed rises to such an extent that it rapidly becomes oxidised, externally by the hot gases, which are more or less mixed with oxygen, and internally by the steam. The strength of the metal when thus over-heated is reduced to such an extent that rupture may, and does, take place. If the construction is such that thorough active circulation is produced in all parts, there is little chance or opportunity for the formation of such steam pockets; one of the best proofs of good and rapid circulation in one boiler as compared with another may be safely gauged by the amount of water evaporated per square foot heating surface in a given time, with equal combustion, and equal temperature in the waste flue gases leaving the boiler, that is the best circulation will give the highest factor of evaporation per square foot heating surface.

Laboratory experiments have shown that the co-efficient of transmission varies from one to five, according as the motion of water is nil or very great. In the practical application of forced circulation to different types of evaporators, and in condensers, it is a well-known fact that the more rapid the circulation the higher the efficiency of the absorbing surface, and steam generators of whatever type are no exception to this rule. The higher evaporation per square foot heating surface, is proof of the best circulation, and it follows from this that the tubes forming the heating surface are kept cooler.

I have prepared a few rough diagrammatic sketches to represent some of the best known types of water-tube boilers. They are not intended in any way to indicate the details of construction, but merely the course of the circulation, so far as it is necessary to show,, and by this means assist us to compare them one with another.

We will take the straight tube type first.

No. 1 DIAGRAM is intended to represent the Babcock and Wilcox, Hornsby, Heine and D'Allest types, they being all pretty much on the same lines. To compare those diagrams with the essential features, I suggest as being necessary in a water-tube boiler :----

(1) Strength. This, I think, may be conceded to all the types I am going to deal with.

(2) Flexibility. Not perfectly fulfilled, due to the fact that two or more straight tubes are fixed into the same rigid end connections.

(3) Good combustion. This can only be obtained with difficulty in any furnace so placed, due to lack of combustion chamber space.

(4) The heating surface usually ample, but arrangement not the best to utilise the most heat.

(5) Inspection and cleaning. This is fairly well provided for in all.

(6) The construction is conducive to the formation of steam pockets, due to the nearly horizontal position of the tubes, and that the tubes have not perfectly free supply and discharge, outlet and inlet areas being only 8 per cent. to 15 per cent., according to the number of tubes in height or in one section.

No. 2 DIAGRAM is intended to represent the Yarrow and Blechynden types (the latter having a slight curve in the tubes to facilitate removal and replacement).

(1) Strength conceded.

(2) Flexibility not perfectly fulfilled, but with the comparatively short tubes of less consequence.

(3) Combustion. This should be better, due to more room.

(4) Heating surface ample arrangement not the best.

(5) Inspection and cleaning. Fairly well provided for.

(6) Should be perfectly free from steam pockets, freedom for inlet and discharge equals 100 per cent.

No. 3 DIAGRAM is intended to represent the Niciausse and Durr types. (They both have what may be termed field tubes.)

(1) Strength conceded.

(2) Flexibility all than can be desired.

(3) Combustion deficient; lack of room.

(4) Heating surface ample, arrangement not the best.

(5) Cleaning and inspection, with considerable trouble.

(6) Liable to formation of steam pockets, due to horizontal tubes, outlet and inlet areas being much reduced.

It will be observed that the tubes of this boiler cannot be drained right out, except with great trouble.

No. 4 DIAGRAM is intended to represent the Belleville type. (1) Strength conceded.

(2) Flexibility very well provided for.

(3) Combustion bad.

(4) Heating surface sufficient, arrangement indifferent.

(5) Cleaning and inspection, very indifferent to bad.

(6) Very conducive to formation of steam pockets.

This type is sometimes called the foaming class, due to the discharge pipes being above the water line.

We now come to the Bent tube type.

No. 5 DIAGRAM is intended to represent the Thornycroft and Mosher (U.S.A.). They are both of the so-called foaming type —that is, the discharge is above the water line.

The Thornycroft "Speedy" type, brought out about 1885, this being the first vessel in the British Navy of any importance to be fitted with "Thornycroft," or, in fact, any watertube boilers on a large scale; then the "Daring," a similar type of boiler, both with very much bent tubes.

No. 6 DIAGRAM is intended to represent a later type of Thornycroft, also Normand, Reed, White-Forster, Fleming and Ferguson, and Mumford, which are all pretty much on the same lines, but the diagram is more in keeping with Thornycroft.

(1) Strength conceded.

(2) Flexibility, all that could be desired; perhaps the best in this respect.

(3) Combustion. Pretty fair to good.

(4) Heating surface ample, and fairly well arranged.

(5) Inspection and repairs said to be no great difficulty.

(6) The formation of steam pockets very remote.

The "Thornycroft" boiler has certainly had a most remarkable record. Since they were first introduced in 1885 up to 1901, a period of about 16 years, there has been over 1,070,000 I.H.P. fitted to the different navies, this being at the rate of nearly 67,000 I.H.P. per annum, and does not include boilers of this type supplied outside the navies. Not a bad record for bent tubes.

They have given evaporation up to 12 and 13 lbs. water per square foot heating surface, per hour (that is, dividing the total evaporation per hour by the total heating surface), and over 100 I.H.P. per ton of boiler.

You will observe a difference in the two Thornycroft diagrams. Shown in the "Speedy," the whole tubes discharge

above the water line, where in the later form only about half. This alteration was made in deference to the wishes of some steam users, where the boilers are often out of use, as "Torpedo Boats," when they fill the boiler full of fresh water to protect it from corrosion, and with the "Speedy" type this could not be done, so they made the highest point of every tube at its entry into the steamdrum.

No. 7 DIAGRAM is intended to represent the "Morrin" climax boiler. This is formed with a central verticle shell, having numerous tubes bent to the form of a loop, and expanded directly into the shell; the furnace is all round the central shell.

(1) Strength conceded.

(2) Flexibility, all that can be wished.

(3) Combustion indifferent.

(4) Heating surface sufficient.

(5) Inspection and repairs rather difficult.

(6) Conducive to the formation of steam pockets, tubes being too near the horizontal position.

No. 8 DIAGRAM is intended to represent the Stirling type of boiler.

(1) Strength conceded.

(2) Flexibility very well provided for.

(3) Combustion good.

(4) Heating surface ample, and well arranged to utilise the heat to the best advantage.

(5) Ample provision for inspection, cleaning and repairs.

(6) The formation of steam pockets very remote; in fact, hardly possible, each tube having 100 per cent. area of discharge and inlet, and the circulation all that could be desired.

This boiler in its present form has been remarkably successful since its introduction, and it contains many of the best features that are essential in steam generators of the watertube type.

The combustion chamber is high and roomy, and conducive to good combustion; the tubes forming the heating surface are nearly vertical, being less conducive to the formation and accumulation of scale or soot. The feed water enters the boiler at a point farthest removed from the greatest heat, where it must pass down the back bank of tubes, over which the hot gases finally pass to the chimney, thus reducing the final temperature of the waste gases, due to contact with a cooler In the back bottom drum, most of the solid matter surface. that the water may contain is precipitated where it can be blown out from time to time, and thus in a large measure prevent the scale-forming matter getting into the hottest parts of the boiler. With the superior circulation obtained in this boiler, the co-efficient of transmission is very high, and the

general efficiency is very good. It will therefore stand forcing to a very considerable extent with little reduction of efficiency and without the slightest risk of injury to any of its parts.

I may point out that the steam is taken from the middle drum, where baffle plates are fitted to prevent the possibility of any fine spray being carried off by the steam that might pass from the front drum by the upper connecting pipes, when the boiler is being forced very hard. The upper connecting pipes between the top drums tend to superheat the steam to a certain extent.

The feed water is supplied to the boiler through the back top drum, where you will observe there are no connecting tubes below the water line till the bottom back drum is reached; the feed supply must, therefore, pass down the back bank of tubes before it can get into what may be termed the steam generating and hottest parts of the boiler. In its passage down this back bank of tubes, it gets practically heated to the temperature, due to the pressure in the boiler. The application of heat in this manner is very conducive to the precipitation of any solid matter the water may contain. As most scale-forming matter precipitates very freely when subjected to considerable heat, the sediment fails to the bottom of the lower back drum, where it can be blown out from time to time, the water in this drum being fairly quiescent, the agitation not being sufficient to prevent or disturb the settlement of the sediment.

According to the nature and temperature of the feed water being supplied to the boiler, so is it divided over the whole of the back bank of tubes, or confined to one, two or three rows of tubes. This is done by fixing a plate in the drum, thus forming a division between the rows of tubes, which is easily placed in any desired position, to suit the conditions.

Thus the back bank of tubes or part of them, as the case may be, acts the part of an economiser or feed heater.

The gases leave the boiler where the feed water enters, an arrangement peculiar to this boiler, and one of the important conditions necessary for high efficiency.

I do not know of any other type of water-tube boiler where this important feature can be taken advantage of in the same simple and effective manner.

In conclusion, I have no hesitation in saying that the watertube boiler, in some shape or form, will be the boiler of the future, as the possibilities of improvement in them are greater and in the majority of points they far excel even now.



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Discussion.

Special Meeting, August 19, 1903.

Mr. Geo. Turner (President) said he rather objected to the term "tank" as applied to our old friend the shell boiler; it might convey the idea of its being square. There was, however, one sense in which that term was appropriate, namely, as a storage for a large amount of heat. It was well known that fires could not be cleaned so readily and quickly in the brick-lined furnace of a water tube boiler, as in a shell boiler, and the heat stored in the latter formed a valuable help to get over that process without loss of pressure, a matter of some consequence in many circumstances. The question of accidents also struck him. Was it a fact that there were fewer accidents in the case of water-tube boilers than shell boilers ? It would be interesting to know, for instance, whether the cruiser "Blanche" had water or fire-tube boilers. It seemed to him that, now, when the principles of construction were better understood there were as many accidents in the one type as the other. The water-tube accidents might, indeed, be more numerous, though perhaps individually less serious. One main point before the Institute was, he thought, that it had not been proved that the water-tube boiler was more economical than the shell boiler; it seemed to be in this respect a question of conditions, and equally good results could be got from either type if they were properly considered. The question of the suitability of the fuel to be used was one that very often seemed to be given insufficient consideration when determining on the type of boiler to be used. Generally it might be taken that a high-class coal would give in practice better results in a brick-lined furnace than a fuel in which the percentage of mineral impurities was high.

Mr. Geo. Higgins thought that the value of Mr. Fyvie's paper would be added to considerably if he would furnish some information derived from actual experiments with water-tube and other boilers in support of the assertions he made. For instance, on page 8 he almost admitted that most watertube boilers were not so economical as regarded the consumption of coal as the old marine boiler, and he attributed that to the want of combustion chamber space. That was a very important point. Was it a fact that there was a lack of room for combustion in some of the types of boilers? What experiments proved it? Then, again, his assertion about the formation of steam pockets in the tubes. Had these steam pockets

been detected, and where, and what reason was there for thinking that steam pockets formed more readily in horizontal tubes than in vertical ones?

The German manufacturers were cautious, canny men, and nearly all of their boilers (and he had examined about a dozen illustrations of them recently), had tubes just slightly inclined to the horizontal, resembling, in fact, very much the tubes in Fig. I. of Mr. Fyvie's paper. It was, therefore, evident that nearly horizontal tubes were believed to be as good as nearly In such matters as this it seemed to him vertical ones. (Mr. Higgins) that confirmation should be forthcoming in the shape of actual tests. While dealing with the question of horizontal versus vertical tubes, he asked whether it was known which was more efficient as regarded heating surface. Were the horizontal better or worse for heating purposes than the vertical? It was time some results were known. Possibly Mr. Fyvie or other members might be able to give some information as to the points he had raised.

Mr. Stone: In talking of the relative advantages of the two types of boilers, no mention was made of the important factor of capacity per cubic foot. Mr. Higgins referred to the question of evaporation for the two types of boilers. Of course figures could be obtained showing either type of boiler better; so much depended upon the conditions of the test, such as the ability of the firemen, etc. It was, however, extremely difficult to determine which type of boiler would be the better. He had seen many tests in which the watertube boiler had proved superior in economy to the shell boiler, and vice versa. Another important fact with the water-tube boiler was the possibility of being able to rapidly raise steam.

He accepted the leading statement in the third paragraph of Mr. Fyvie's paper, i.e., "It requires a considerable amount of ignorance to speak positively on such a subject." If his remarks appeared to be over positive he would only plead as justification that he had not had personal experience with any of the types of boilers with which the paper deals. The subject brought before the Institute by Mr. Fyvie is a very important one, for though, as Mr. Fyvie truly says, "the old tank boiler is dying very hard," he thought most of us will admit that it is dying the more surely, and therefore it behoves all engineers who hope to keep up with the times to learn the merits and demerits of the various types of water-tube boilers which manufacturers and designers offer to them.

Mr. Fyvie has done well to set out concisely those features which he considers essential to a good water-tube boiler, and he thought the majority of engineers will add that these features are equally important in shell boilers. He thought one additional feature might have been added with advantage,

and that is—the disposition of the more important portions so as to minimise deterioration due to corrosion through leakage, sweating, or other causes.

Whilst Mr. Fyvie's paper embraces the subject of water-tube boilers at large, he thought it must be admitted that local engineers are practically interested in but few of the types referred to. The majority have been developed for special purposes, such as use in war vessels, and can only have a passing interest for us, as may be created where fresh principles have been embodied, or recognised difficulties overcome by improvements in construction.

Diagrams 1 and 8 cover the types of water-tube boilers which can make any serious pretension to being represented in Australia. He would, therefore, confine his remarks to these, and will follow the author's order in dealing with the essential features.

(1). Ample Strength, etc.-Mr. Fyvie says: "This, I think, may be conceded to all the types I am going to deal with." He supposed we must admit that all designers should provide for ample strength, and that no designer would plead guilty to the neglect of this, the feature of first importance in all high-pressure boilers. The question, however, which we have to consider, is what are the risks in the process of construction or subsequent repair of the stresses originally provided for, being exceeded, and if exceeded, how far are they likely to affect the probable life of the boiler or the seriousness of the result of a failure. He could not help thinking that the large number of holes in the cylindrical shells of the class of boiler illustrated by Figs 2 to 8, into each of which a tube is expanded, introduces a very great degree of uncertainty as to the actual stress in the narrow bridges of metal between the holes; and which may be accentuated by the bending of the tubes due to differential expansion and contraction with change of temperature, especially so with the construction shown in Fig. 8, which is the least flexible. The stresses in the flat tube plates of locomotive and other multitubular fire tube boilers are very different to those in the perforated cylindrical shells of the boilers now under discussion. In the latter the stress caused by expanding the tubes, by the differential expansion of the tubes under change of temperature, and the tensile stress balancing the internal steam pressure all act in the same direction, tending to rupture the shell in its weakest place. In the fire-tube boiler the tube plate only has to withstand the stress induced by expanding the tubes, the steam pressure is balanced by the tensile stress in the tubes and shell plates, which stresses are at right angles to those set up in the process of expanding the tubes. If leaky tubes occur in the cylindrical tube plate boilers the greater trouble

of getting in to use the expander is likely to lead to the workman trying to make a sound job and save himself subsequent trouble at the cost of undue stresses in the shell.

To perforate the cylindrical part of the boiler appears to me to be wrong in principle, and likely to shorten its life; and further repairs in this, the weakest part (which is also subjected to the greatest stresses, viz., the bridges between the tubes) must be difficult to effect. Again, a failure of this part of the boiler, which is in its most important element, would cause very serious consequences.

In the class of boilers covered by Fig. 1, no such structural weakness exists, the uncertain stresses caused by expanding tubes do not affect the drums, which are the most vital parts of water-tube boilers. The tubes are easy to get at, and the inducement to over expand is certainly less. The stresses in the headers due to expanding and steam pressure will be less, and can be more easily met and effectively provided for. The small cross section of the headers renders the stresses due to steam pressure in them almost negligable.

Flexibility .---He should be inclined to reverse Mr. Fyvie's comments under this heading, with respect to the two classes of boilers represented by Figs. 1 and 8. The question of flexibility cannot well be separated from that of the distribution, and liability to considerable variations, of temperature. The triangular construction adopted in Fig. 8 is the most flexible, and at the same time admits of the greatest rigidity. Nothing could be much better than a simple triangle, or much Differences worse than a compound triangle in this respect. of temperature between the inner and outer tubes in Fig. 2 will only cause one element to swing in or out, as the case may be, with respect to the other element. If the two lower elements of Fig. 2 were connected, no such swinging can take place, and this is the condition that obtains in Fig. 8. Three drums connected by three tubes give perfect flexibility with respect to small changes in the lengths of these tubes, but it also forms a very rigid frame, resisting the swinging which differential expansion in any one nest of tubes tends Such differential expansion must then clearly be to effect. provided for in the individual tubes themselves.

The charge of rigidity may also be laid against Fig. 1. But in Fig. 1 it will be seen that provision has been made to equalise the temperature and temperature changes as far as possible for all tubes. It will be seen that the hottest gases impinge on but a portion of the length of each tube, and that the reversal of the direction of the flue gases across the system of tubes tends to equalise the average temperature of all, and so reduce to a minimum the differential expansion which might otherwise cause trouble. In Fig. 8, on the other hand, no such equalising conditions exist. The innermost row of

the first nest of tubes is protected from change of temperature to a considerable extent by the layer of fire bricks used to determine the path of the flue gases, whilst the outermost row of tubes is exposed for its whole length to the fierce heat of the fire, or impact of cool air during the process of firing. The conditions of circulation also affect the temperature changes adversely. It seemed to him that the rectangular tube frame of Fig. 1 is more flexible than the triangle of Fig. 8, and at the same time careful provision has been made to minimise the inequalities of temperature of the tubes in Fig 1, whilst the worst possible conditions exist in Fig. 8.

Combustion.—He agreed with the author of the paper that the high combustion space above the furnace in Fig. 8 has some advantage over the more restricted furnace room in Fig. 1. The adoption of the Scotch furnace with fire brick on the lower set of tubes, which is not shown in Fig. 1, however, removes a considerable part of this disparity.

Heating Surface Sufficient, etc.-This is simply a question of the evaporative output demanded from the boiler, and only affects the nominal rating as given by the maker, and overload capacity available in times of emergency. The arrange ment of heating surface so as most effectively to take up heat is a question in which scientific principles are more directly From Figs. 1 and 8 it will be seen that the direcconcerned. tion of the hot gases with respect to the tubes is as widely different as possible in the two types. In Fig. 1 the gases move always at right angles to the tubes, which is the best for ensuring their perfect mixing, and so preventing them from escaping without coming in contact with the tube surfaces. In Fig. 8 the gases move parallel to the tubes for the greater part of their path, which is hardly in accord with what is usually considered good practice.

Inspection, Cleaning and Repairs.—Here again he should transpose Mr. Fyvie's remarks, for straight tubes are certainly more easy to inspect and clean; and the tubes really constitute the boiler. In the same way he thought repairs where straight tubes are used, should be effected more readily with less delay, and at less cost, than when the tubes are bent, and repairs to a perforated drum would certainly be a more serious matter from all standpoints than repairs to, or even the complete renewal of a header.

The nearly vertical disposition of the tubes in Fig. 8 will certainly lessen the deposit of fine ash on their upper surface, but it does not affect the true deposition of soot, which takes place when hot flue gases come in contact with a comparatively cool surface, and which we all know takes place almost as rapidly on the vertical tubes of superheaters, notwithstanding their high temperature, as on the vertical and cooler tubes of an Economiser.

Formation of Pockets, Circulation, etc.-He could not follow the author's remarks under this heading, for he tells us that in Fig. 8 each tube has "100 per cent. area of discharge and inlet, and the circulation is all that can be desired." Confining our attention for the time being to the first two nests of tubes which form part of the first triangle. Apparently the circulation in this portion of the boiler is intended to be upwards in the nest of tubes, adjacent to the furnaces, and downwards in the second nest. The force tending to cause circulation through these is the difference in the density of the mixture of steam and water in the two nests of tubes. But heat is imparted to the water in both nests of tubes, and presumably steam is generated in both. If, then, steam is generated in the second nest of tubes, remembering the assumed direction of circulation, this steam must descend with the water into the lower drum, and from there find its way through the first nest of tubes to the front upper drum.

If, on the other hand, the steam generated in the second nest of tubes passes upwards into the upper central drum, it is clear that the circulation cannot be as assumed in the first triangle. If the steam formed in the second nest passes in the direction assumed, i.e., downwards, then through the bottom drum and upwards through the first nest, the greater part will evidently go via the last row of tubes, or those that enter the lower drum at the highest point. If this state of things exists there is a risk of these tubes becoming almost depleted of water, with the attendant dangers of overheating when the boilers are forced, and certainly the unduly large proportion of steam to be carried by those tubes would be liable to permit of greater and more frequent changes of temperature than could otherwise occur, the consequences of which have already been referred to.

As in each separate nest of tubes some are exposed to hotter gases than others, and their inlets and outlets are also at different heights in the drums, all the conditions obtain which are essential to the starting of local circulation ; this is especially the case with the No. 2 nest. By local circulation I mean that some tubes in one nest may have the water moving through them in the reverse direction to that in the rest of the tubes in the nest. If local circulation does take place, such circulation must detract from the useful capacity of that nest, as a unit in the triangular circulation, which is evidently intended to be the normal condition.

Similar difficulties arise with respect to the circulation in the second triangle containing the second and third nests of tubes as components. The more he endeavoured to unravel the mysteries of the circulation in this type of boiler the more

perplexing do they become, and the more he became inclined to think that they are accountable only to the laws of chance.

In diagram No. 1, no such difficulties occur. The down-take tubes are situated at the coldest part of the boiler, and can hardly become steam generators to an appreciable extent; and in any case they are not called on to carry steam generated in the tubes proper.

The sum of the areas of the up-takes is much more than sufficient to carry all the steam the boiler should be called on to generate. The distribution of the heated gases is such as tends to equalise the generation of steam in all tubes, and so maintain a uniformity of circulation through all. Local circulation in a rectangular circuit, consisting of two headers and two tubes, can only take place, if the quantity of steam generated in a lower tube is much greater than that generated in a higher tube and the down-take is too much The fact that the direction of circulation is uprestricted. wards, and is the same in all the heated tubes is a point greatly in favour of this type of boiler. Nothing is left to chance. The scientific principles which govern the movement of water at different temperatures, or of mixtures of water and steam of different densities, appear to have been kept in view by the designers. Steam, which is always liable to be given off irregularly, is not asked to descend into a water-The irregular evolution of steam in any tube filled drum. acting for the time being as a down-take, may, by its momentary increase, upset the balance and reverse the direction of its circulation. Uncertainty as to the direction of circulation implies the possibility of stagnation, in which case nearly vertical tubes in which steam is being rapidly formed may become practically "steam pockets" or "chambers."

The angle of inclination of a tube is not nearly so important a factor as the certainty or uncertainty of the direction of circulation in determining the probability of the formation of steam chambers. Indeed, where uncertainty as to direction of circulation exists it is quite possible that a tube will discharge steam and water simultaneously at both ends, and thus become for a short interval an intermittent steam generator and water hammer combined.

Many other points raised by Mr. Fyvie's paper are worthy of consideration, but he felt that after his introductory remark he should not be justified in trespassing on the President's good nature, seeing that he had already exceeded his allotted time.

Mr. Newbigin said it seemed that after Mr. Stone's comments there was little left to say on the subject. He would like, however, to raise one or two points. On page 10, clause B, in Mr. Fyvie's paper he stated that it was an advantage to have the

tubes nearly vertical. It seemed to him (Mr. Newbigin) that. this would have the effect of causing the gases to flow parallel to the length of the tubes instead of across them. Generally speaking, the transference of heat was a minimum when the two fluids flow in the same direction. Thus, boilers in which the gases flow across the tubes at right angles should have a greater efficiency as regards the amount of heat transferred than those in which the gases flow parallel to the tubes. On page 10, section C, Mr. Fyvie stated that each tube ought to have a perfectly free inlet and outlet. It was by no means clear that there was any objection to a somewhat restricted outlet. Provided the downcomer area was sufficient, there should be no disadvantage in having an increase of velocity at the discharge end of the tube. In fact, if such discharge area were restricted, there would probably be a slight increase in the circulation due to the increased percentage of steam in the column. Again, on page 10, Mr. Fyvie states that the co efficient of transmission varies according as the circulation is nil or very great. This is, no doubt, true in the case of condensers and evaporators where there is always a supply of colder fluid replacing that which becomes heated. The analogy however, does not hold good in water tube boilers, as practically speaking, the whole of the water in the boiler is at constant temperature. The ratio of the transmission of heat is primarily a function of the difference in temperature, and thus no increase in the circulation of a fluid at constant temperature could increase the rate of transference of heat, other things being equal. If there was sufficient circulation in the boiler to prevent the formation of steam pockets, it is very doubtful if any increase in the circulation would improve the efficiency. Similarly if no steam pockets are formed, increased circulation will not tend to further cool the tubes, since their temperature depends on the temperature of the water in the boiler and not on the gases. Regarding No. 2 Type Boiler in Mr. Fyvie's paper, some figures came under his notice of a little express boiler which he thought were worth mentioning. This boiler had 1,100 square feet of heating surface, and 42 squre feet of grate area. With 5in. forced draft the evaporation was 28 lbs. per square ft. of heating surface and the fuel burned about 100 lbs. per square ft. The efficiency of the boiler was naturally not very grate area. remarkable, but to stand an evaporation such as this the flexibility must be somewhat better than Mr. Fyvie seems to infer.

Mr. Rowe said that in reference to the question of the water-tube boiler versus the shell boiler, he thought there was such a thing even amongst engineers as a fashion, and he thought that they were now suffering from the fashion of using water-tube boilers. The water-tube boiler has characteristics which placed it high above the tank boiler for special purposes, but

for most purposes, and especially for land boilers—and that was what mostly concerned the members—he thought there was a great difference of opinion. He had gone into the question of the merits of these boilers, as connected with electric supply stations in England. He carefully went through the boilers there, and separated the water-tube from the shell, and he thought the result might be fairly taken as the barometer of the opinion of modern engineers. The result was as follows: There were 2040 boilers mentioned, but unfortunately the horse-power was not given. Out of this number 1040 were shell boilers. Therefore it seemed that the opinion of modern engineers was very much divided, and on that account it gave them scope to discuss the matter very fully.

Many of the difficulties that were once met in the tank boiler had been now done away with. The expansion troubles in the flues were now entirely obviated by the use of "absorber" flues, and this had further resulted in the discontinuance of the use of cone pipes. As to the relative efficiency, he agreed with Mr. Stone that taking the two classes of boilers and testing them under the same conditions, equal results would be obtained.

He had figures before him of a $30 \ge 8$ Lancashire boiler, and also of a Babcock boiler. These were in two different places; one in London and the other in Brussels. Both were fired by the "powdered coal" system, which is independent of atmospheric conditions, or of conditions of the fireman, and in both cases they gave practically the same efficiency. Therefore, he took it that from these tests, the efficiency of the two boilers may be considered equal. As to the pressures that could be carried, the tank boiler was being made to stand 2001bs. per square inch, and he thought that for the present this met all reasonable demands.

The question of cleaning of the surface was a very important point to engineers. Up to the present it had been admitted that the best class of boiler was the one that could be inspected over every part of the surface. In type No. 1 the whole of the surface could be seen; in No. 7 this could not be done.

He also thought that the question of cleaning the inside surface of water-tube boilers was a most important one. With the advent of water-tube boilers there appeared to have grown up a number of manufacturers who made a speciality of cleaning apparatus for these boilers.

Mr. Adamson said: The members of the Institute have to thank Mr. Fyvie for a paper which would certainly provoke a considerable amount of discussion, for the question of the safe and economical generation of steam is of importance to all engineers, no matter to what branch of the profession they may belong. He was quite in accord with the author in

thinking that the boiler of the future will undoubtedly be of the water-tube type, if only on the ground of safety at the high pressures now being universally adopted, though this is only one of its advantages. The question of safety is not, he thought, sufficiently considered, and unless one has had actual experience of the results of a boiler explosion, one is apt to under-estimate its effects.

He thought the chief reason that the shell boiler is so long dying is that the majority of engineers are very conservative and opposed to radical changes; and this especially applies to the mercantile marine. America undoubtedly was the home of the water-tube boilers, and engineers there probably had fewer prejudices to overcome than those in older countries.

The whole engineering world is indebted to electrical engineers for most of the recent economies effected in steam generation; and the reason is very plain. Coal is their raw material, and they have welcomed and encouraged every effort that has been made by boiler makers and others to effect a saving in their coal and labour bill.

It is worthy of note, therefore, that water-tube boilers are almost universally adopted in all large electrical plants. At the present time in England a number of large electric power plants are being erected to supply electricity for industrial purposes over large areas. Four of these are now at work, and, although the type of engines and generators differs in each case, there are water-tube boilers of type 1. Mr. Brown, electrical engineer for the large power house supplying current for the Sydney tram system, recently stated that during his trip round the world he found that four-fifths of the boilers in all the large electric plants throughout the world were water-tube boilers of type 1.

Another reason for the slow progress made by water-tube boilers in the mercantile marine, is that the type first largely adopted has proved unsatisfactory and very wasteful in fuel, and engineers have condemned all water-tube boilers because one particular type was bad. He thought, perhaps, Mr. Fyvie may not be aware of the number of ships, apart from warships, that are fitted with water-tube boilers giving every satisfaction. One firm have nine steamers so fitted, one of which has now been running over ten years, and it is stated that besides being lighter and more economical in fuel, the cost of up-keep is less than with the Soutch boilers. In the British and American Navies the progress made by this type of boiler has been phenomenal. During 18 months from January, 1901, to June, 1902, these two navies alone ordered 350,000 H.P.

With regard to the efficiency of water-tube boilers on board ship, he could not agree with Mr. Fyvie when he states that it is conceded that they have proved less efficient than the fire-tube type, and that shipowners would find no advant-

age from the reduced weight, as they would have to carry more coal. Even with type 4, which has not always proved satisfactory, some very good results have been obtained. In the "Practical Engineer," of June 5th, 1903, it is stated that "The 'Spartiate' cruiser has arrived at Hong Kong from Portsmouth. She averaged on the voyage 13 knots, which is her cruising speed. She has burned less coal than any other warship, British or foreign, which has ever visited Hong Kong ; altogether 2600 tons, . . . while the 'Blenheim' cruiser, fitted with Scotch boilers, used nearly 4000 tons for an average speed of under 12 knots."

Again, in same periodical, of May 22nd, 1903, it says: "An interesting full-power trial has recently been made by all ships of the Mediterranean squadron. On an extended run it was found that the vessels with the water-tube boilers consumed from 1.7lbs. to 2.1lbs. of fuel per indicated horse-power per hour, while in the case of the ships with cylindrical boilers the rate varied between 2.2lbs. and 2.9lbs. At the same time the speed of the Belleville boiler-ships was in some cases 3.5 miles per hour greater, and in no case was the excess speed less than $1\frac{1}{2}$ miles."

The s.s. "Martello," of the Wilson line, is running across the Atlantic regularly, and the owners, in a letter to the press correcting some misstatements, said that on the first trip across the Atlantic, after water-tube boilers had been installed in place of cylindrical, the coal consumed on the round trip was 100 tons less than the average of three years with the old boilers. The saving in weight also amounted to 100 tons, so that in this case the advantage to the owners was very considerable.

He thought Mr. Fyvie was in error when he stated that all the large navies have adopted the practice of installing a certain proportion of shell boilers for cruising. The British Navy are certainly trying this course, but they are only following the Americans, who tried this plan and discarded it in favour of all water-tube. The vessels now building for the Dutch Navy are fitted with all water-tube, whereas they used to have a percentage of shell. He did not know what other countries are doing, and should be glad if any member could tell him.

An independent expression of opinion from a man whose position gives him a chance of comparing the merits of watertube and shell boilers under similar conditions is always interesting, and this would be his excuse for reading what Admiral Melville, engineer-in-chief of the American Navy, says in one of his annual reports when dealing with the boiler question: "We suffered severely in our short war with Spain from dropped furnaces in cylindrical boilers. I do not think that a properly designed water-tube boiler will give more trouble with the use of impure water, such as sometimes we

have at sea, than any other boiler. The chief engineer for the 'Annapolis' has stated to me that the boilers of that ship were easier to manage and easier to maintain in a high state of efficiency than are cylindrical boilers."

In answer to a question of the President's I may say that the usual practice is to key on slabs of firebrick to the boiler casing, and no trouble has resulted.

Mr. Fyvie then lays down certain rules which he considers a good boiler should conform to, and analyses some typical Taking design No. 1 and following Mr. Fyvie's condesigns. ditions-1st, strength, conceded; 2nd, flexibility-he must disagree with him, as the whole of the boiler is made throughout of steel, and the water in the boiler is nearly the same temperature in all its parts, as he could demonstrate in the model, which with the permission of the President he would have the pleasure of showing; consequently all parts of the boiler are quite free to expand and contract without strain. The expansion, also, is very slight, for it has been found by experiment that with a temperature of 2500deg. Fah. on one side of a boiler plate, and a water temperature of 350deg. Fah, on the other, the temperature of the hot side of the plate was only 70deg. more than the water. (The model was subsequently shown at work). In all cases furnaces should be made to suit the fuel to be burnt. He did not think any engineer would claim that one particular type of furnace is suitable for everything, and it is one of the advantages of this type of boiler that it is comparatively easy to adapt the furnace to the fuel.

4. The heating furnace is arranged so that the flue gases in their path to the chimney are split up and thoroughly envelop the tubes; and they also cross the tubes at right angles, a most important point. The heating surface is ample, and will utilise economically all the heat that can be generated in the furnace.

5. Inspection, cleaning, and repairs. All these points are very fully provided for.

6. The boiler is so constructed that the circulation is positive and continuous. There is no such tendency to form steam pockets as Mr. Fyvie states. This circulation depends on the difference in head in the up-comer and down-comer. If the former is small as compared with the tube area, there is a larger proportion of steam in it, and the difference in head and consequent velocity is all the greater.

Experiments have proved that large up-takes and downtakes are tending to produce reverse currents and hindering the circulation. Dealing with this subject, Mr. William Kent, in his recently published book, "Steam Boiler Economy," quotes the late Dr. Chas. Emery, who says: "Sectional boilers provided with water up-takes and down-takes from the heating

surface to a separate drum will circulate on the same principles and operate satisfactorily. Curiously, this will be the case whether the up-takes be large or considerably contracted, the fact being that with a large area of down-take, a large quantity of water is moved at a slow velocity, while with less area a less quantity of water is moved, but at a higher velocity, produced by a greater head, due to the fact that less water is mixed with the steam during its upward movement, and the density of the column is less." I have just received some interesting information from Germany bearing on this particular point. Steinmuller, who makes a boiler similar to Type 1, evidently thinking there might be something in favour of large up-takes, designed a boiler having them about 191 inches wide, but not finding the results he anticipated he introduced a movable diaphragm, so that he could reduce the area of the up-take. He then made a series of tests, by which he determined that widths from $6\frac{1}{4}$ in. to $7\frac{3}{4}$ in. gave the best results. These dimensions correspond with the usual practice in this type of boiler. When the width was increased it was found that interfering down currents were set up, and intermittent ebullition.

Theory after all is not everything, and we must come to the results attained in actual practice; and it seemed to him that a series of tests made by Lt.-Commander A. B. Willits and Lieut. B. C. Bryan, of the U.S. Navy, on a boiler of type No. 1, supplied to the "Cincinatti," replies to all Mr. Fyvie's objec-tions to that type of boiler. One test was made with the sole object of seeing how rapidly steam could be raised. The boiler contained nearly $4\frac{1}{4}$ tons of water at a temperature of 72 deg. Fah. Fires were started with light wood at 9.40, the blower being in operation, in five minutes steam was formed ; in ten minutes the gauge registered 85lbs., and in 12 minutes 40 seconds from the start the gauge registered 2151bs. pressure. An examination of the boiler afterwards showed no injury or change in its condition. This test, he thought, proves that as far as flexibility and circulation are concerned, the boiler could hardly be improved upon. A series of tests were then made at different rates of firing, and with different classes of fuel, observations being made on every possible point of value He would have liked to have given the tests or interest. in extenso, but it would take too much time, and he only quoted results that bear on Mr. Fyvie's paper. With rates of combustion varying from 19.60 to 59lbs. per square foot of grate per hour, the percentage of Co² in the flue gases ranged from 11.8 per cent to 14.5 per cent., which rather contradicts Mr. Fyvie's argument that good combustion "can only be obtained with difficulty." Further, the flue temperature was 466deg, when the boiler was burning 19.6lbs, per square foot of grate, and evaporating 5.18lbs of water per square foot

of H.S. per hour from 212deg., and when burning the very large amount of 59.33lbs. per square foot of grate area, the flue gases were under 900deg., and the enormous amount of 13.67lbs. of water was evaporated per square foot of H.S. per hour. This, of course, does not compare with the test quoted by Mr. Newbigin; but in his case they had 5in. of forced draught, as against $1\frac{1}{2}$ in. in this. He thought he was justified, therefore in saying that Mr. Fyvie's statements with regard to the value of heating surface, circulation and combustion in type No. 1, are against the experience gained by actual practice.

He would not go through all the types Mr. Fyvie has brought to our notice, and would pass on to No. 8. Dealing with the dif ferent points in the order Mr. Fyvie places them:

Ist. Strength. This he considered not too good; the drums, as will be seen, having a large number of holes in them, and the metal in between being liable to be strained when the tubes are expanded. He thought the structure is mechanically weak. The mud-drum also being of W.I. in a cool place comparatively, is liable to external corrosion, especially as soot may collect on the top between the tubes, and this may be an element of danger.

2nd. Flexibility. In this boiler we have tubes of varying length, and the amount of expansion will naturally vary. The tubes have certainly a slight curvature, but it seemed to him that this unequal expansion must of necessity throw a side strain on the expanded joints, and this may cause leaky tubes.

3rd. Combustion.—This would depend on the class of fuel and method of stoking. A lofty combustion chamber is useless with short flaming coals, such as anthracities, only adding to the radiating surface, and with bituminous coals smoke will not be prevented, as the gases are rapidly brought into contact with the comparatively cool surface of the tubes.

4th. Heating surface.—This does not seem to him to be arranged to the best advantage, as the path of the gases is mainly parallel with the heating surface, and it has been proved by experiment that when the flue gases travel at right angles to the tubes the H.S. of the latter is 30 per cent. more efficient than when the gases glide along. He did not think the fact that the tubes are nearly vertical will prevent the accumulation of soot outside or scale in, as anyone who has had much experience with Green's economisers will know that if the scrapers are not run, soot cakes very rapidly and also that with water containing scale forming matter it is not uncommon for the tubes to become solid; the tubes are, of course, absolutely vertical. A test made on an economiser shows that cleaning the tubes regularly made a difference of

6 per cent. in the efficiency of the whole plant. The temperature of the water was only raised 88 deg, Fah. instead of 153deg. Fah. for a week, when cleaning had been neglected.

5th. Provision for Inspection, Cleaning and Repair.—This condition seems somewhat neglected in this type of boiler. One cannot very well inspect the interior of a bent tube, a desirability when corrosion may be suspected, and the cleaning would not appear to be an easy matter. There may be facilitics for cleaning soot from the outside of the tubes, but none are shown. Repairs also would seem to be a rather troublesome matter.

6th. Circulation.—He has been quite unable to trace the course of the circulation, and, if as Mr. Fyvie just stated, both front nests of tubes are upcomers, we only have one tube connecting the two lower drums supplying eight tubes, and this hardly gives 100 per cent. area of intake.

I see that Mr. Fyvie claims that the back tubes of the boiler act like an economiser, but surely if they are sufficiently cool for this to be the case, there will be a danger of sweating and external corrosion; in the back drum also there will be the full temperature of the steam in the top part, and comparative cool water below.

Another objection to boilers with nearly vertical tubes and a small water level area, is that they are apt to have the water level fluctuate violently, causing wet steam.

To sum up the whole question of the best type of boiler, I would again like to quote the late Dr. Emery, who, during a discussion on tubulous boilers at the American Society of Naval Engineers, said: "In his opinion, the best form of boiler for reasonable rates of combustion is one with inclined tubes connected by up-takes and down-takes to a chamber or drum above, as in many sectional boilers."

Mr. G. Weymouth said that Mr. Adamson had remarked that it was a sin to put scale-forming water into a boiler of any description. Unfortunately, many boilers in this State had to use water of this description. In Ballarat recently Mr. G. Richards had brought under his notice a case where the mine water contained such a large amount of scale-forming matter that it reduced the water way in the discharge pipe from 8in. to 3in. in about twelve months. This water was tried in the boilers diluted with town water, but owing to the rapid formation of scale and increased consumption of fuel it was discarded, and town water only used. There were, however, many mining concerns which were wholly dependent for their boiler feed water on the water pumped from the mine. Mr. Fyvie, in his paper, would lead one to believe that most of the scale-forming matter was precipitated in the bottom back drum, and that the front drums and tubes would be free

from deposit. This he failed to see, as, if the feed water contained a fixed percentage of magnesia, lime, etc., the percentage would increase, owing to evaporation of the water, and scale would be formed in all the drums and tubes, unless the boiler had some remarkable property of purifying the water before it passed from the back drum to the others.

Mr. Wm. Fyvie, in reply, said he was very gratified indeed at the great interest that had been taken in his notes on "Water-Tube Boilers," judging by the discussion which had been the outcome. He was very sorry that we had not some good champions of the old type of shell boilers, and had been hopeful that their case would have been better supported, as our president had suggested before the discussion that all types of steam boilers should be discussed. He need hardly attempt to reply to the whole of the points raised in the discussion, but will make an effort to reply to some of the criticisms which have more directly been the outcome of the paper. The President rather objected to the use of the term "tank" applied to the shell boiler, and he noticed he made use of that objectionable expression, and regretted he did so, for he had a considerable amount of respect for an old friend that had served so long. The storage of energy in the form of steam and water is certainly greater in the shell boiler than the water-tube, but this is where the risk comes in, and what the water-tube type in a large measure has been designed to overcome. It must not be forgotten that this extra storage is not available for use unless you have a drop in the working pressure, more or less.

Regarding the question whether there were fewer accidents with water-tube boilers than shell boilers, he was not able to answer, but thought there is no doubt that the shell boiler accidents are generally much more serious and disastrous in their effects.

Regarding economy, he had no doubt from his own experience, given equal conditions of combustion and working, the water-tube boiler is more economical than any type of shell boiler. But with many types of water-tube boilers good combustion is most difficult to obtain, and this accounts for one of the most common sources of inefficiency. This and the suitability of fuel he would go into further on.

Mr. Rowe states that among the electric supply stations in England, the number of shell boilers is a little in excess of the water-tube; that is, 1040 shell to 1000 water-tube, but he does not give the horse power. It will be well within the mark if we rate the water-tube at $2\frac{1}{2}$ times the power of

the shell, which gives the water-tube a pretty good lead. Mr. Rowe would make us believe that all the many troubles formerly experienced with the shell boiler had entirely disappeared with the introduction of "absorber" flues; but there are many troubles that this antidote cannot reach. Every user of the shell boiler does not think it a simple matter to clean them. Some little time ago the author was through a place where they use a great many of this type, and they considered the cleaning was such a serious matter that they preferred after a time to make a new boiler instead of cleaning the old one. They had a boiler-maker's snop, which they kept going all the time. He saw many with scale varying from one inch to three inches thick round the narrow water space in the Cornish boilers. He did not learn what the efficiency of such a boiler was. He mentioned this because a great many people thought that it is only the water-tube boiler that suffers from scale. The thicker plate will hold out against the action of the fire for a longer period, but at what cost in fuel, perhaps more than the boiler was worth, and if people will work with boilers scaled in the manner he had mentioned it was easily seen that it paid better to make a new boiler than work with the old one. The old ones were thrown out in the yard, and he was told in a few years they cleaned themselves, and one or two which he saw during this process seemed to be getting along that way, for lie reached in and pulled off a piece about the size and thickness of his hand. He was much interested in this new process, and thought how simple it would have been in many cases of his own experience if he could have got the owners to have spent the money on the extra boilers necessary to work this process effectually.

Replying to Mr. Stone, where he remarks, "that the majority of the water-tube boilers illustrated and described are only of passing interest to us," he would like to point out that the only practical knowledge we have relating to the circulation of the water was gained from the many practical experiments carried out in the development of these boilers. He felt quite safe in saying there is not another feature connected with steam engineering, where theorizing has been of so little value in bringing to light the features or laws that regulate the circulation of water in water-tube boilers. The remarkable results obtained with those "Express Boilers," under the most severe and trying conditions, give us the most valuable guide we can possibly have. Practical experiments have been the lines on which this remarkable steam generator has been developed, and anyone who wishes to know about water-tube boilers and their development cannot afford to neglect the history of the "Ex-

press Boiler," and that is one of the main reasons for my bringing them pretty fully before you on this occasion.

STRENGTH.

TUBE HOLES IN THE DRUMS .- Mr. Stone considers "the perforating of the cylindrical part weakens the plate in figs. 2 to 8." He quite agreed with him in this respect, so also does the drilling of rivet-holes, for securing the plates together, and he says "that the expanding of the tubes weakens the bridges between the holes." A similar argument can be brought against the closing of the rivets in the rivet holes of two plates by an hydraulic riveter, which exerts many times greater stress to the material than the expanding of a tube in its hole. But as with the rivet holes so with the tube holes; the plates are made of sufficient strength and an ample margin is left in the finished article after all the manipulation is completed. He thought there was not a watertube boiler-maker that had not adopted this type of construction more or less, and boilers for the very highest pressure built are nearly all of this type, for the one very good reason that stays (as we understand them in boiler work) are unnecessary, and when we find all the noted and experienced makers adopting this type, and nearly all the most modern types of water-tube boilers are more or less of the perforated drum type, he thought we are quite safe in accepting it. And among all the many thousands of boilers of this type that have been built (running into many millions of horse power) he could not recollect a single failure due to the weakness referred to by Mr. Stone.

Mr. Stone also refers to "deterioration due to leakage, sweating or other causes." This trouble, of course, refers equally to all types of boilers, and as long as we make them of W.I. or mild steel, they will be subject to corrosion, if moisture (by leakage or any other means) with the addition of the heat present is allowed to play its deadly work on the plates or other parts of the boiler, it will soon reduce the factor of safety, but such conditions should never be allowed to obtain with any type of boiler. If there is a leak it should be stopped at once, and as for the sweating, he had never come across this in any type of boiler while at work. If the foundations and general surroundings are dry, sweating will not occur; he had never yet seen any boiler working at such a low rate that the water vapours in the gases of combustion would condense on the surfaces; that is, after the boiler has been fairly to work. (A little sweating occurs with all boilers when started cold.) Keep down the leaks, and the moisture from external sources, and there need be no cause for anxiety in this direction; but if such treatment

is allowed to continue for any length of time, he did not care what type the boiler might be, the wasting produced by corrosion will soon give grave cause for anxiety.

FLEXIBILITY.—Mr. Stone says "he would be inclined to reverse my comments under this heading with respect to figs. 1 and 8." The author could not agree with him on this point at all, and his somewhat laboured reasoning rather confirmed him in his own opinion than otherwise. A glance at fig. 8 is sufficient to decide anyone that it is a much more flexible structure than fig. 1, and even supposing the charges of rigidity produced by the triangles and compound triangles to which he refers were to hold good (which he did not admit), there is sufficient curvature in the individual tubes to provide for any variation in expansion that is ever likely to occur, and this is amply borne out in actual practice.

In fig. 1, where the straight tubes to the numbers of 8 or 10 are expanded into two rigid-end headers without the smallest possible chance of compensation for the difference in temperature between the tubes (which in this boiler is at times very great), either the expanding tube bends to absorb the elongation, or the other tubes draw at the headers. What most usually occurs is that the expanding tube bends, which he presumed, was due to its being in a more plastic state by excessive heat. This can be seen by an examination of the lower rows of tubes in many boilers of this type that have been some time at work under a moderately high pressure and evaporation.

COMBUSTION.—On this point it was quite refreshing to find that Mr. Stone agreed with him, and he thought all would admit that good combustion was the very first and most essential feature, if anything like efficiency was to be obtained, and those conditions were fulfilled in fig. 8 in a more perfect manner than in any other type of water-tube boiler that has come under his notice.

Mr. Stone states "that the adoption of the Scotch furnace with fire bricks on the lower set of tubes removes a considerable part of this disparity." After many elaborate and costly experiments the author had carried out with this very type of Scotch furnace, he found not the smallest degree of improvement. The results, when everything was clean, were practically the same, but this had the serious disadvantage of gathering the soot much faster, and the layer of bricks made the matter of cleaning the tubes more difficult, so that the efficiency fell off very rapidly.

HEATING SURFACE.—The efficiency of the heating surface to absorb the heat depends more on the active circulation of the water in the tubes than the direction of flow of the gases outside the tubes. But in reference to the arguments that the gases flow parallel to the tubes in fig.

8, he could not agree with this, for the simple reason that the gases must cross the four banks of tubes at right angles before they can reach the chimney, the only difference being that the gases have a longer distance to travel among the tubes in fig. 8 than in fig. 1. In fig. 8 the heating surface and flow of gases are arranged in the most suitable manner to give the highest thermal efficiency; that is, the flow of the hot gases is in the opposite direction to that of the water, the feed water entering where the gases leave the boiler.

INSPECTION, CLEANING AND REPAIRS.—Here, again, Mr. Stone lays much stress on the straight tubes, but the advantage of this is much more apparent than real.

For the inspection and cleaning of the boiler, indicated by fig. 8, it is only necessary to remove the five man-hole doors, no matter what size the boiler, when the whole of the internal parts may be cleaned and inspected. The bends on the tubes are so slight that it is possible to see down the tubes by means of an incandescent light, but I do not put much dependence on this class of visual inspection in a tube of 4-inch diameter, over 21/2 to 3 ft. long. The tubes are easily cleaned by tube scrapers. Externally every tube and part of the boiler can be carefully inspected by getting in through the side doors in the brickwork, and the outside surface of every tube can be seen and felt by the hand from end to end, and if a blister or a leak should occur it can be discovered at once. The tubes may be readily examined externally while the boiler is at work through those side doors.

For inspection and cleaning of the type indicated by fig. 1, if it consisted of 100 tubes (not by any means a large unit), you have to remove one man-hole door, one hand-hole door, and 200 headernuts, caps, bolts and plates, consisting of 800 pieces, before you can see into the tubes of the boiler, then by holding a light at the other end of the tube you can see through, and for the first 12 inches or 15 inches at each end, he admitted one can inspect the tube fairly well (about 12 per cent. or 15 per cent. of its total length), but visual end inspection beyond this length is of very little importance for the inside of a rough tube, unless in case of a very heavy deposit of scale which the eye could detect at the distance by the reduced area of the opening. From his own experience in this respect he found the unaided eye cannot detect anything less than a reduction of about 1-16 inch all round, whereas by passing standard size scrapers through you can prove at once the thickness of scale in the tube; but this end visual inspection cannot detect anything of the nature of a blister, leak or fracture, unless it is such a serious nature

that the tube has parted altogether. With this type of boiler it is impossible to inspect the outside of the tubes, except the top and bottom rows, and experience has proved, in the case of defects, that it is far more important to provide facilities for the inspection of the outside of the tubes than the inside.

CLEANING.—As for the cleaning of the tubes internally, there is very little difference between that of figs. 1 and 8, the slight bend on the tubes of fig. 8 makes verw little difference. As to the replacement of tubes, when this becomes necessary, in fig. 1 with straight tubes it may appear a very simple matter, but in most cases it is anything but a simple matter. In nearly all cases the tube is more or less blistered, buckled and swollen or enlarged, and this blistered and buckled mass must be pulled through the front header tube hole by block and tackle, and the risk of injury to the surfaces is therefore very great, so much so that the surface has often to be dressed up with a file or other means, and a ferrule put in to make a tight job, and of course the header has suffered a permanent injury.

In the case of replacement of tubes in fig. 8, it is only necessary to cut the defective tube close to the tube sheet top and bottom, and pass the old tube out through the furnace door or one of the side doors; cut out the two nipples, pass in the new tube, place it in position, and expand both ends. There is no necessity for pulling the tube through the tube hole.

He might point out that there is not a tube in the boiler that cannot be replaced in very little time when the boiler is sufficiently cool to work in without disturbing any other tube or part of the boiler, and when a defective tube is replaced the boiler is as good as new.

CIRCULATION AND THE CONDITIONS LIKELY TO PRODUCE STEAM POCKETS.—He stated that in fig. 8 each tube has 100 per cent. area of discharge and inlet, and the circulation is all that can be desired, and he hardly thought this could be gainsaid, for the simple reason that the tubes are of uniform diameter throughout their length, and each tube is connected independently to the top and bottom drums, so that no tube is called upon to carry more than the steam generated and the circulation due to its own length; and to confirm this, the best argument he can bring forward in support of this contention is the working model.

The circulation in the first and second bank of tubes is upwards from the first bottom drum; in the third bank of tub's it is downwards into the second bottom drum; from the second bottom drum to the first bottom drum and so on. Now Mr. Stone raised the question that there was only one tube join-

ing the two drums for every eight upward tubes, inferring, he presumed, that this was not sufficient; but he must surely forget that the volume of discharge at the top of each tube is many times greater than the volume of solid water necessary to be supplied at the bottom, the relative volume of steam at 100 lbs. pressure to that of water being about 230 to one, and at the top of the circulating tube the greatest proportion of the fluid discharge is steam, and it has been proved by actual experiment that the number of tubes connecting the bottom drums now fitted could be considerably reduced without affecting the result at this point. And to prove this with the model, he had two glass-stand tubes made -one fitted to each bottom drum, and long enough to stand above the level of the water in boiler, to test the difference. in pressure of water head, between the front and back drums, because if anything of the nature to which Mr. Stone refers were to obtain, there would be a very pronounced difference in the height of the two water columns. He had this tested at rates of steaming from 3 lbs. water evaporated per square foot heating surface per hour to 5 lbs. of water evaporated per hour, and the greatest difference was only about 1-8 inch. the water being a little unsteady at the highest rate of steaming, heating surface about 24 square feet.

CIRCULATION.—He thought it is now pretty well agreed all round that the causes of circulation or movement of water in boiler tubes is due—

1st. To the difference in density of the water produced by its expansion or increased volume on the application of heat, which may be illustrated by a U tube, with both ends connected to a vessel of water above, and heat applied to the U. In the leg that gets the greatest heat, the water will be expanded more and the column will be of less density than the other or cooler leg; circulation will commence, but this circulation is very sluggish.

2nd. When the water is all heated to the same temperature, and small steam bubbles are being formed in the hottest leg, the density of this column is much further reduced, and the circulation increases.

3rd. When steam is generated rapidly and the difference in the density of the two columns has reached the maximum, due to the heat applied, the circulation will be very rapid, and the force available to produce this circulation will be the difference in density between the up-cast and the down-cast pipes, less the friction of the pipe.

Mr. Stone's theory might hold good if the circulation in all tubes subjected to heat were upwards, and only in such tubes as were not subjected to heat the circulation was downwards. This theory, he believed, was held by many up to

the date of the excellent and extensive series of experiments carried out by Yarrow, Thornycroft, and Professor Watkinson, on models at atmospheric pressure, and those of a more recent date by Yarrow and Thornycroft on models and boilers at the usual working pressure, and it was found in all cases that the circulation under the working pressure conditions was better and more uniform than when working st atmospheric pressure. Yarrow's experiments proved, beyond a shadow of a doubt, that the application of heat to a downcomer did not retard but really increased the circulation, so much so that by heating the down-comer to the same extent as the up-comer, the speed of circulation was increased by over 50 per cent., and further, that circulation was set up in a U. tube of considerable length by three small burners applied to one leg, and when this was fully established, five (5) large burners clustered round the other leg of the U. pipe were lit one by one, and the rapidity of the circulation was thus greatly increased, and was maintained in the same direction, the tube which was so much more highly heated remaining the down-comer. The three small lamps applied to the up-cast pipe were then extinguished, but the current of steam and water was still maintained in the same direction, although the whole of the heat applied was received through the down-comer pipe, and this was at 150 lbs. pressure. In all cases the circulation was found to be more rapid and more permanent under high pressure than under atmospheric pressure, and a peculiar feature is that no steam bubbles were ever seen formed in the down tubes, even with all the heat applied to them. From many trials and experiments, Messrs. Yarrow had satisfied themselves that within certain limits the rapidity of the circulation depended mainly upon the total amount of heat applied, irrespectively of the manner in which it was divided between the descending and ascending columns. This clearly proved to his mind that any boiler constructed after the types illustrated b" figs. 2 and 8 can be thoroughly relied upon to maintain a uniform and efficient circulation. Messrs. Yarrow devised a very nice arrangement to determine the direction and speed of flow of the mixed water and steam in the tubes of their boilers when working under pressures of 150 to 200 lbs. Small screw propellers were suspended in the tubes by spindles working through packing glands. On this spindle outside was mounted an arrangement for indicating the direction and speed of flow of the water in the tube.

In the earlier days of the Yarrow boiler, they made them with outside down-cast pipes, but they were found to be of no practical value, and only acted as so much radiated surface.

From similar experiments carried out on tubes arranged at a small angle from the horizontal, similar to fig. 1, the circulation could not be maintained in one direction unless the up-comer tube was kept at a considerably greater temperature than the down-comer, whereas in the vertical ones the circulation was maintained with the whole of the heat applied to the down-comers, as before described.

Seeing that the laws of gravitation regulate circulation in the tubes, it follows that vertical tubes, or those nearest to the vertical position, will give the highest efficiency, if it were only due to the fact that there is less frictional resistance.

The vertical tube has another great advantage. The steam bubbles in ascending are practically afloat in the water, with little or no friction to retard their progress upwards by contact with the walls of the tube. With the horizontal tube the steam bubbles are held against the upper part of the tube, with a pressure due to the pressure or head of water in the boiler, producing considerable frictional resistance to their passage, and keeping the water from contact with this part of the tube, with risk of over-heating.

One other great disadvantage with the horizontal tubes is that when a scale has formed on the tubes, should any of it get displaced as the concentrated mass falls on the semicircular bottom of the tube, and there it remains on the most vital part of the tube on which the flame plays, and it will not take long under those conditions to bring ruin on that tube if it be directly over the fire; so that the safety of the tubes to a great extent "depends on their luck."

With the vertical tube no such thing can take place, for if scale forms and gets detached, it will simply fall out of the tube into the bottom drum, a place where it is perfectly harmless to the boiler. The horizontal tubes collect the dust and soot much more readily. With the vertical tube you may get a little soot on the tubes occasionally, but they are clean when you finish blowing.

So long as we use a drum A, two headers B and C, and one tube D only, we run no risk; but as soon as other tubes, such as E, F, and G are added, our troubles are likely to begin. While the boiler is worked easy all may go well; but when heavier demands are made on it, the resistance at L and M begins to tell, and the circulation becomes disturbed. The resistance at L tends to send the water along G, F, and E, and the resistance at M causes D to draw water from the lower ends of E, F, and G. These tendencies may cause the circulation to go on correctly in C, D, and B, whilst the water in E, F, and G may remain practically stagnant, or even flow in the reverse direction from B to C, or the cir-

culation may be maintained along E in the proper direction and back again through F, while that in G remains stagnant. The result of the setting up of any of these subsidiary circulations is, of course, over-heated and burst tubes.

Mr. Newbigin "holds that the flow of the gases across the tubes gives a greater efficiency or transference of heat than if flowing parallel to the tubes." The author did not admit that the flow of the gases is parallel in fig. 8, as he stated already that the gases had to cross the tubes four times. Mr. Newbigin seems to think "a restricted area at the discharge end of a steam-generating tube would be an advantage, as it would probably increase the velocity at discharge, due to the increased percentage of steam in the column." He surely forgets that the only force he has got to produce the velocity is the difference in weight of water and steam mixed between the down-cast and the up-cast tubes. The makers of the Belleville boiler type, Fig. 4, take a very different view to this, for they restrict the opening at the inlet very much, and use a non-return valve.

He could not agree with Mr. Newbigin when he says "that increased circulation will not increase the rate of transmission or evaporation." He thought this was pretty well agreed on by most engineers. It has been proved, beyond a doubt, in many evaporators, by using a pump to produce increased circulation considerably beyond that due to natural circulation, the temperatures remaining the same, the rate of transmission has been increased two or three times. This has been often tried in steam generators, with considerable improvement in the rate of transmission and efficiency of the generator, but the mechanical troubles were against their permanent adoption. He was indeed very pleased to learn from Mr. Adamson that the water-tube boiler was making such progress in the mercantile marine, and that the efficiency now being got was so encouraging. He sincerely hoped it was a permanent stand they were taking. Certainly such results as he gives roughly had not come under his notice.

According to Mr. Adamson, and also Mr. Newbigin, they would make us believe that the difference between the temperature of the tube and the water inside vary very little, and did not exceed 70 deg. F. In connection with this he would like to give briefly the results obtained by A. J. Durston, of the Royal Navy, from a very extensive series of most carefully conducted experiments. One of the tubes give a mean difference in a tank boiler of 180 deg. F., working on a natural draft of 7-10 inch of water; and in water-tube boilers the difference of temperature varied from 60 deg. F. at very slow rates of combustion, to 210 deg. F. at the higher

rates. This was with perfectly clean boilers and pure water. When the tubes get a little dirty the temperatures are liable to be considerably increased. Those results were confirmed by experiments carried out by Mons. Normand, of Havre, in France. It is also a well-known fact that copper tubes will not stand in this type of boiler for the very reason that the temperature is often too high for that material, and that only low carbon steel was suitable.

Further experiments carried out by A. J. Durston gave the following results :---

 1st. —With pure water, fire=1,500°F. gave 240°F. —212°F. =28°F. differ.

 2nd.
 ,, ,, ,, 2,200°F. ,, 280°F. —212°F. =68°F. differ.

 3rd. — ,, ,, ,, and layer of grease 1/32" thick, fire 1,500°F, —212°

 = 118°F. difference.

4th.—With 5% mineral oil, fire=2,300°F. gave 310°F.—212°F.=98°F. differ. 5th— ,, 24% paraffin, fire=2,100°F. gave 330°F.—212°F=118°F. differ. 6th— ,, 24% methylated spirits, fire=2,500°F. gave 300°F.—212°F.= 88°F. difference.

7th—With greasy deposit 1/16'' thick, fire = 2,500°F. gave over 500°F. 212°F. =338°F. difference.

Mr. Adamson says "boilers with nearly vertical tubes and small water level area are apt to produce wet steam." This is rather a vague statement, as he does not say to what type of boiler he refers. This argument only holds good in cases such as fig. 2, where the discharge of steam is practically uniform all over the surface of the water.

I think the rest of Mr. Adamson's arguments have been pretty well treated when dealing with Mr. Stone's.

In answer to Mr. Weymouth's remarks regarding the precipitation of the scale-forming matter in the back drum. By blowing off a little from the mud drum from time to time in the usual way, the greater portion of the precipitated matter can be blown out of the boiler. He did not know if Mr. Weymouth contemplated that this or any other type of boiler can be expected to run from one cleaning to another without the regular blowing, whch must be done with all types of boilers, and if neglected where much solid matter is contained in the water, he was afraid the boiler would soon come to grief, no matter of what type.

Mr. Higgins desired some information derived from actual experiments. The author gave a few particulars of trials carried out by Prof. Ewing, F.R.S., M. Inst. C.E., London, on a boiler of fig. 8 type, at the West Brompton station, of the Brompton and Kensington Electric Supply Company. The boiler tested was guaranteed to evaporate 6000 lbs. per hour, with a flue temperature not exceeding 600 deg. F. During the trials a much larger evaporation was given, with a much lower flue temperature.

		TRIAT. A		TRIAL B
Duration of trial	SE .	4 93 hrs		1 983 hrs
Water evaporated (total)		30 520 lba		15 860 lbs
(per hour)		2020 105		10,000 105.
Coal (total) " (per nour)		0,020 ,,	•••	12,300 "
Coal (boat)		4,704 ,,		1,890 "
Coal (per nour)		954 ,,		1,472 "
Coal (per sq. it. of grate)		2,222 "		3,433
Water evaporated per lb. of coal		8.41 ,,		8.40
Pressure in boiler by gauge		155 lbs. p	er	155 lbs. per
A SUL A REAL PROPERTY AND A LOCAL A		sq. in.		sq. in.
Temperature of feed		74°F.		761°F.
Temperature of flue		455°F.		590°F
Water collected in separator		391bs		101bs
Proportion of water collected	in	1		10105.
separator		1.000		1.500
Draught gauge (inches of water)	-	0.4		0.75
Equivalent evaporation from and	at	9 5601bg		14 7101ha
212°F per hour	200	5,500105.	•••	14,110105.
Equivalent eveneration from and	••••	10 0011		10.011
919°E neglity of 1	at	10.031bs.		10.01bs.
212 F. per Ib. of coal	•••			
Equivalent evaporation from and	at	4.8		7.4
212 F. per hour per sq. ft.	of			
heating surface				

The general result of the two trials are tabulated below:

From these figures it will be seen that the boiler has greatly exceeded the performance required of it by guarantee, in respect both of evaporation and of flue temperature. The final trial shows that it stands forcing exceedingly well, giving a very high evaporation with dry steam, and with a good thermal efficiency. The action of the boiler was satisfactory in every way.

September 29, 1900."

(Signed) J. A. EWING.

From the above it will be seen that the evaporation in the first trial the boiler exceeded the maker's rating by over 33 per cent., and the final flue temperature was lower by 155 deg. F., burning 22.2 lbs. of coal per square foot of grate, with a draft of 4 inches water; the moisture in the steam being 1 in 1000; the evaporation being at the rate of 4.8 lbs. water per square foot heating surface. In the second trial the boiler exceeded the maker's rating by 106 per cent., and the final flue temperature was lower by 10 deg. F., burning 34.3 lbs. of coal per square foot of grate. This was with a draft equal to 75 inches water (a draft that can be had from many chimneys); the moisture in the steam being only 1 in 1000; the evaporation being at the rate of 7.4 lbs. water per square foot heating surface. The efficiency feli off very little, being 10.03 in the first trial, and 10 in the second.

In reply to Mr. Higgins, regarding the assertion about the formation of steam pockets in such boilers, as that illustrated by figs. 1, 3, and 4. Supposing a boiler, type fig. 1, having 10 tubes high, 18 ft. long, 4 in. outside diameter. This will give about 3³/₄ in. internal diameter; and supposing we have an evaporation of 3 lbs. per square foot heating surface, at 100 lbs. pressure; this will roughly give 180 ft. H.S. $180 \ge 3 \ge 3.85 = 34.65$ cubic ft. steam per min.

34.65 x 1,728

=454 ft. per min. will be the velocity of dis-132

charge at the nipple, if it was dry steam only.

If we take twice this speed, which will be no uncommon occurrence in actual practice when the fire is at its best, this will give us a velocity of discharge at nipple of 908 ft. per minute, if it were dry steam only.

Take 7.4 lbs., as given in Professor Ewing's test, of fig. 8, would give a velocity of 1120 ft. per minute.

And if we take Mr. Adamson's figures of 13.67 lbs., it. would give us a velocity of considerably over 2000 ft. per minute. It would be interesting to know where he got his head of water to produce this velocity. But you must remember we have an ever-varying mixture of steam and water flowing up this header, whch offers very much greater resistance than if it were all steam or all water; and to still further increase the friction and general disturbance we (are supposed to) have each horizontal tube in this section discharging its equal quota directly at right angles to the ascending column. Could any arrangement be better devised to upset and prevent the constant and uniform flow or circulation which Mr. Stone and Mr. Adamson tried to make us believe goes on inside the headers of fig. 1.

In support of his assertion, he would like to quote from results of experiments carried out by a Mr. Brull, a late president to the Society of Civil Engineers, Paris. He devised apparatus to determine the amount and direction of wager circulation in the tubes of an installation of 5000 horse power of boilers of type No. 1. He did not know what type of apparatus was used, but perhaps similar to that used by the Yarrow already described. The result of the experiments proved that the flow from the back to the front headers was confined exclusively to the very lowest row of tubes. In all the other rows the flow is reversed, being from the front to the back headers.

The duty required from the boilers was light, viz., 2.3 lbs. per square foot heating surface per hour.