SESSION 1906-1907

A Review of the Belleville Boiler Question

By Mr. F. J. KEAN, B.Sc. (Lond.),

READ AT

58, Romford Road, Stratford,

On Monday, April 23rd, 1906.

Chairman: Mr. W. C. ROBERTS, R.N.R.

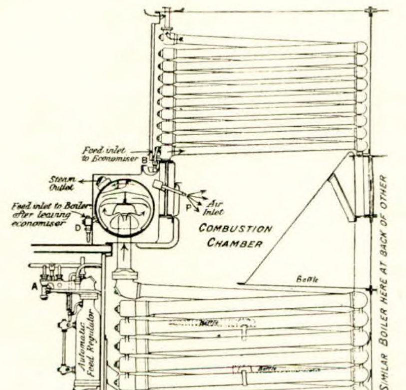
As Marine Engineers, most of the Members of this Institute will have followed pretty closely the discussions which have taken place in recent years upon the vexed question of the suitability of the Belleville water-tube boiler for the purpose of generating steam in the warships of the British Navy. But unless you have been actually engaged upon the construction of these boilers or have gone to great trouble in searching through back numbers of periodicals and engineering text-books it is probable that you will not have been able to follow very closely what was the precise nature of the questions at issue. The Author first began to take an interest in this subject whilst engaged in assisting with the erection of several of these boilers on board ship, and has since devoted a large amount of time to the problem of endeavouring to obtain a concise account of what we may term the "Belleville boiler question."

In the first place we have to find out how it came about that this boiler was adopted as the standard pattern of steam generator for the British Navy. Although the cylindrical type of marine boiler has always proved itself a good servant in practice, still it has one or two features which are undesirable from a "naval" point of view. The chief objections against it are its large size and its slow steaming properties which are due to the large quantity of water that it contains. When the importance of having a quick steaming boiler first became apparent, the only type of boiler in existence which looked anything like the right sort was the water-tube boiler designed by M. Belleville. There does not appear to have been any other type which had been tested under working conditions at that particular time and which had proved so satisfactory; hence it came about that the Admiralty adopted this boiler as their standard type and caused it to be fitted on board a large number of our largest warships.

I. General Description of the Belleville Boiler.

The modern type of Belleville boiler consists of two principal parts—

(1) The *generator*, or boiler proper.
(2) The *economiser*, or feed-water heater.



The generator is formed of a number of sets of tubes placed side by side over a fire grate, with a steam-drum fastened across the top and a water-collector across the bottom. The generator is so placed that the bottom tube of each set, or *element*, is about 2 feet above the bars of the fire-grate. Just above the top row of tubes there is a free space which is called a combustion chamber, and then above this comes the economiser, the distance between the top row of generator tubes and the bottom row of economiser tubes being about 5 feet. The economiser is arranged in a similar manner to the generator, and has a cold-water collector across the bottom and a hot-water collector across the top. The passage of the flames and hot gases on their way up through the tubes is guided by baffle plates, and they meet together in the combustion chamber preparatory to passing up through the economiser whence they make their way up the funnel.

II. Detailed Description of the Belleville Boiler.

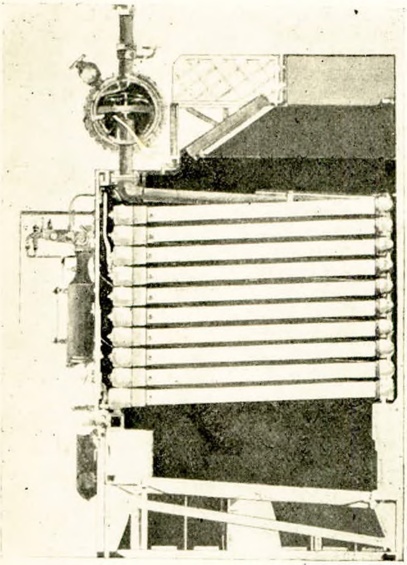
In order to appreciate the difficulties which surround the construction of these boilers it will be necessary to examine each feature separately as follows :—

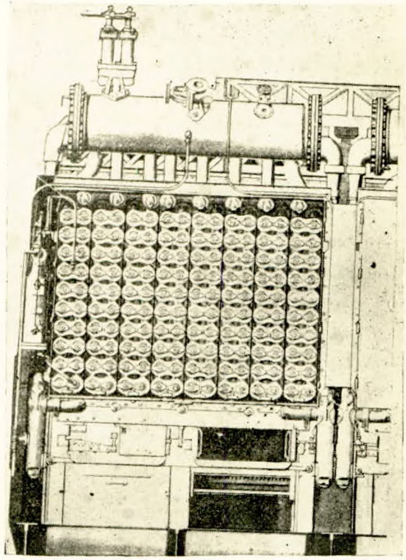
(a) *The Generator and Economiser Elements.*

Seven *elements*, or sets of tubes, placed side by side, make up the generator, each element being composed of fourteen tubes arranged in two columns, side by side, which are connected at the ends by junction boxes that rest one on top of the other.

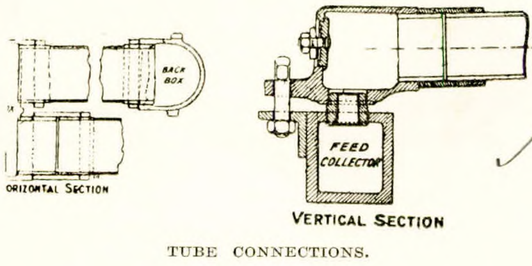
The water in these tubes enters and leaves the junction boxes at the same level, but on passing along a tube it rises about two or three inches, and so in this manner it can be made to climb from the bottom of the element to the top. The tubes are about 7 ft. 6 in. long, $4\frac{1}{2}$ in. diameter, and $\frac{1}{4}$ in. thick. Six elements placed side by side form the economiser, each element being about ten tubes high. The length of an economiser tube is about 6 ft. and its diameter $2\frac{1}{2}$ in. All the tubes are made of solid drawn steel and coated inside and out with zinc by means of an electrolytic process. The junction boxes are made of cast steel, those at the front end of the boiler having handholes provided in them for inspection purposes.

After the boiler has been tested under hydraulic pressure, and just before the preliminary steaming, it is customary to inspect all the tubes to see whether any are obstructed. The examination is most conveniently conducted by removing the handhole doors of the front junction boxes and passing an





incandescent electric lamp, fixed to the end of a long rod, right down to the back end of one of the tubes, the light is then reflected back from the back junction box up the companion



TUBE CONNECTIONS.

tube, and by this means the two tubes are thoroughly examined at the one time. An important point to note is that the joint of the door is made inside the box by a thin asbestos-ring. Since the doors are more or less oval in shape, it would be difficult to "face" the flanges on them, but they may be ground fairly true upon an emery wheel in a very short space of time. The tubes are screwed into the junction boxes both at the back and front end of the boiler, and instead of adopting the usual method of making a steam-tight joint, viz. by a taper thread, the practice is to have the pitch of the thread on the tube slightly different to that in the box so that the two jamb together. They are then further secured by a back nut called a "ring." Of the two tubes which run into each junction box one screws in direct, but the other is made shorter in length and coupled up to a steel nipple which is screwed into the box. The connector is called a "sleeve," and is kept in position by a "ring," so that "sleeve" and "ring" take the place of the usual "socket" (or connector) and "back-nut" in ordinary pipe work.

The generator and economiser are enclosed in a steel casing which is made double, the space between being filled in with non-conducting material; the front of the casing is provided with two large doors through which the elements can be removed. These doors are provided with double locks, so that the tubes may be inspected by unfastening one lock and leaving the other closed, the arrangement being a safety device; sight holes are also provided in the middle of the doors. Each junction box of the three bottom rows of tubes is fitted with a fusible plug which is arranged to indicate the absence of water in the lower part of an element.

The tubes may be kept free from deposit on the outside surface by means of scrapers or by the steam tube sweeping apparatus which consists of a flexible metallic tube with a nozzle on the end, the steam jet being controlled by a lever which opens and shuts the steam valve.

Before cleaning the tubes the fires are allowed to burn low, and then are pushed to the back of the grate out of the way.

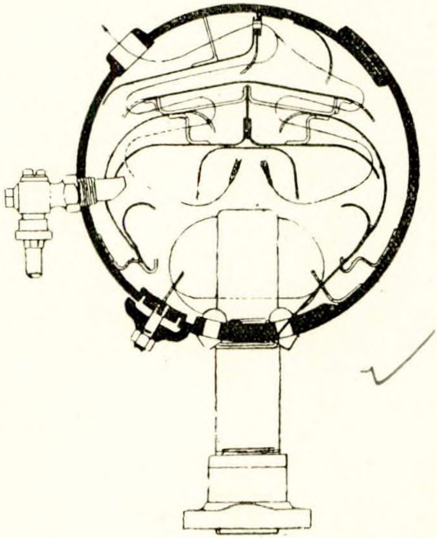
The boiler casing in the neighbourhood of the fire-grate is lined with firebricks.

(b) *The Feed-Water Collector.*

As its name implies, this vessel collects the feed water as it comes in from the mud-drums, and then distributes it to the various elements, but as there are only two mud-drums, one at each side of the boiler, some means had to be devised to prevent all the water going up into the wing elements and none going up into the central ones. The bottom junction box of each element fits over a conical steel nipple which is screwed into the top side of the feed-water collector ; the diameter of hole in the nipple is only 1 in., whereas we have seen that the diameter of the tube itself is $4\frac{1}{2}$ in. and consequently the necessary throttling action is obtained. The following method is adopted for coupling up an element to the feed collector :—A bar is inserted under the lug on the bottom junction box and the whole element raised up a couple of inches ; two thin rings of nickel are now placed over the cone of the nipple and the element is allowed to drop down into position ; this forms an excellent joint and the element is then anchored by a single tee-headed bolt. The cross-section of the collector forms a square.

(c) *The Steam Drum.*

This is a cylinder made of mild steel plates which is placed horizontally across the tops of the elements at the front end

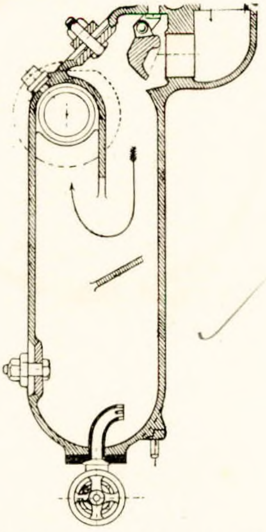


THE STEAM DRUM.

of the boiler. It contains a large number of baffle plates and the whole of the interior surface is coated with zinc. The elements of the generator are connected up to pipes which lead up into the interior of the drum and terminate about 10 in above the bottom, so that the discharge takes place well above the water level in the drum. The connexion is made by means of a flanged joint secured by four bolts, the jointing material being gauze-wire and red-lead putty. The ends of the drum are steel castings which are turned circular, after which the shell plates are riveted on. Each "end" contains a handhole and also has a steel pipe screwed into it termed a "downcast pipe." This pipe leads down outside the boiler casing to the mud-drum and is coupled up to it by a sleeve and ring. The diameter of the pipe is $4\frac{1}{2}$ in. On the top side of the drum seating blocks are provided for stop valve and for air and pressure gauge cocks ; there is also a block on the front of the drum for the feed check valve and one underneath for a drain cock. The diameter of the steam drum is about 2 ft., and its length about 7 ft.

(d) *The Mud-drums.*

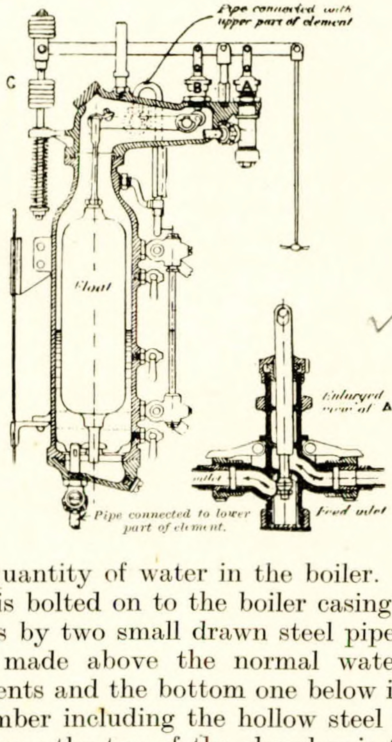
These are steel castings which are placed one at each side of the boiler. Each mud-drum contains a manganese bronze,



non-return valve which can swing freely on a pivot, and a vertical baffle plate ; it is also fitted with a blow down valve, a drain valve and a salinometer cock. The vessels discharge into the feed-collector by means of an elbow pipe, the joints being made by sleeves and rings as before. These particular joints are however very awkward ones to make, and it would certainly simplify matters if they could be replaced by flanged joints, for the Author has known it to take an experienced workman a whole day to couple up one of these elbows.

(e) *The Automatic-Feed Apparatus.*

This consists of a float which, as it rises and falls with the level of the water in the float chamber, opens and shuts a valve on the feed pipe, and admits or stops the admission of feed water to the economiser, and in this manner automatically



regulates the quantity of water in the boiler. The cast steel float chamber is bolted on to the boiler casing and connected to the elements by two small drawn steel pipes, the top connexion being made above the normal water level in the generator elements and the bottom one below it. Everything inside the chamber including the hollow steel float, is coated with zinc. Across the top of the chamber is fixed a straight horizontal lever A B C, which has its fulcrum between A and B. Part of the weight of the float is balanced by the downward pressure which the spindle B exerts, due to the lead weights at C, and the motion of the float is guided by a spindle at the bottom. To the outside of the float chamber at the top a small valve box A is secured, which is however not connected in any way with the inside of the float chamber, but is only placed here for convenience. Two pipes lead into the box A, one comes direct from the feed pumps through a *hand* feed-regulating valve and delivers the feed-water into A, and the other takes the feed-water from A direct to the cold-water collector of the economiser. Under normal circumstances the float chamber is half full of water, as indicated by the gauge glass on the front ; but if the water level falls the float falls too, and in falling raises the spindle B. Since A and B are on opposite sides of the fulcrum when B is raised, A is depressed and consequently the valve A is opened ; this admits water to the economiser and brings the boiler level up again. The float now closes A and stops the admission of feed water until such time as the boiler level falls below normal again. The glands A and B are made steam-tight with special antifriction (Belleville) packing and knife edges are used wherever possible to reduce friction. Should there be any doubt as to whether the apparatus is working satisfactorily it should be tested by pulling down the handle attached to the lever A B C.

(f) *The Furnace Air-Supply.*

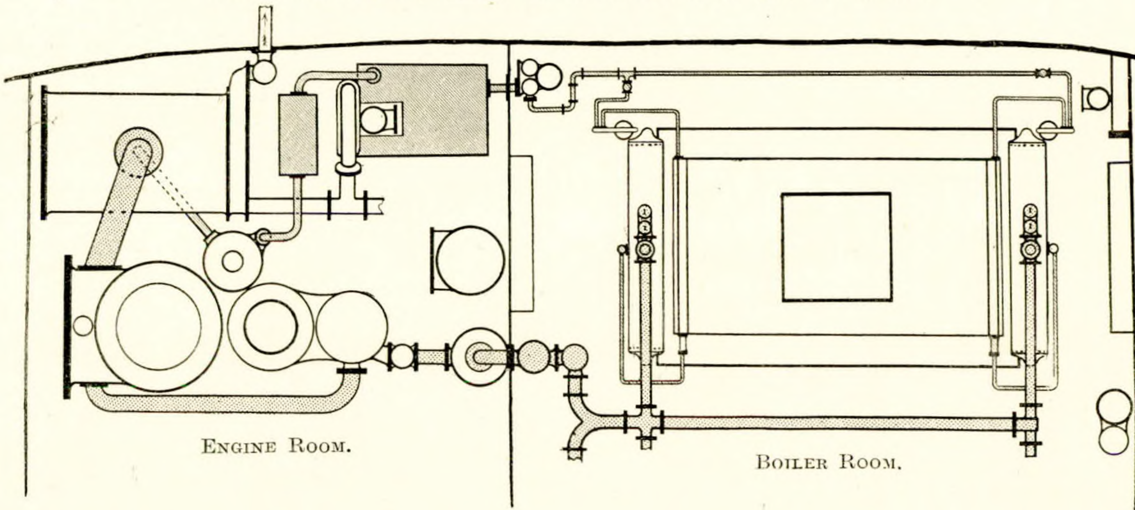
Owing to the close proximity of the water tubes of the generator to the fire grate it is found advisable to supply air above the fire in order to promote combustion ; this air is supplied by an air-blowing engine at a pressure of about 10 lbs. per sq. in. to an iron pipe situated outside the casing just above the fire doors and provided with a large number of cocks to regulate the supply. A similar pipe supplies air to the combustion chamber for the purpose of thoroughly mixing the gases of combustion.

III. General Arrangement of a "Belleville" Plant.

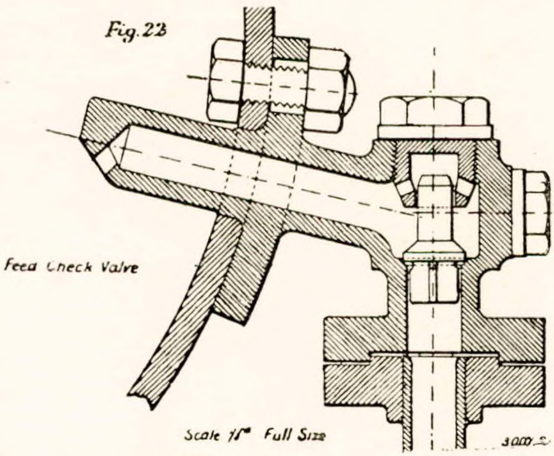
For the sake of simplicity it will be best to consider the case of a pair of Belleville boilers supplying steam to a compound condensing marine engine.

A powerful Weir feed-pump sucks the water from the feed tank in the engine room and delivers it at a pressure of 700 lbs. per sq. in. through a hand feed-regulating valve into the valve box attached to the float chamber of each boiler. The float then automatically admits the water through the valve A to the

General arrangement of a Belleville Installation.



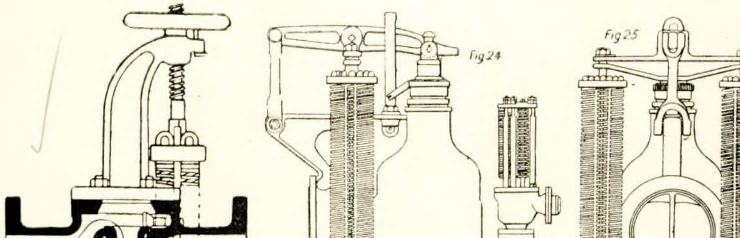
cold water collector of the economiser. From this collector the water passes through a number of small tubes, each of which is fitted with a non-return valve, into the economiser elements. It circulates up through these elements, abstracting heat from the flue gases on its way up, and is discharged at the top into the hot water collector. Leaving the hot water collector it passes down a pipe leading to the feed check-valve on the front of the steam drum. Passing through the valve, it is squirted through a tiny hole into the interior of the drum. Here it meets the hot water which has been discharged from the pipes



connected to the generator elements, mixes with it, travels along the bottom of the drum and falls down the downcast pipes into the mud-drums. In the mud-drums the water is subjected to a sudden change in the direction of its flow; being sent up again and through the elbow pipe into the feed collector by means of the vertical baffle plate. It is customary to add lime to the feed water in order to collect any grease left in it, and the lime and grease form together a sort of mud. When the water is subjected to the sudden change of direction in the mud-drum this mud falls out of it and is deposited in the bottom of the drum, whence it is blown off at regular intervals.

Leaving the feed-collector the water enters the generator elements through the conical nipples and circulates up through them, a large part of it being converted into steam on its way up. The mixture of boiling water and steam is then discharged into the steam-drum against the baffle plates. Most of the water then falls down to the bottom of the drum, and mixing with the incoming feed-water returns to the mud-drums. The steam is drawn off through the stop-valve, and, unfortunately, if the rate of evaporation happens to be fairly high a considerable quantity of priming water is carried off with the steam in spite of all the baffle plates which are fitted to prevent it. In order that the supply of steam to the engines may be fairly dry, some means has to be devised to remove this water, and the following method is adopted. Suppose the engines require dry steam at a pressure of 300 lbs. per sq. in. the boilers will generate steam at 350 lbs. per sq. in., and this steam will then be first reduced in pressure and then passed through a separator before it enters the engines. A special type of reducing valve is used, in which the steam passes through ports cut in the valve casing into the interior of the valve itself which is hollow and shaped like a diving-bell.

The valve is suspended inside the casing by a spindle from an external horizontal lever and is so arranged that a spiral



Belleville Steam Reducing Valve

spring connected to this lever always tends to pull the valve downwards and uncover the ports, thus admitting steam to the engines; but as soon as the pressure acting on the interior of the dome of the valve rises to 300 lbs. per sq. in. the valve will have overcome the pull due to the spring and the ports will now be, closed ; the pressure now begins to drop again, but is prevented from so doing by the valve again uncovering its ports, and so on. Means are provided for adjusting the tension of the spring so that the steam pressure may be kept constant at any required value at the engines. Leaving the reducing valve the steam passes through the separator and into the h. p. valve-chest. Passing out of the low pressure cylinder the steam enters a surface condenser, is condensed, and pumped out into the hot well. The air-pump then discharges the hot water through a grease extractor into the feed tank, which completes the cycle of operations and leaves the water exactly where it was at the start.

IV. Defects in the "Belleville" Boiler.

It was in the year 1903 that a Special Committee, which had been appointed by the Admiralty to inquire into the working of the Belleville boiler in the ships of the Royal Navy and to report as to a suitable type of boiler to be fitted in future war-ships, presented its report. The report contains an account of a series of trials on two vessels, the *Hyacinth* and *Minerva*, which were specially selected for the purpose, the *Hyacinth* having Belleville water-tube boilers and the *Minerva* cylindrical return-tube-boilers.

Among the defects which were noted in the Belleville boilers we may refer to the following :—

(1) The circulation is defective and uncertain.

(2) An automatic feeding arrangement of a delicate and complicated kind is absolutely necessary for the safe working of these boilers.

(3) The great excess of pressure over that in the boilers which is required in the feed pipes and pumps.

(4) The considerable excess of boiler pressure over that at the engines.

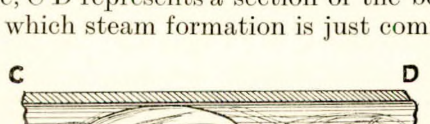
(5) A separator with an automatic drain is required to get rid of the water carried over from the boilers when any sudden excessive demand for steam is made.

(6) There is a constant and excessive loss of feed-water.

It is worth while examining a few of these criticisms, as by so doing we may learn a good deal more about the behaviour of the Belleville boiler under working conditions. With regard to the first defect :—We may explain this statement of the Committee by considering what happens during the process of steam raising as observed by the Author in a model of this type of boiler in which the elements were composed of glass tubes. When the fires are first lit the water in the bottom rows of tubes gets hot and expands. It first of all tries to go backwards up the downcast pipes, but is prevented from so doing by the non-return valve. Steam bubbles now begin to form and rise to the upper sides of the tubes ; the bubbles increase in size and finally two or three push their way up through the element to the surface of the water. The process of steam formation continues to get more rapid and large bubbles are discharged in quick succession at the water surface. And now a curious thing happens—the hot water is pushed forward up the tubes and discharged in little jets into the steam drum and the whole element is filled with a mass of water and steam which sways to and fro, each discharge into the steam drum being followed by a corresponding suction through the non-return valve. The boiler is then fairly under weigh and continues to feed itself automatically by the arrangement previously described. The reason why the discharge into the steam drum is so jerky is because of the succession of shocks which is imparted to the water by the abrupt changes of direction it experiences in the junction boxes.

Steam Formation in the Belleville Boiler

In the figure, C D represents a section of the bottom tube of an element in which steam formation is just commencing. At



some point on the tube where the temperature is highest a steam bubble such as A is formed which gradually increases in size until it occupies the whole tube for a length of some inches. The pressure of the steam goes on increasing inside the bubble until it is sufficiently great to set the whole of the water in the element in motion. As soon as this mixture of water and steam is blown forward the pressure in A drops, and cold water is driven in through the non-return valve to fill up the space; at the same time the bulk of the water which has been pushed forward begins to drop back again, the two streams meet together with a small bubble between them, but only remain at rest for an instant until the pressure rises again and the process is repeated.

If we examine the process of steam raising in a model boiler composed of a uniform glass spiral we find a perfectly continuous discharge into the steam drum owing to the absence of the aforementioned shocks.

Another peculiarity which has been noted in the actual boilers when under steam is that when the engines to which they are supplying steam are suddenly stopped the level of the water in the gauge glasses often drops suddenly and goes nearly out of sight, with the result that the feed-valve A opens wide and the pumps race away to supply the deficiency and bring up the level again. The reason for this is as follows :—Since the water has to be pushed up into the steam drum it follows that the pressure in the lower generator tubes must be slightly in excess of that in the upper rows of tubes in order to overcome frictional resistances ; moreover, since the water is discharged bodily into the steam drum there cannot, strictly speaking, be said to be ANY WATER LEVEL AT ALL except when the boiler is not steaming, so that we are led to the conclusion that the gauge-glasses merely indicate the "head" of water which is equivalent to the excess of pressure required to drive the mixture of water and steam up through the elements. Now for fast steaming this pressure head must of necessity be greater than for slow steaming, and so the height of the water in the gauge glass on the float chamber will stand higher in the former case than in the latter ; but we have already seen that the float is so adjusted that it will not let any more water in until the level falls below half glass. Hence, when the demand for steam is suddenly increased the amount of water in the boiler is reduced, and when the demand suddenly ceases, as in the instance quoted, the amount of water is automatically increased. Knowing this peculiarity it is customary to allow for it by removing some of the lead weights at C and working with an *apparent water-level* of more than half glass, when the rate of evaporation is high.

Water Level in the Belleville Boiler

The level of the water in the boiler is supposed to be indicated by two gauge glasses, one placed on the float chamber of the automatic feed apparatus which is attached to the left *wing* element, and the other mounted on a column which is attached to the right wing element (or vice versa).

We have already seen that these gauges do not indicate the *level* of the water in the elements, but only register the pressure-head in the lower tubes above that in the upper tubes, but at the same time it must be noted that they do indicate the *presence of water in the two wing elements* to which they are connected, but they are utterly incapable of registering the *absence of water* in any of the other elements, so that if by any means the conical nipple which leads into a central element happens to get choked up by some obstruction the fireman has no means whatever of ascertaining this fact except by observing the fusible plugs, and it is quite possible for the tubes to have become seriously overheated before the plugs blow. The only really safe method under all circumstances is to have a gauge glass on every element of the boiler—next to this comes a minute and careful inspection of the interior of the tubes, every time the boiler is opened up.

If from any cause an element does happen to get short of water, it is the bottom tubes which get empty first and the top ones last, whereas one might at first sight expect the contrary, viz. that the water would boil off at the top of the element.

Coming now to the second defect, viz. the complicated automatic feed arrangement, we realise the necessity of this apparatus because the total quantity of water in the generator at any given instant is so small and the demand for steam is so great that no human being could hope to keep a constant amount of water in the boiler for any length of time by hand regulation alone—it thus becomes essential to have a sensitive automatic apparatus. We may also note in this connexion that every other type of boiler which is fitted with an automatic feeding apparatus has the float placed in the steam drum itself where there is always a depth of several inches of water below it and plenty of free space above it, so that its action does really depend on the *actual boiler water-level.*

With regard to the statements made which refer to the high pressures employed, we find that the enormous pressure in the feed pipes is necessary to overcome frictional resistance in the feed valves and pipes and in the economiser elements ; in both cases we realise that it is objectionable because of the trouble of keeping the joints tight under these excessive pressures. The automatic drain referred to in statement No. 5 as being attached to the separator is arranged as follows :—A hollow steel float is fixed inside the separator to a horizontal lever which passes through the shell of the separator and has some lead weights hung from the extreme end. The lever actuates two small plunger valves placed one each side of its fulcrum ; one valve admits live steam from the top of the separator to the drain valve, the other valve communicates with the condenser. The drain valve has a piston fixed on the upper end of its spindle and the top side of this piston is placed in communication with the steam pressure or else with the condenser—depending upon which of the small plunger valves is open. If the water in the separator is below the pre-arranged level the float dips down—this opens the steam valve and the steam pressure acting upon the top of the piston keeps the valve shut. If on the other hand the water rises above this level, the condenser valve is opened, and since there is now a vacuum above the piston the pressure in the separator lifts up the drain valve and blows off the water into the feed tank.

The great loss of feed-water mentioned in statement No. 6 was chiefly due to the joints of the handhole doors not being properly faced up and also to the varying thickness of the asbestos rings used. But we also find that the cylindrical boilers of the *Minerva* lost a great deal of feed water and also developed other defects, such as "birdsnesting" in the smoke tubes (supposed to have been due to the use of retarders in the tubes which were fitted to regulate the air passing through the fires).

V. Advantages of the "Belleville" Boiler.

The Belleville boiler is superior to the cylindrical boiler in the following properties :—

1. It has a higher thermal efficiency.
2. It raises steam quicker.
3. It is not so heavy.

Here are a few figures which were obtained on the trials previously referred to :—

(a) *Thermal Efficiency.*

Power developed.	Cylindrical.	Belleville.
2,000 H.P.	69·7	77·2
5,000 H.P.	68·0	71·8
8,000 H.P.	61·4	73·3

(b) *Equivalent evaporation per pound of coal, from and at* 212°*F.*

Power developed.	Cylindrical.	Belleville.
2,000 H.P.	10·26	11·46
5,000 H.P.	10·33	11·0
8,000 H.P.	9·27	11·03

(c) *Comparison of Weights.*

	Weight of Boiler Room Installation in tons.	Max. output of steam per hour in cubic feet.	Output per ton of Boiler Room weight.
Cylindrical .	567	167,100	295
Belleville .	454	178,700	394

VI. Conclusion.

It will be sufficient to state that steam can be raised from "all cold" in about forty minutes (in a Belleville boiler) to show that this boiler is a very rapid steamer. There is perfect freedom from injurious strains because the tubes are quite free to expand in every direction. It is astonishing how deceptive the weight of a "Belleville" plant is—one would naturally expect that when only such a small quantity of water was contained in it the boiler would be extremely light, but it is the weight of the firebrick settings, the separator, the air-blowing engines, etc., which have all to be taken into account, so that compared as a whole with an ordinary boiler equipment the saving in weight is greatly reduced. As an offset against the above advantages must be set the disadvantages already named, together with the fact that the management of Belleville boilers requires far more skill and experience than cylindrical boilers ;

even the Government contractors find it advantageous only to employ those men who have had previous experience in this class of work in order to facilitate the erection of these boilers in the shop as well as on board ship. The coupling up of mud-drums to downcast pipes and feed collectors is a job which calls for men of great skill if it is to be done expeditiously. Another thing to note is the large amount of "spare-gear" required for a Belleville plant compared with that for an equally powerful cylindrical boiler plant. Each boiler must have at least one complete spare element for the generator and one for the economiser, because it is found to take far less time to put in a complete element than to replace a damaged tube; then in addition we have spare rings, sleeves, nipples, tubes, float gear, etc.

With regard to the trials of the *Hyacinth* and *Minerva*, as well as in the light of more recent experiences we find that the Belleville boilers have done much better than most people anticipated; particularly has this been the case on board H.M.S. *Terrible* (formerly one of the most troublesome ships in this respect) and in a good many of the ships of the Japanese Navy; but it seems to be pretty generally admitted that while these boilers have and still do give very good results when properly constructed and managed, and although for a great number of years the Belleville was the *best type* of water-tube boiler, still of recent years other types of water-tube boilers have been invented which give even better results and are less troublesome to manage. It is not surprising therefore to read in the Committee's report "That they (the Committee) are of opinion that the Belleville boiler has no such advantages over other types of boiler to lead it to be recommended as the type for use in His Majesty's Navy." Such then is the history of the rise and fall of the Belleville boiler in the ships of the British Navy.

Mr. KEAN illustrated his remarks by means of a number of diagrams and lantern slides.

The CHAIRMAN: We have listened to an interesting paper on this important subject. Mr. Kean has put himself to a great deal of trouble to explain most lucidly all the different parts of the Belleville boiler—not only its advantages, but also its disadvantages. It seems to me to be a very intricate boiler. If any one present has had experience in working these boilers, we shall be very pleased to hear what he has to say. Japan showed a sensible plan in adopting only part water tube boilers.

Mr. J. R. Ruthven said he had had no experience with the Belleville boiler, although of late years he had experience with other water-tube boilers. He thought Mr. Kean had described the boiler very clearly, and had brought all the points forward. On the whole he thought his review had made it to appear rather worse than he thought it was. He would be glad if Mr. Kean would tell them about the air in the combustion chamber. The drawing appeared to show that the air was in the combustion chamber above the tubes, but he understood that there was also air below the tubes. Was that so? and what was the effect of having air under the tubes in comparison with over the tubes? Under the tubes seemed to him to be the best place. It was not clear whether it was possible to get into the steam collector, which was 2 feet diameter. Perhaps the end came off altogether, but he did not see any reference to a manhole. He thought there were members present who had had experience with Belleville boilers, and he would like to hear their observations. It was a most important question to-day, both for the Navy and for all of them.

Mr. A. H. Mather said they were indebted to Mr. Kean. The paper was in a most attractive and useful form, giving practically the history of the rise and fall of the Belleville boiler. The paper went into the details clearly, both as to advantages and disadvantages. Mr. Kean had enumerated six defects, but another which caused a great deal of trouble might be added, and he did not think that trouble had ever been properly cured. He referred to the lead plugs in the ends of the elements. Those plugs certainly caused more trouble than a great many other parts of the boiler. He had never had any personal handling of the boiler, but had seen a good deal of it when on trial. He remembered one instance when the lead plugs caused so much trouble, that during the last few hours of the trial they were "going" continually. As often as one went out they opened the door and put in another. In the end they could not even do that, as the steam was going down so fast, owing to the frequent opening of the smoke-box door, that they let them alone, and kept the door closed. The distilling and evaporating plant was kept at work as hard as possible, but could not cope with the losses of water. That was a thirty hours' trial, and at the finish, when the ship came to Plymouth Breakwater, there was not enough water left to run the electric lighting plant. He had noted the views of the reducing valve showed that Mr. Kean had dealt with it very thoroughly, but had not made any mention of a small fitting on the engine side of that valve. On all those reducing valves there was fitted a safety valve on the engine side to prevent the pressure accumulating beyond that required for the high pressure engine casing. He remembered an instance of one of the early ships, fitted with Belleville boilers, rushed out on trial in a hurry. A pipe was supposed to be—but was not—connected from that safety valve back to the condenser or feed-tank. The ship went out and was run at a pretty good speed. Suddenly a "stop" order came from the bridge. There was a roar from the valve, and the engine-room became full of steam. The safety-valve had lifted and the steam could blow clear through the engine-room. That accident was not due to faulty design, but had arisen through not having the pipe fitted. This reducing valve was one of the features in the early days of the Belleville boiler that was looked upon as a great objection, but had been rectified. Strictly speaking, those boilers could not be said to have any water-level at all, and was an objectionable point to most engineers and attendants who had been accustomed to the good plain water-level of the old type of boiler. That, however, was got over, and they now understood the action of the boiler, and had more confidence in handling it.

Mr. W. Lawrie said he had had no experience with the Belleville boiler. He thought that Mr. Kean had approached the subject in a rather broader spirit than they had been in the habit of finding in some other papers. They would agree that he had dealt with the subject very fully and very clearly. In regard to the question of water-level, to which Mr. Mather had just referred, he said it was almost impossible to have such a thing as a water-level in a water-tube boiler of any sort. There was such a small quantity of water that it was almost an impossibility. Unless they could balance evaporization with the feed-water used they could not get a water-level with any water-tube boiler. He had no practical knowledge of it, but it had been explained to him that in the early days they had a hand feed, and the man used to go and turn the water on and off, and look at the gauge-glass, and it was a chance between the gauge-glass and the check-valve all the time. They got over that by taking the check-valve adjusting handles off and giving the check-valves a very small area. When they came to know that things like that had to be done, they would see the necessity for an automatic valve. The automatic feed arrangement referred to by the author would not, he considered, be very useful on board ship. He was afraid they would not work with any reliability. On land boilers it was another matter, but at sea he did not think it was possible. Speaking in regard to the *Minerva* and *Hyacinth* trials, he said that they had had that before them so often that they need hardly refer to them again. They had had many references to those trials. There was not the least doubt that the finding of the committee was generally accepted by engineers as being the only possible finding they could come to. That committee was composed of men of great experience, and they were set a task which they carried out very thoroughly, and they condemned the Belleville boiler. He thought it would be useless for them to argue in the face of that decision. The efficiency of water-tube boilers had been tested in many ways. If they were to test the efficiency of a water-tube boiler alongside a marine boiler for three months, he did not think there would be the slightest question as to which would show the best efficiency. If they took the water-tube boiler as it left the works clean, he thought they would get a better result from it. They talked of blowing the dirt off the tubes with steam, and also of scraping. He had been told that the scraping was a very tedious operation, and if they scraped all those tubes carefully they were going to take a lot of time. If they used steam to blow it off, they would very often find they were increasing the trouble by caking the soot on the tubes, and making it so hard that they would have to chip it off. Taking it all through, he thought the defects of the Belleville boiler were very much greater than its advantages. In the Navy they made a great talk of getting up steam in forty minutes, but he did not think they would require steam in forty minutes even in the Navy. He did not think they would require the men-of-war in forty minutes. His opinion was that they would have time to get up steam at any rate. When he had last spoken on that subject he thought he had said the last word on the water-tube boiler question. He would now say that if it was a good thing, it would come into use and would be adopted, no matter what any body of engineers or any one else thought; because our marine engine superintendents knew what was the best. When the water-tube boiler was as efficient as the Scotch boiler for everyday hard work it would be adopted for everyday work. So far as the Navy was concerned they did not know what their procedure was. Now the Admiralty seemed to be going ahead of the mercantile man and trying to be up-to-date, but he did not think everything had been quite a success. But, in the matter of experience, he did not think they should have put so many Belleville boilers into so many first-class ships. It was a mistake for which they had had to pay.

Mr. D. S. Lee, R.N.R., said he had seen good results from the Belleville boilers when the engineers in charge had studied them, and had taken proper precautions and proper means for obtaining the best results. Others had been very unfortunate. He would like to ask Mr. Kean why the lower rows of tubes always curved away from the fire. He had never been able to obtain a proper answer to that question, although he had seen many cases where it had happened. The tubes always curved upwards, away from the fire. It was quite correct what Mr. Lawrie had said, and he thought there had been a good deal of experiment with water-tube boilers, but no doubt they would be able to adopt the best one.

Mr. W. E. Farenden asked if all the tubes were of the same thickness. Were not the lower tubes made thicker than the higher rows of tubes? Would Mr. Kean also kindly explain the thermal efficiency to which he had referred in the course of his paper?

Mr. Wm. T. Tucker: Referring to fusible plugs I have known these to be called musical plugs owing to their continuous blowing out, and I have seen steel plugs put in to save all the worry and trouble. I have even heard that several naval engineers have plugged up all the holes with steel screws, deeming fusible plugs to be useless. It is quite a common practice now in the Navy to work Belleville boilers without the non-return valves in the mud-drums.

The Belleville automatic feed regulators are not quite reliable owing to some of their parts working through glands which can be made any degree of tightness, and so cause irregularities in working. A skilful man, of course, is less liable to screw the glands down too tight.

The author states that a Belleville boiler can get up steam in forty minutes, but I have seen a much quicker rate of steaming in a Danish cruiser, fitted with the Babcock and Wilcox boilers: in which case, from the time of lighting fires, the ship was going full speed in exactly twenty-five minutes. The engines had been partly warmed up with donkey boiler steam previous to lighting fires in the main boilers.

Mr. Lawrie mentions that in his opinion the cleaning of soot off water-tube boiler tubes is a difficult matter, and that if a steam-jet were used it would cake the soot on to the tubes. I have proved the steam-jet to be very efficient; even if the steam did cake the soot on to the tubes, there is nothing to prevent one from using an air-jet, which is now used in some ships.

I beg to differ from the remarks of the Chairman where he says that the Japanese have shown us a way out of any risk, by using one in five cylindrical boilers and four in five water-tube boilers. This was first adopted by the British Navy, but dropped lately in favour of a complete installation of water-tube boilers.

The author thinks the cause of bending upwards of the bottom tubes is due to the under side of the tube being hottest, but this does not explain the result. All water-tube boilers behave this way—some more than others—but I have not yet heard of a satisfactory explanation of the cause. If the tube was hottest and weakest at the bottom, it ought to bend down, I should think, and not up, as in an overheated furnace crown.

One great point in favour of water-tube boilers is, that the stoke-holds containing them are generally much cooler than a stoke-hold with cylindrical boilers. In a war ship having Babcock and Wilcox boilers and cylindrical boilers, there was a difference between the temperatures of the stoke-holds of about 20° F. in favour of the former.

Mr. KEAN then replied to the points which had been raised. First of all, he said, he must thank them for the careful manner in which they had followed his paper. He had been interested in the subject right from the time when he began his apprenticeship. Later on, when he began to see his way around, he got to know more about the boiler, but even then it was not possible to find out all the details from practical experience: it was necessary to augment practical experience with reading. He had done a good deal of reading. One or two good works that he might mention in that connection were: *The Marine Steam Engine*, *Marine Boilers*, and various other reference books on engineering, and also papers. He had found it very useful to construct a little model of a boiler with glass tubes, which showed the circulation of the water. He had learned a good many things from that model. He was sorry that none of those present had had any actual sea-going experience of the Belleville boiler, because, personally, he also was in the same position, his sea-going experience with Belleville boilers being limited to a few trial runs in the Channel. Mr. Ruthven had raised a question as to the air being above and below the tubes. As a matter of fact the air was below both sets of tubes. The air was at the bottom below the generator tubes, and at the top below the economizer tubes. It was found that very often when the gases got to the top of the generator elements combustion was incomplete, and if they supplied the necessary air they could complete the combustion on the way up through the economizer. Mr. Ruthven had also raised a question as to getting into the steam collector. There was a manhole on it, but he did not think any one could get into the collector. A man could get his hand into it. Mr. Mather had made some interesting remarks about the lead plugs. He thought they had had the same trouble in all ships with those fusible plugs, due, he thought, to the composition of the metal not being suited to the high temperature of the steam, and he thought that since then an improvement had been effected. He had been reminded that he had not dealt with the relief valve. He had had a somewhat similar experience to that described. Those hastily rushed trials of the Belleville boiler to which Mr. Mather had referred seemed to have been the order of the day. Mr. Lawrie's remarks on the subject had been very interesting. It was true that in all water-tube boilers the level fluctuated greatly, but what he (the author) desired especially to point out was that in this particular type of boiler the water went (so to speak) round and round in a more or less continuous stream, and hence it was not possible to have any water-level at all—not even a fluctuating one. In regard to Mr. Lawrie's question as to which type of boiler, the water-tube or the marine boiler, would after three months' service show the best efficiency, he must say again that he had not had sufficient practical sea-going experience that would entitle him to speak. Still, so far as efficiency for everyday hard work was concerned, it was only what every one would expect that those boilers of the water-tube type did not stand the wear and tear so well. As a matter of fact, after a certain period of service, they would find very little of the original boiler, one part after another having been renewed. In regard to zincing, the process was as follows: A plate of zinc was placed in a bath of sulphate of zinc and the tubes that were to be galvanized were also placed therein and hung up by wires, their position being frequently changed to ensure a uniform coating of metal being deposited all over them. They made the zinc plate the positive pole and the tubes the negative pole. Then they passed a heavy current of electricity, at low voltage, through, and the zinc off the plate was deposited both inside and outside the tubes. According to all accounts, pitting had been very much stopped by the use of lime in the feed-water, and also by the better coating of the tubes. He did not know whether any case of quick steam-raising occurred during the recent war between Russia and Japan, but in the case of a surprise attack by torpedo boat destroyers he was of opinion that a fast steaming boiler might very possibly be worth double its weight in gold to a large battleship.

With regard to the question of personnel, that was supposed to be at the bottom of the whole matter. If they did not know much of the Belleville boiler, or if they relied upon a book only, they could not hope to manage it properly. He had been told that they changed ships so often that men came off cylindrical-boilered ships and were transferred to ships with Belleville boilers, and were expected to know the ins and outs of the boilers in two or three months. It was not to be expected that in so short a time the men could acquire the necessary knowledge. With regard to Mr. Lee's question as to the curling upward of the tubes, he thought that was due to the bottoms of the tubes being hotter than the upward side, owing to the fact that they were nearer to the fire; this caused unequal expansions—but the subject was one which required further investigation. The case of a furnace-crown was different, because in that case there was a heavy load on the crown, due to the mass of water above it. Mr. Farenden had asked if the lower tubes were not made thicker than the upper ones. The average thickness of the tubes was $\frac{1}{4}$ inch, but the top ones would be about $\frac{3}{16}$ inch in thickness and the bottom ones $\frac{5}{16}$ inch in thickness. Mr. Farenden had also asked for an explanation of thermal efficiency. They knew that every pound of coal fired, if completely burned, was capable of giving off a definite quantity of heat. That quantity of heat might be ascertained by means of a coal calorimeter, or might be calculated from the coal analysis, and was called the "*calorific value*" of the fuel. A usual figure for the calorific value was 15,000 British thermal units per lb. of coal. Again, every pound of steam formed contained a definite quantity of heat, which quantity might be ascertained by reference to the saturated steam tables. If, then, they knew the number of pounds of water evaporated per lb. of fuel burned, they could find out how much heat had been given to the water in the boiler by every pound of coal that was burned on the grate. If all the heat developed by the combustion of the coal could be transmitted to the water in the boiler, the thermal efficiency would be 1, or 100 per cent.; but that never could be realized in practice, because a large amount of heat must of necessity pass away up the funnel, and be lost in other ways. But in any case they had—

$$\frac{\text{Quantity of heat transmitted to the water in the boiler per lb. of coal burned}}{\text{Quantity of heat which 1 lb. of coal gave out if completely burned}}$$

as an expression for the thermal efficiency of the boiler. For instance, in one trial made by the students on the wet-bottom locomotive boiler at University College, London, at which the author had assisted, the following measurements were made :—

Description of fuel : Nixon's navigation coal.
Quantity fired per hour : 113·1 lb.
Pounds of water evaporated per hour : 663 lb.
Temperature of boiler feed : 112·90° F.
Pressure of steam in lb./in.^{2} absolute 99·58.
Gauge pressure : 88·43 lb./in.^{2}.

Now the calorific value of 1 lb. of that coal was 15,090 B. thermal units, and the total heat in 1 lb. of dry saturated steam at the pressure given was 1,108·8 B. Th. U. (reckoned above the feed temperature), and the number of pounds of water evaporated per lb. of coal burned was $\frac{663}{113 \cdot 8} = 5 \cdot 86$, and since each pound of steam required 1,108·8 B. Th. U. to convert it from water at the feed temperature into steam at the boiler pressure they found—

Quantity of heat transmitted to the water in the boiler per lb. of coal burned $= 5 \cdot 86 \times 1{,}108 \cdot 8 = 6{,}450 \cdot 7$ B. Th. U., and that gave thermal efficiency $= \frac{6{,}450 \cdot 7}{15{,}090} \times 100 = 42 \cdot 8\,\%$.

In the experiment they had a rather poor thermal efficiency, but that was due partly to the type of boiler, but chiefly to the bad chimney-draught. Anyway, it demonstrated the method of obtaining the thermal efficiency. In actual practice they never got as much out as they had to put in, and the efficiency, therefore, could never be 1. Strictly speaking, testing for the thermal efficiency, they ought to have a steam calorimeter under the stop-valve leading from the boiler in order to measure the dryness of the steam. There were various methods of doing that, but there was no steam calorimeter at the present time that they could regard as being absolutely reliable and accurate. Mr. Tucker's remark in regard to the "musical" plugs had, he thought, already been answered. That gentleman had also referred to the galvanizing of the tubes. In regard to that he might say that the tubes were not now galvanized. Everything was zinced. It was true that if the tubes got overheated the zinc got burned off, but under normal conditions they still retained the coating of zinc. He had never used the steam-jet for cleaning the tubes, so he was afraid he could not settle between Mr. Tucker and Mr. Lawrie on that point.

The CHAIRMAN remarked that they were very much indebted to Mr. Kean for his interesting paper, and for the lucid way in which he had answered the questions that had been put to him. He dared say that all engineers present that evening, who belonged to the commercial marine, would rather stick to the old type of boiler in preference to the one which had been described that night. In the mercantile marine they did not have such a staff as they had in the Navy. To his mind those boilers were far too complicated ever to be adopted in the mercantile marine, as it would be impossible to get a sufficient staff of men to keep them in good repair and thorough working order. In the merchant service there were too many changes of engineers and firemen. There was a change every time they came to port, and it was almost impossible to educate men up to understand efficiently the working of the Belleville boiler. He thought with Mr. Lawrie that it was a great mistake to put a complete installation of Belleville boilers on board any vessel. He thought the Japanese had showed them a very good object lesson in installing one-third of the Scotch type of boiler and two-thirds Belleville, and he thought they were adopting a similar system in the British Navy.

Mr. W. McLaren said it gave him much pleasure to propose a hearty vote of thanks to Mr. Kean for his paper. In one instance where a boiler was required it was a question of price whether a Lancashire or a water-tube boiler was installed. The Lancashire was displaced, and then it lay between the water-tube and the locomotive type. The water-tube was so excessive in price that they adopted the locomotive boiler, which had given since fitted every satisfaction, and that alongside a water-tube boiler, which was not to be compared with it. He hoped that Mr. Kean might come amongst them again and give them something of his university experience.

Mr. J. R. Ruthven seconded the proposition, and regretted that there had not been more said by those who had experience with water-tube boilers, as he knew that some of them could have said a great deal more had they been so minded.

The proposed vote of thanks to Mr. Kean was carried by acclamation.

Mr. Kean, replying, said he thanked them very much for the kind way his paper had been received. He considered it a great honour that they had permitted him to read his paper before them. People seemed to get the opinion that a "B.Sc." could never have had any practical experience. He might say that at the outset he did not intend to study for the degree, but had intended to work up and obtain his chief's certificate. He had to thank the Honorary Secretary for the kind way in which his letter, offering to read the paper, had been responded to, and he must again thank them for the exceedingly generous manner in which they had treated him that evening. He was very pleased to have been able to hear some interesting experiences, and he would have been very glad if some of those who had had good sea-going experience with high-pressure water-tube boilers had been present to join in the discussion.

The Chairman then referred to the various outings which had been arranged for the summer, observing that cards giving details could be obtained on application, which should be made as early as possible.

A vote of thanks to the Chairman terminated the proceedings.

58, Romford Road,
Stratford,
July 24th 1906.

It would be noted by Members of the Institute that the name of the President appears in the list of Peers created on the occasion of the King's Birthday celebrations. The following telegram was sent to him on June *29th* :—

> " Right Hon. W. J. Pirrie, President, Devonshire House, Belgrave Square—Please accept congratulations from Institute of Marine Engineers. ADAMSON."

to which the following reply was received :—

> " Adamson, Institute Marine Engineers, 58 Romford Road, E.—Very many thanks for your kind congratulations. Pirrie."

In connexion with this the following paragraphs from the *Marine Engineer* of July *16th* may be quoted :—

> " The news of Mr. Pirrie's elevation to the peerage was received with great satisfaction in Belfast, the unanimous verdict being that the honour is richly deserved. He is the head of one of the most famous shipbuilding firms in the world. That it is famous may be attributed mainly to the great ability and enterprise of the man who has been so highly honoured. Lord Pirrie—if that is to be his title—has done much for Belfast. How much may be briefly summed up by the question : What would Belfast be without Lord Pirrie and the Queen's Island ? "

> " In the list of those chosen to receive honour on the occasion of the King's Birthday we note the Right Hon. W. J. Pirrie, President of the Institute of Marine Engineers, elevated to the peerage. The Presidents of the Institute have been singularly chosen in past years from those who were marked for distinction ; this year is therefore no exception."

J.A.

PREFACE.

---

58 Romford Road,

Stratford,

April 9th, 1906.

A joint meeting of the London Association of Foremen Engineers and Draughtsmen and the Institute of Marine Engineers, called on very short notice, was held in Cannon Street Hotel on Saturday evening, April 7th.

The meeting, which was presided over by Lieut. Carlyon Bellairs, R.N., M.P., was called on the request of several influential engineers in order to consider and discuss a meditated proposal on the part of the Admiralty to make certain changes in the engine rooms of the Navy, and at the same time consider and discuss the working of the new system of training the executive engineers. There was a large attendance, the crowded hall testifying to the interest in the subject, which was introduced in the following paper by Mr. W. J. Harding, R.N. (Member).

Jas. Adamson,

Hon. Secretary.