

MR. R. GRANT said that he was pleased that the matter had been brought before the Association for consideration. In a subject so wide as that of water-tube boilers it was to be regretted that the author had not referred to that class of boiler for marine purposes, and that he had only mentioned, in passing, boilers with bent tubes. He (the speaker) would have liked to have seen a comparison between bent tube and straight tube boilers, more especially with regard to durability. Under this head he thought the bent tube possessed advantages over the straight tube. With all water-tube boilers, as now constructed, there must be a considerable amount of unequal expansion between the tubes nearest the fire and those furthest from it. Those nearest the fire would naturally be heated first, and immediately commence to expand, whilst those in the rear would remain comparatively cold. With the bent tube this expansion was met by the spring at the bends, but with the straight, rigid tube severe straining must take place. The author, in his remarks with regard to durability, said (speaking of a Cornish boiler): "As soon as the fire is started the top of the furnace tube becomes hot, causing expansion, while the bottom of the shell is perfectly cold. This tends to bulge the flat ends outwards, hence the heavy gusset stays used in shell boilers." He would like to point out that the gusset stays used in shell boilers are for staying the flat ends against the steam pressure, and not for the mere expansion of the flue. The author also said: "When all the water becomes heated the whole of the structure elongates, and straining will occur unless proper provision has been made to counteract it." If a shell boiler elongates when the water becomes heated, so will a water-tube boiler; also, if straining is set up in one, so will it be in the other. To his mind, no straining took place in a boiler elongating by being heated. It was only natural that it would elongate. It was when you endeavoured to stop that elongation, and when the heating was local, that the trouble began.

He would also like to know what the author meant by "proper provision" being made to counteract the straining. He

did not think the reasons given by the author for the absence of stays in water-tube boilers were correct. The reason that no stays were required was that the parts are mostly cylindrical, and the flat surfaces so small as to need no staying.

With regard to facilities for cleaning and repairing, he thought that shell boilers were much easier to clean, repair and examine than water-tube boilers. The surfaces which would always give trouble were those that came in contact with the water. The outside of a tube could always be chipped and cleaned with ease, but it would be impossible to get the same results on the inside. Any pit-holes or other defects could always be seen on the outside, and the tube or any other defective part made good at once; but when pitting or corrosion took place on the inside of the tube (which could not be seen for fully nine-tenths of its length) it left the condition of the boiler an unknown quantity, and some day, when least expected, a tube might burst without any warning whatever, and not perhaps without serious personal injury. Again, if a fire-tube pitted through, it made itself known by a small leak, and need go no further, as it could at once be stopped, without interfering with the working of the boiler, until such time as it could be renewed.

MR. JOHN TODER said that the author had opened up a subject which laid claim to be one of the most important problems of the day. Steam users were asking the question, "What type of boiler must be adopted, tank or water-tube?" and our modern engine builders were designing for high pressures, which in many cases were out of reach of tank boilers.

Then came the question of design of water-tube boiler, and we all had our own opinions on that point.

He noticed that the author had commented on bent *versus* straight tubes, and he was pleased that the Scotch Stirling Boiler had been placed in such good company as that of the Normand and Thorneycroft's Speedy (he purposely termed it the "Scotch" Stirling boiler in order to distinguish it from the American Stirling, which is of totally different design and not in any way connected with the Scotch Stirling).

The boilers he had mentioned were of the bent-tube family and had done excellent work. In the years 1885 to 1901, a period of sixteen years, Thorneycroft's bent-tube boilers were fitted to

76	vessels in the British Navy,
67	.. .. German Navy,
29	.. .. United States Navy,
84	.. .. other navies of the world.

These boilers represented an I.H.P. of one million seventy thousand four hundred and forty (1,070,440), and he thought that spoke well for water-tube boilers with bent tubes.

He contended that bent tubes were much more elastic than straight tubes, and better able to adapt themselves to the very severe and varying temperature to which they were subjected.

It was well known that boiler experts of the day were aiming to design water-tube boilers which would promote rapid and definite circulation in one direction, and it was absolutely essential that each unit or pipe, as you might choose to call it, should have a perfectly free inlet and outlet equal to the area of that unit, and if such conditions were not complied with, what would happen? Formation of steam pockets, which with heavy firing would lead to water-hammer with its deadly effect, viz., burnt tubes in the vicinity of the greatest heat. Touching on the dreaded water-hammer action, he would call attention to the author's statement that he had not heard of loss of life or limb, nor injury to property having resulted through the use of the type of water-tube boiler he had under his charge, meaning Babcock & Wilcox's horizontal tube type.

There were many cases of serious accident and loss of life recorded by using this type of horizontal water-tube boiler in the Board of Trade reports, and he would refer to a case which occurred at Runicorn, in Cheshire, already mentioned by a previous speaker.

The Board of Trade reported on this case as follows: "The boiler from which the explosion occurred was one of a set of

six Babcock & Wilcox's boilers, installed at the Castner-Kellner Alkali Company's Works, Cheshire. Considerable trouble had been experienced with the tubes blistering and bulging during the three years the boilers had been at work. Four days before the explosion, the boiler was closed down for the purpose of renewing some tubes which were bulged. The boiler was started again the same day, and four days afterwards, on one of the firemen hearing a hissing noise, it was again closed down, and it was found that one of the tubes just replaced had bulged at a distance of about 4 feet from the front header. The bulging had two slits extending for about  $\frac{3}{8}$  in. in length by about  $\frac{1}{16}$  in. wide; the thickness of the material was reduced by wasting from  $\cdot 15$  of an inch to  $\cdot 031$  of an inch. The tube was found on examination to be free from heavy scale and, the bulged portion being cut for better inspection, it was noticed that the lower half of the tube, where the bulge had taken place, was covered with a coating of black oxide of iron, undoubtedly formed by steam having been in contact with the tube while it was red-hot; the upper portion of the tube at this place and the rest of the tube were coated with a thin white scale. The oxide of iron was about  $\frac{1}{32}$  in. thick. The inspector was of the opinion that these slits were caused by overheating of the material through shortness of water in the tube, this being brought about by over-evaporation."

The opinion of Mr. Harris, senior engineer surveyor to the Board of Trade at Liverpool, Mr. George Gray, engineer surveyor to the Board of Trade, and Mr. Stromeyer, chief engineer to the Manchester Steam Users' Association, was that "Owing to too heavy firing and the want of a better diffusion of the flame, steam pockets had been formed, and that what was technically known as the 'water-hammer' action had been set up. In this way the water, they thought, had been prevented having full contact with the plates, it had been travelling backwards and forwards, leaving a space where there was only steam. Hence, the tube became overheated and consequently exploded."

There were many other points to be gone into, but if time permitted he would like to have the opportunity of demonstrating the working model of the Scotch Stirling Water-tube Boiler.

MR. W. FYVIE said that a case had come under his notice lately where two such boilers were in use (one working while the other was spare). He thought they had been in use about two years. Outside the boilerhouse there was quite a stack of damaged tubes which had given away from time to time. The trouble became so bad that they decided to make it a rule to cut out the bottom rows of tubes every twelve months to prevent, in a measure, their giving out at an awkward time.

In all his experience with this type of boiler, he had never got beyond 3.2 lbs. water evaporated per square foot of heating surface per hour (5 to 6 lbs. being common practice with the old Cornish type). With the Thorneycroft *bent* tube, 12 to 14 lbs. per hour was no uncommon occurrence with a fairly good factor of efficiency, and they gave up to 100 I.H.P. per ton of boiler, including water and all fittings.

The operation of taking out damaged tubes and replacing by new ones was not always such an easy matter as the author made out. In most cases, damaged tubes were more or less blistered, burned and out of shape, and this blistered and shapeless mass had to be pulled through the tube hole in the header, with considerable risk of injury to the surfaces of tube hole. If that was injured or cut, it was no small matter to get the next tube water-tight, and no uncommon thing to have to use a thin liner on the outside of the tube.

Trouble was also caused by the small bricks forcing the baffles directing the gases getting displaced and the luting dropping out, and it was all but impossible to get brick and luting made good again, failing which the gases would take a short-cut to the chimney.

If it were necessary, as it sometimes was, to plug the ends of the tube, leaving the replacement to a more convenient season, the troubles of removal were increased.

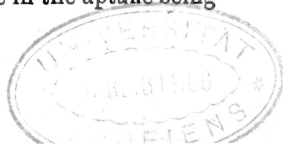
It would be observed that to clean such a boiler it was necessary to remove all the caps, and if there were 100 tubes there must be 200 caps, bolts and plates. These caps and header faces were milled to a fine surface, and were very easily damaged by a scratch or other injury, and this meant scraping up the surfaces again before a water-tight joint could be got. In water-tube boilers of best design these caps were quite unnecessary.

He would call attention to a trial carried out by the Kirkstall Forge Company, Leeds, of two water-tube boilers working under similar conditions, with the waste heat from heating furnaces after heating the iron, one a Babcock & Wilcox and one a Scotch Stirling. Results as follows:—

	B. & W.	Stirling.
Feedwater ... ..	130° F.	130° F.
Water evaporated per lb. of coal charged to the furnace ...	5.55 lbs.	7.52 lbs.
Flue temperature leaving boiler	510° F.	395° F.

This test gave a difference of over 35 % in efficiency in favour of the Scotch Stirling

MR. A. J. ARNOT said that the question of circulation in water-tube boilers was, of course, an important one, and he thought that Mr. George Babcock, in a lecture delivered at the Cornell University, February, 1890, had treated very fully with that point. In that lecture, consideration had been given to the circulation obtained in a Babcock & Wilcox boiler of 2823 sq. ft. of heating surface—similar to the boilers in use at the Sydney Power House. Mr. Babcock had demonstrated that with a velocity of 17 ft. per second (which was obtained with the head of water in that boiler, viz., 4½ ft.) and with an equal quantity of water and steam passing upwards towards the drum, and the boiler evaporating 17 % in excess of the rated power of the boiler, the water would make 218 circuits before being evaporated. He had also shown that when the boiler was working at a quarter its rated capacity, the water would circulate 870 times before it became steam, one-fifth of the volume in the uptake being steam.



In experiments carried out by the Babcock & Wilcox Co., it was shown that there was a necessity to guard against having the uptake at the upper end of the tubes too large, for if sufficiently large to allow downward currents therein, the whole effect of the rising column increasing the circulation in the tube would be nullified. This would be readily seen if the uptake was considered to be very large, when the only head producing circulation in the tubes would be that due to the inclination of each tube taken by itself. This objection could only be overcome when the uptake was so small as to be entirely filled with the ascending current of mingled steam and water.

In a recent publication by Mr. William Kent—editor of "Engineering News" and author of "The Mechanical Engineers' Pocket Book,"—it was stated, at page 241, that "sectional boilers provided with water uptakes and downtakes from the heating surface to a separate drum, will circulate the water thoroughly, and operate in a satisfactory manner. Curiously, this will be the case whether the uptakes be large or considerably contracted."

That statement was taken from the "Journal of the American Society of Naval Engineers," and, after commenting very fully on the subject of circulation in boilers, the writer summed up his remarks as follows:—

"In the writer's opinion, the best form of boiler for reasonable rates of combustion is one with inclined tubes connected by uptakes and downtakes to a chamber or drum above, as in many sectional boilers."

In a model boiler of the Babcock type with glass tubes, it could clearly be shown that continuous and rapid circulation existed in all the tubes connected to the one-header and uptake. In a boiler of that type it would at once be recognised that where heat was intense the steam rose and formed in pockets on the upper side of the tube, which passed quickly into the headers. The fact that the upper side of the tube was not directly acted upon by the furnace gases was of considerable moment, as it prevented burning of the tubes, which otherwise might take place.

In a boiler with vertical tubes steam pockets were formed on all sides, so that those against which the furnace gases impinged, or ran parallel with, were bound to become overheated. That point was also demonstrated clearly in a glass model.

In the Babcock type of boiler the circulation was not only positive but well defined, there being no tendency to induce water to circulate in a downward direction at the hottest part of the boiler.

With boilers consisting of several drums and nearly vertical tubes, it had been demonstrated that, in the tubes immediately over the fire, circulation was in a downward direction, which was contrary to the direction it should naturally assume. Consequently, with those different tendencies there must arise points at which circulation ceased in neither direction, and therefore a liability to scale and over-heating at those points. In boilers of that description, owing to the ill-defined circulation mentioned, wet steam had been produced, and in two cases to his knowledge an additional drum—making six drums in all—had been fitted to the top of the boiler to enable the users to obtain drier steam.

It has been stated by manufacturers of bent-tube boilers that there is considerable difficulty in removing a defective tube, and that, when this defective tube is in an inner one, it becomes necessary to cut away a number of good tubes to permit of its removal.

He thought that those who had used Babcock & Wilcox boilers would agree that such a procedure was never required in their case, as only the defective tube had to be removed and that could be done in four hours by an ordinary fitter.

The cleaning of a Babcock & Wilcox boiler of 250 H.P. should not cost more than £2 at the outside, and he thought that the great point in its favour was, as the author of the paper had stated, that it was possible to see through every tube and know the condition of the boiler. This was a very desirable feature and a great set-off against the use of the hand-hole fittings which are used with this boiler. After an experience of



11 years, he (the speaker) could testify to the fact that those hand-hole fittings were not the slightest trouble, and their removal and refitting could be done by an ordinary mechanic without any supervision.

The question of safety raised by the author was undoubtedly a most important one. It was an eloquent testimony to the absolute safety of the Babcock & Wilcox boiler, that with 4,000,000 H.P. in use throughout the world, under all conditions of service, not a single explosion had occurred which could cause damage to life or property. With the ordinary shell type of boiler it was well known that many disastrous explosion had occurred, causing not only destruction of property but serious loss of life.

The heating surface of boilers had been referred to, and in that respect he would quote the able treatise on "Boiler Efficiency," by Brian Donkin, in which clearly shows, on page 223 that, with 377 experiments of all classes of boilers, the best efficiency is obtained at an evaporation of  $1\frac{1}{2}$  to 3 lb. of water per sq. ft. of heating surface per hour. After 3 lb. and up to 9 lb., the efficiency gradually diminish.

It was a well-known fact that to evaporate much over 3 lb. per square foot was to permit the flue gases to escape at a higher temperature, which, of course, meant a loss of efficiency.

To utilise a bank of tubes connected with the boiler as an economiser—which is advocated by some water-tube boiler-makers—was contrary to the simplest theory, and not in accordance with experiences, for if any part of the boiler was at a temperature lower than the steam temperature, it tended to cool the steam produced, and would naturally reduce the efficiency. He knew of cases where such rear banks of tubes on a boiler of the bent-tube type had been completely choked up with scale after 900 hours work.

MR. J. SCOLAR said that there was a striking diversity of opinion amongst engineers upon the respective qualifications of the water-tube steam generator, and that of the shell or fire-tube

type, and though each party might have claims which justified some decision in the matter, still the various types of boilers appeared to be in very much the same stage of efficiency as they were 15 or 20 years ago.

In the first place, one must start at the coal pile, and assuming that there are 14,500 heat units in one pound of good coal under perfect combustion, this would be equal to an evaporation of 15 lbs. of water from and at 212 degrees Fah. Yet most engineers were perfectly satisfied if they got an efficiency of 9 to 10 lbs. of water evaporated per pound of fuel under ordinary working conditions.

If steam generators were to be classed as up-to-date appliances, he considered they should be able to utilize at least 80 % of the heat energy contained in coal at a normal rate of working, and 85 % under more favourable conditions. Although the general arrangement of most water-tube boilers might afford opportunities for correct design, there certainly appeared to be a lack of combustion space and deficiency in air supply arrangements generally, and in some of them the furnace was so placed that not more than one-third of the heating surface was directly over, or very close to, the fire grate, the effect of which was to cool the gases below the point of ignition. In those cases it was possible for gases which had not given out the full extent of heat to pass away into the main flue unconsumed, and numerous instances occurred where such gases become ignited by means of stray sparks, and burst into a volume of flame, after passing into the flue. If the combustion of the gases was not perfect, a complete transmission of the heat was not practicable; consequently, the effects of uneven expansion and contraction would appear. Perfect combustion could only be relied upon by a proper supply of air, and that must be regulated to suit the nature of the coal used.

For water-tube boilers having slightly inclined tubes, he was of the opinion that the best effects were to be gained from such an arrangement as would permit of the gases being carried in

the direction of the tubes, so that they might be completely enveloped in flame, and prevent any accumulation of soot, or refuse, tending to produce cooling effects on the upper surface. At the same time, he thought that if the tubes were properly distributed, there was no necessity to stagger the headers, and that this would present an element in structural economy, as well as more efficient combustion.

It was claimed by most makers of water-tube boilers that they possessed in a lesser or greater degree the feature of definite circulation, and, as it was obvious that the frictional resistance of the flow of water was less in straight than in bent tubes, any diversion of the current would reduce the momentum and produce eddies, thus retarding the flow and causing the suspended matter to become deposited in the form of scale; consequently, the introduction of bent tubes seemed to him to somewhat defeat the object aimed at.

If the heat could be equally as well applied to vertical tubes as to horizontal ones, then the more nearly vertical the tubes were the better the circulation, but as that application was somewhat difficult, some makers placed them on an incline, and so arranged as to provide for the greatest separation of steam. It was doubtful, however, if that provision was properly made in all cases. Where it was not there would be a tendency to form steam spaces, and if the tubes were abruptly curved, or placed too horizontal, when exposed to the hottest part of the fire, these steam spaces would undoubtedly form, and the tubes might be raised to a critical temperature, and dangerous oxidation set up. Such danger could only be prevented by perfect circulation, and that meant that the parts must be well designed and properly arranged to overcome such difficulties. He was quite prepared to admit that if the return tubes or down comers were of adequate area, the tendency would be to assist circulation; at the same time the fact could not be overlooked that if the tubes were placed in a somewhat horizontal direction, the escape of steam must be retarded, even in large tubes, and of course to a