PAPERS ON ENGINEERING SUBJECTS.

RECENT MODIFICATIONS IN BOILER DESIGN.

A modification to the design of Yarrow boilers has recently been adopted in some of H.M. Ships with a view to making the heating surface of such boilers more effective. This alteration has permitted a reduction in the total heating surface for a given power, that is in the number of tubes fitted in a given boiler.

A considerable saving in the weight of these boilers has resulted.

In order to make the reasons influencing the recent alterations more clear, the laws affecting the transmission of heat in a boiler should first be considered.

There are three methods of heat propagation by which heat is transmitted from the burning fuel to the water in boilers namely, conduction, convection, and radiation.

Conduction is the passage of heat from particle to particle of a body at rest, by direct contact. The quantity of heat (H) passing by conduction across a unit surface of a body in a unit of time depends on the conductivity of its substance, the difference of temperature between its cold and hot sides, and the thickness (x say) of the body, and may be expressed—

$$H = C\frac{(T - t)}{x}$$

where C is a constant for any given substance, in other words, its conductivity.

It is by conduction alone that heat is transmitted through the metal of a boiler tube.

Convection only occurs in gases and liquids, and may be described as the process by which heat is carried throughout the mass in virtue of the movement of the particles of the heated body. By its means the heat of the gases which are constantly being generated in the furnace is transferred to the boiler tubes.

The rate of diffusion of heat from the hot gases to the tubes of a boiler depends upon two factors, both of which are dependent upon the difference of temperature between the gas and the surface of the boiler tubes. The first factor expresses the effect of the natural diffusion of the gas, that is, the heat which would be given to a body containing the hot gas while at rest, and depends for any particular gas only upon the difference of temperature between the gas and the body receiving the heat.

The second factor depends, however, in addition to the temperature difference, upon the density and the velocity of the gas, and increases with them.

If H is the heat given up in a given time the relation is expressed by—

$$H = A\,(T - t) + B\,(T - t)\,w\,v$$

where A and B are constants, T and t the respective temperatures of the gas and the surface receiving heat, w the density, and v the velocity of the gas. With the gas velocities usual in boilers the first term in the equation is exceedingly small in comparison with the second term, and is not usually taken into account.

Thus, generally speaking, the higher the gas temperature and the higher the velocity of the gases in a boiler, the greater will be the amount of heat transmitted to the surfaces over which these hot gases pass.

Radiant heat is analogous to light in that heat can only be imparted from a radiant body in straight lines to surfaces which it can " see," so to speak, and the law of its transmission, known as Stefan's law, is expressed by—

$$H = C\,(T^4 - t^4)$$

in which H is the quantity of heat received by the cold body in a unit of time, and T and t are the absolute temperatures of the hot and cold body respectively. The formula, which presupposes that the receiving body totally surrounds the source of radiant heat, is evidently not closely applicable to calculations for practical boiler work, but it serves to give an idea of the influences affecting the transmission of heat by this method.

Considering now a water-tube boiler of the Yarrow or any other type used in the Service, it need hardly be said that those tubes adjacent to the furnace are most severely heat-stressed. Not only do they receive more heat by way of convection owing to the higher temperature of the gases to which they are exposed, but their exposure to the radiant heat of the burning fuel in the furnace and the glowing brickwork and furnace fittings, entails their receiving practically all the heat from this source, and in practice they transmit therefore to the water a very large proportion of the heat generated by the combustion of the fuel.

The degree of forcing to which water-tube boilers can be subjected depends—presupposing a satisfactory circulation of water in the boiler (which is of the utmost importance)—upon the temperature which the metal of the boiler tube can be allowed to attain without sensibly prejudicing its strength or causing its deterioration. In accordance with the laws of conduction the temperature of the gas and water sides of a boiler tube will be different, the difference depending in any case upon the amount of heat being received. The temperature on the water side of the tube will also be higher than the water contained in the tube, the difference being dependent upon the readiness with which the heat is passed on from the metal to the water as well as upon the heat it receives. Evidently, the greater the amount of heat received by a tube the more intense will be the evaporation inside and therefore the greater the amount of steam generated on the surface. Steam is inferior to water as a conductor of heat, and tubes receiving the greatest amount of heat consequently have greater difficulty in passing the heat on, and their temperature will be higher for both reasons.

We have seen that the fire rows of tubes will receive more heat than other rows in a boiler, and anything that can be done to reduce the disproportionate amount of heat received by the fire row tubes will add to the durability of the tubes or alternatively will allow, for the same degree of durability, the boiler to be more highly forced.

Examination of the available results of boiler experiments appears to show that the first fire rows of tubes in an oil-fired Yarrow boiler when run at the rates now usual in T.B.D.'s receives approximately 54 per cent., and the second fire row receives 13·5 per cent. of the total heat given up to the boiler, while the last row of tubes receives a very small amount. Of the heat received by each of the two fire-row tubes, it is estimated that 58 per cent. and 38 per cent. respectively is received as radiant heat.

It requires to be noted that the above estimates are partly based on observations of high gas temperatures, the accuracy of which is open to question by reason of the difficulty in obtaining reliable readings, especially in the presence of sources of radiant heat, and further some uncertainty that the readings so observed are representative of the mean gas temperature for the full length of the boiler. The figures given should consequently be taken as representing the probable order of the respective quantities of heat rather than precise values.

Fig. 1 shows the ordinary arrangement of fire-row tubes, and Fig. 2 shows a re-arrangement which has been designed with a view to diverting some of the heat ordinarily received by the fire-row tubes to tubes further in the tube nest, thus obtaining a better average absorption of heat in all the tubes in the boiler.

The heat received by the first fire-row tubes from the hot gases (as distinct from that received by radiation), employing the figures referred to above, is about 23 per cent. of the total heat received by the whole boiler. The heat transmitted in this way varies as the temperature difference, as the density of gas and as the velocity of the gas. If the velocity of the gases past the fire-row tubes is reduced, the quantity of heat given up should be less. In the re-arrangement of fire-row tubes, Fig. 2, it will be seen that the area for the flow of gases between successive fire-row tubes is appreciably increased in comparison with Fig. 1, and consequently the velocity of gases is reduced, and therefore the heat transmitted should be less since the temperature difference and the density should remain unchanged. Similarly, for the second row of fire-row tubes the area for flow of the furnace gases is increased, but not to the same extent as the first row, in view of a portion of the heat in the gases having already been given up to the latter. It has been estimated that the heat from this source given to each tube of the first fire rows in Fig. 1 should be about halved by the reduction in velocity of the gases passing the tubes resulting from the alteration in Fig. 2.

As regards radiant heat it will be noticed from Fig. 2 that five tubes now receive the direct rays that three tubes would have taken in the older arrangement, so that the total amount of radiant heat received by the *first* row of tubes will be much less than before, even though it is unlikely that the re-arrangement will lead to a sensibly different furnace temperature. It is probable, however, that each individual tube in the first fire row will receive more radiant heat than before, owing to the increased surface exposed, but it should be observed that owing to this increased surface the radiant heat striking any unit area of a tube will not be much altered. There is no obvious reason, therefore, why the metal at any point of a tube should be much more highly heat-stressed due to this cause than in the arrangement shown in Fig. 1.

On the whole, it has been considered the change in design may reasonably be expected to lead to each fire-row tube receiving less heat than before, and to improved durability as a result of their lower temperature.

The change would, however, necessarily be attended by a higher temperature of the gases at the fifth row of tubes if, as is expected, less heat is received by the fire rows, and consequently, were the same arrangement of the small tubes fitted as before, the gases would leave the boiler at a higher temperature, and this would, of course, lead to a reduced boiler efficiency. This effect would probably be small, as the last few rows of tubes only each deal with about 2·5 per cent. of the total heat supplied to the boiler, but it is somewhat accentuated by the fact that the extra space taken up by four rows of large tubes fitted in the new arrangement necessitates one row of small tubes being omitted when the standard sizes of steam and water drums are fitted.

The re-arrangement of small tubes shown in Fig. 3, which is fitted in conjunction with the arrangement of fire-row tubes in Fig. 2, has been designed with the object of improving the efficiency of this part of the heating system. As the furnace gases pass on through the tube system their temperature is reduced, and therefore their volume in proportion to their absolute temperature at any point. In the ordinary lay-out of tubes in the Yarrow boiler, the area for the flow of gases between the small tubes is constant until the baffle fitted over the last

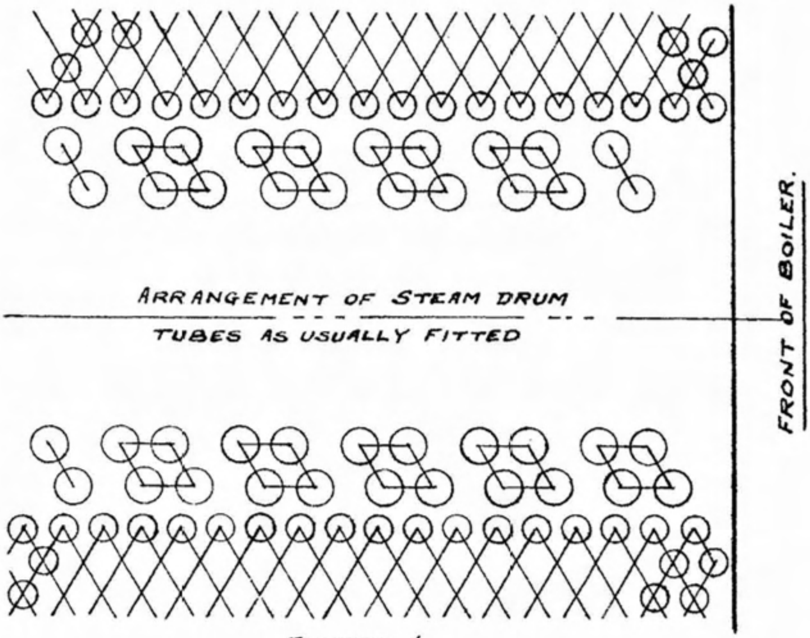

FIGURE 1.

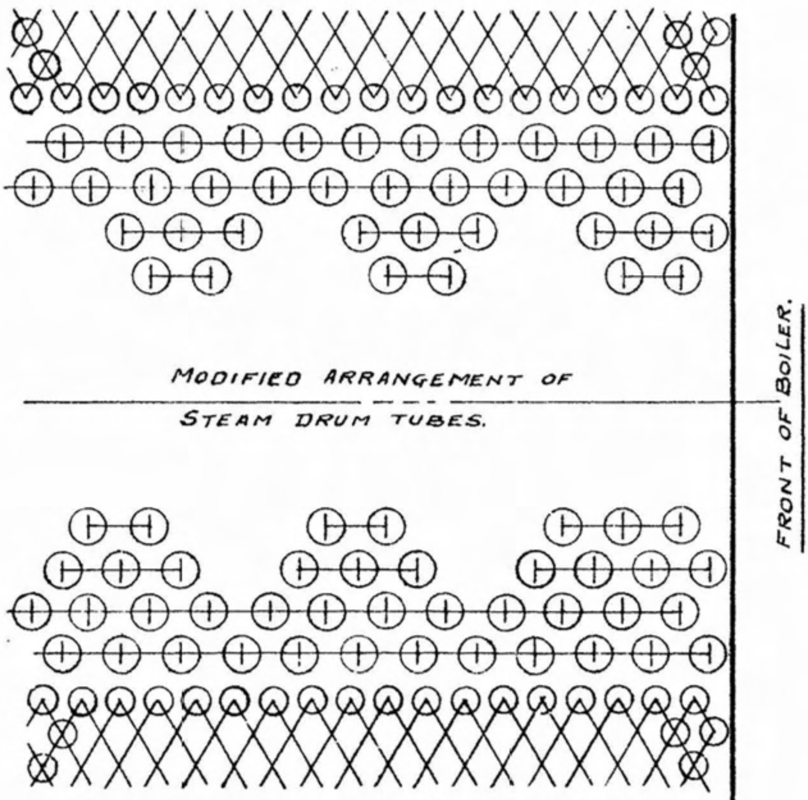

FIGURE 2.

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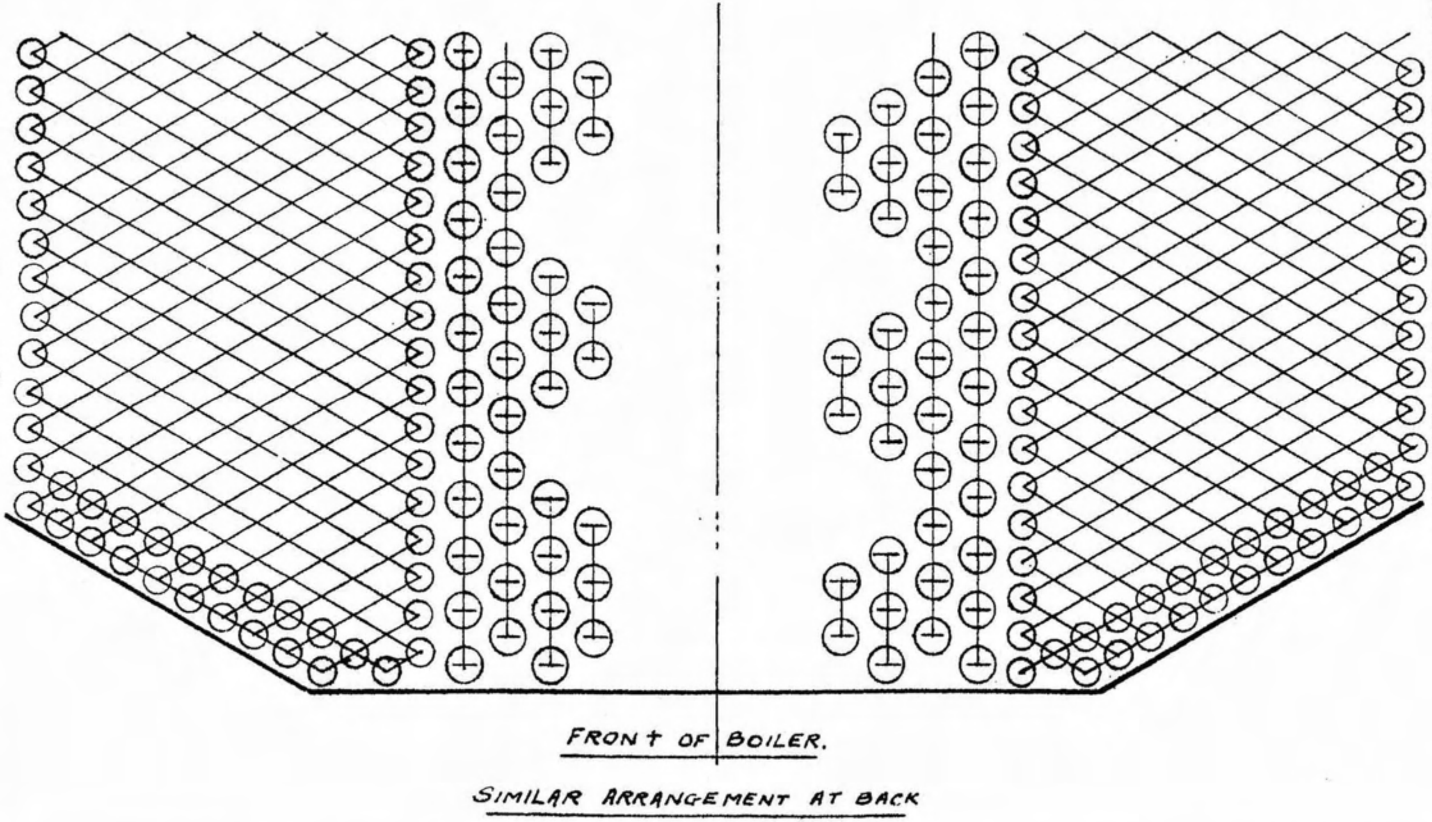
FIGURE 3



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row of tubes is reached, when it becomes much reduced. Therefore as the volume of the gases decrease the velocity decreases, and with it the rate of heat transmission, up to the last row on tubes where the velocity is again considerably increased by the baffle.

It is not possible in practical boiler design to provide entirely for the area for flow to be proportioned throughout to the changing volume of the gas. For one thing, an adequate provision has to be left in the cooler part of the tube system to give sufficient downcomer area, and further any very marked diminution in the areas would entail an increased air pressure, by reason of the increased resistance to flow, which might outweigh the improvement in efficiency resulting from the improved heat transmission.

In the arrangement shown in Fig. 3, commencing at the ninth row, one tube is omitted for each succeeding row, in effect cutting out the tubes at the outer corners of the tube nests, thus giving a successively decreasing area for flow which amounts at the last row to a reduction of 15 per cent. as compared with the eighth row. It is to be noted in passing, that the final area so obtained is greater than that realised by the baffle usually fitted on the last row of tubes, and in the new designs referred to the depth of the baffle is decreased, and so arranged that in conjunction with the reduced area already provided by the arrangement of tubes, an aggregate contraction of area of 30 per cent. is provided at the last tube row.

Both the alterations described involve a reduction in the heating surface of the boiler which aggregates about 15 per cent. of that fitted in the original arrangement, and leads to a reduction of about 5 per cent. of the weight of the boilers.

Some of the latest T.B.D.'s are fitted with this arrangement of tubes. In the circumstances obtaining it has not yet been possible to carry out boiler efficiency trials to demonstrate what is the precise effect on the efficiency entailed by the change in design, but, as far as can be judged from the usual contractors' trials, it appears that there is no noticeable practical difference in this respect. A final judgment on the durability of the design must, of course, be reserved pending extended experience on service.