mass depended entirely on variation of temperature in two parts of the liquid or gaseous body, and yet they were told by almost everyone who had written on the subject that feed heating improved the circulation.

This was claimed an economy and, as far as he could judge, the error arose from an assumption that the natural law was for heated gases or liquids to rise, whereas it was a fact that gravity acted with more effect on the colder, denser part of the mass, thus producing a downward displacing motion in this colder part, in the same way as the force of gravity acting on the heavier atmosphere caused the balloon, or lesser specific gravity, to be displaced upward.

But what must be the result of feed heating in boilers? The results must be twofold, first the stoppage of natural convection, and also a checking of wasteful and possibly harmful circulation. Assuming that the feed water was put into a boiler at water level, and comparatively cold, this water by a natural law, viz, that of gravitation, would immediately descend past the hotter, lighter water, displacing the latter and setting up an enhancement of the natural convection in much the same way as water in a pot was kept revolving by the impetus of a spoon. Now, if the feed water was heated, say, to boiling temperature, it simply mingled with the water in the boiler, and also checked, by its inertia, the circulation. Thus, feed heating must and did produce an economy—even though they used and returned the heat of live steam to do it—not by improving circulation, but by lessening convection and checking circulation, both, as has been shown, wasteful processes. He knew that much was made of the dangers arising from the want of circulation in boilers, mainly the tendency to internal stresses from variation of temperature, but the peculiar fact was that in marine and other internal-fired boilers the greater the circulation the less was the water affected below the surface tubes. What he meant was clearly shown on Plate IV., Fig. 5, where it would be seen that the currents did not affect the lower water at all, and all that was depend on to keep the bottom of the boiler warm was conduction, which would be necessarily much improved if the water were not circulating. Moreover, once the water was thoroughly warmed, the elasticity of the metal should be sufficient to take up the very small variation of expansion due to a range of temperature so small as, say, from 200 to 400, the widest possible range in boiler shells. Taking the usual co-efficient of expansion, ·000006 for a boiler shell under these conditions—and they are extreme—assuming a length of 12ft., the extension would be 1/5″ or ·14 %. When trouble had occurred it had in all probability been through want of circulation when warming up, the introduction of cold feed or vibration.

He had thus briefly tried to show that in a boiler they must depend on boiling rather than evaporation, that circulation was not essential for this, and that from any point of view circulation must be a loss of efficiency. He knew this was against the accepted creed, mainly because too much was made of precedence.

Summarising, therefore, he concluded they shall have in the boiler of the future less tendency to thin plates in heating surfaces, unless as a question of first cost—flat heating surfaces in preference to small curves in tubes—shallow water—no circulation, or as little as possible, and with boiler once warmed up (this having been accomplished either by the design or by feed heating), plenty of water level area, and as much reserve of boiler water as possible.

The primary difficulty in the above combination would be the extraction of the heat from the gases and the possibility of having sufficient heating surface area in limited space, but he felt sure that once these somewhat drastic conditions were accepted as essential—once the engineer was able to break away from conventionalism and fashion—these difficulties would soon be overcome. Moreover, it would become less difficult as the present crude method of using coal became extinct, for ultimately whereever steam generators were used they would be fired by mineral oil, or by coal gas of high calorific value highly compressed for transport, and our ships, instead of coal bunkers would be equipped with gas tanks, for, as the bye-products of gas manufacture become more and more valuable, it would pay better to burn gas (the extra cost of which had been compensated for in the bye-products) than coal.

DISCUSSION.

Mr. Shirra said that whilst there was much obscurity there was also much fascination about the subject of ebullition, but a great deal of that fascination was due to imagination. Even Lord Kelvin had raised physical science up to the point of poetry, so to speak.

As practical men, they would not get into a cylinder containing steam or vapour to watch the various processes going on. A good deal of knowledge had been discovered on the subject, yet a very great deal remained to be discovered. The author had referred to the mythical stories which the artistic imagination had thrown round Watt's domestic tea kettle as a steam raiser, with its great body of water and its large heating surface. He (the speaker) was of opinion that James Watt never thought about steam until he became a mathematical instrument maker in Glasgow College.

Every improvement in the progress of the steam engine had been the outcome of the experience and experiments of men who happened to have heads as well as hands. He was of opinion that the great point in ebullition was to introduce the feed water at the boiling point, thus increasing the mobility of the particles. There was a lot of confusion of thought on the subject of surface tension, ebullition, and evaporation.

The author had not explained the whole subject by simply giving it a name. A great point was made in the paper about the energy required to get up steam. But, after all, what was it? The combustion of 1lb. of coal (to 10lbs. of water) gave $7\frac{3}{4}$ million pounds of energy.

He was not going to say much about the author's ideal boiler, and his idea of explosive generation of steam; he really did not understand it. The author ought to know that before steam could be generated the water must be as quiet as possible. And, after all, what did "explosive" mean. It was a comparative word, and simply meant combustion.

The gas engine was an explosive engine to some extent, but there was no particular loss of energy because the power was raised suddenly. Explosive combustion, however, would quickly destroy the piston and piston rod, and the intense heating would burn the cylinder.

The question about feed-heating was the most interesting point in the author's paper. The effort of all engineers was to maintain circulation down to the very bottom of the boiler. This could be secured by keeping the ashpits as clean as possible so that the heat could strike the bottom of the furnace. He rather liked the peroration of the paper; the author had some very optimistic aspirations which he (the speaker) hoped would come to pass, especially his ideas with reference to mineral oil. He could not see why it should not be. If the author had done no more than draw their attention to what circulation really meant, he had done good work with his paper

Mr. Scoular said that some time ago he had made experiments in connection with the circulation of water in locomotive boilers. It was found that through the want of proper circulation, steam pockets were formed on the edge of the copper sheets of the fire boxes and in order to get out of the difficulty the water spaces had to be widened, and this method was in vogue in locomotive practice in New South Wales to-day. It was only another argument in favour of the circulation of water in boilers. He did not see how steam was going to be generated properly, and corrosion prevented, unless by proper water circulation.

Mr. A. J. Arnott said that the paper had, no doubt, been read with considerable interest by members, especially as many accepted theories had been assailed. The main question in the paper was whether circulation in a boiler added to or detracted from its efficiency. In the abstract one might say it did not increase the efficiency, but by a combination of circumtances, he thought, it could be proved that good circulation was essential to high efficiency, altogether distinct from the part circulation played in the transfer of heat. The author had referred to the ordinary kitchen kettle! If, in his experiments with this culinary apparatus, he had placed a smaller vessel in the kettle, with a hole at the bottom, so as to separate the upward and downward currents, he could have forced the fires to a much greater extent without causing the kettle to boil over, thereby evaporating the water at a higher rate, and preventing priming, a very common fault in shell boilers.

Again, rapid circulation must prevent, to a more or less degree, the accumulation of deposit on the inside of the heated plate or tube, and consequently remove a bad conductor which would otherwise prevent the water coming in contact with the iron plates or tube.

If fires had to be lit some five or six hours before steam was required, apart altogether from the consideration of undue strains, owing to unequal expansion, surely radiation and flue losses must be greater than in the case of a boiler in which, owing to its rapid circulation, steam could be raised in less than an hour.

The statement that the water-tube boiler had not been proved more efficient than the old-fashioned shell boiler he could not admit. Mr. Bryan Donkin, in his "Heat Efficiency of Steam Boilers," gave details of 405 tests of all kinds of boilers, and water-tube boilers were at the head of the list, with an efficiency of 77·4 per cent. According to the author, owing to the energy utilised in circulating the water, the water-tube boiler should have been at the bottom of the list.

Durability must be admitted as a great advantage in boilers when considering the commercial efficiency, and nothing tended more to durability than circulation by preventing unequal strains, owing to the temperature of the water being kept uniform.

With reference to the question of steam reserve, he desired to quote from Dr. Emery, in a discussion on Tubulous Boilers, before the Am. Society of Naval Engineers. He stated:—
"Contrary to our old ideas of large steam space, large disengaging
" surface and quiet ebullition, to prevent foaming, we can
" apparently obtain as good results in a boiler composed of
" long, narrow tubes."

Again, with reference to the question of heat reserve, it was well known that a shell boiler was not so suitable for working at high pressure as a water-tube boiler, for obvious reasons.

Comparing, therefore, a Lancashire boiler at 120lb. with a water-tube boiler at, say, 200lb. per square inch, and fitted with a reducing valve, and assuming that in both cases the steam was used at 110lb. pressure, the Lancashire boiler would contain about 21,500lb. of water, and the reserve of heat would be the difference between the total heat units in a lb. of steam at the maximum and minimum pressure multiplied by 21,500.

1lb. of steam at 120lb. = 1220·2 BTU.
1lb. of steam at 110lb. = 1218·4 BTU.

Difference ... ... 1·8 BTU.

Then the heat reserve was $21{,}500 \times 1{\cdot}8 = 38{,}700$ BTU.

The water-tube boiler at 200lb., reducing to 110lb., we would assume contained 12,400lb. of water.

1lb. of steam at 200lb. = 1232·0 BTU.
1lb. of steam at 110lb. = 1218·4 BTU.

Difference ... ... 13·6 BTU.

Thus the heat reserve was $12{,}400 \times 13{\cdot}6 = 168{,}640$ BTU, or 4·35 times as much heat reserve as in the case of the Lancashire boiler of equal evaporative capacity.

With reference to the difference between evaporation and ebullition, there was no doubt some; but there was a considerable difference between the rate of evaporation when at boiling temp. and below that temperature.

Surely the author's reference to the marine and other types of internally fired boilers only went to show the want of circulation in the section below the fire tubes. With a boiler designed to give perfect circulation there was no difference of temperature worth speaking about in any part of the boiler.

MR. FELL was of opinion that the more rapid the circulation the quicker the evaporation.

MR. MACARTNEY drew a diagram of a contrivance by which he had added to the efficiency and life of marine boilers he had had under his charge.

MR. BOULTON said he had seen an instance in an under fired boiler of the most perfect circulation. The boiler was erected on the bank of a river from which it was fed; consequently it had a considerable amount of silt pumped into it. After running some months it was opened and a bagful of stones, like cricket balls, found inside. That he considered was an instance of perfect circulation.

THE PRESIDENT said that the author had boldly attacked his subject in a way which threatened the undermining of many of the tenets of the engineering profession.

It was difficult to understand some of the ideas propounded in the paper, and he supported the views of previous speakers regarding the matter of circulation. He considered that question a far more important one than as merely affecting the amount of evaporation.

MR. STOWE, in reply, referred to Mr. Shirra's introduction of the "poetry business," and criticised the objections which had been made by him regarding the explosive theory. In reply to

Mr. Scoular, he said it could not be shown that the widening of the steam spaces really improved the circulation. With regard to silt, he maintained that the scale in a boiler was always thickest where the circulation was greatest. He did not think that Mr. Macartney's experiments were of any direct use in deciding the question of circulation.

The main thing was to get a large level and quiet water area. The subject was one worthy of deep consideration, and although in bringing it forward he had submitted himself to a good deal of criticism, yet, at the same time, he felt that his grounds for doing so were pretty safe.

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