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EBULLITION, CIRCULATION, AND EFFICIENCY OF STEAM BOILERS.

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OF all the problems relating to engineering science the most important, and perhaps the least understood, was that of heat, or, if he might be allowed to coin an expression, "Applied Heat." Heat was our useful force and was of far more importance to us than its compeer, electricity, for heat supplied us with all our power, directly or indirectly. It was because of the suitability of water as a means of using the expansive power of heat, that the steam engine became possible, and the boiler was the one part of steam plants that might, with advantage, be given a large amount of thought. Unfortunately the practical man could not get inside to see what was going on, hence much of the reasoning about boilers must be by analogy, and there was therefore not the same fascination about them that there was about a piece of mechanism wherein cause and effect were evident.

One of his earliest recollections was of Stephenson's little 'Rocket" standing in the South Kensington Museum, and he had often wondered why so little advance had been made in boiler design, for, with all the forms of boilers extant, the "Rocket" type remained with very little modification, probably the most efficient generator in modern practice, and he would try to show how many of the modern types of boilers failed to accomplish what was mainly aimed at in their construction, viz., efficiency.

Plate III., Fig. 1., illustrated, by common method, the great loss sustained in ordinary steam plants, converting heat into energy, from which it was evident that there was still great room for improvement in design. It was really the twenty-five per cent. reputed to be passing up the funnel as well as the five per cent. internal loss that it was possible to reduce by design in boiler construction. Of course something must be lost in inducing funnel draught, or should mechanical draught be substituted we still had an indirect loss, though not showing an actual boiler loss—this was one reason why locomotives with their heavy, exhaust steam, induced draught gave such a relatively high efficiency.

It was said eighty-six per cent. had been reached in efficiency tests, though we could not depend too much on figures, especially where evaporative trials were carried out without regard to actual work done by the engines, or of the wetness of the steam evaporated. A boiler might give an immense apparent evaporation, but there might be as much water leaving the boiler as there was steam, which would mean that the real efficiency was only half; thus it might be possible to show that a boiler was doing the maximum possible equivalent evaporation of about 15 lbs. of steam from and at 212° Fah., yet if the wetness of the steam were considered it might drop to 7 or 8 lbs.

It seems that no marked distinction was ever made by scientists between evaporation and ebullition; the latter he would designate boiling, yet on the difference depended many incorrect conclusions and theories which were used so forcibly by the designers of boilers (happily the name boiler was thoroughly appropriate), mainly with regard to the benefits derivable from the enormous circulation these boilers were capable of developing. He wished to make a very marked distinction. Evaporation, as he defined it, and wished to clearly distinguish it from boiling, was really the absorbtion of a liquid, by a gas when these two were brought in contact,and the amount of it would then depend on the surface area of contact and on the dryness of the absorbent gas, and might go on quite independent of temperature. The most important illustration of this was the great principle of atmospheric absorbtion, for thus was the sea water evaporated, without the water ever reaching its boiling point, and in addition to the resulting rain and dew, this humidity acted as a benign blanket, which, spread over the earth at night, prevented the diffusion of the accumulated heat of the sun; benign, for should this blanket be for one night removed and the air left thoroughly dry, there would not be left over most of the earth's surface a vestige of vegetable life, so intense would become the cold through reradiation.

In a boiler, evaporation might and did go on irrespective of boiling for any temperature; the water gave off vapor, filling the steam space, the steam becoming wetter and wetter, until the dew point was reached. The only real benefit derived from circulation, as he would presently show, was that in giving a larger water surface and broken water; there would thus be a slightly larger evaporation.

He must plead guilty to a descent to the domestic kitchen for much of his knowledge; but was not the humble kettle the inspiration of all our modern steam engines? It was really a pity it was not enshrined in every experimenter's laboratory, for its study in active use would teach one much that was useful in thermodynamics, perhaps even more so than the experiments with actual boilers. He had found that if water was placed in a vessel on a fire, particularly if the plates were thin, as the heat became intense enough to vaporise the water on the heating surface, a film of fine bubbles would form, they seeming to grow out of the plate, and the curious part of the phenomena was that, if one of these bubbles should escape, it seemed to melt away or dissolve before the surface was reached. He could not, for long, account for the persistence with which these bubbles stuck to the plate, but it was the escaping bubble which solved the problem. If the water, through which one of these bubbles had to pass, was any degree of temperature lower than was sufficient to maintain its contents as vapor, then the bubble became a condenser, and the vapor was condensed before the surface was reached. This was shown on Plate III., Fig. 2, as also how the bubbles actually diminished. Now, the bubbles on the heating surface were being continually augmented by the heat of the plate, but, the cooler water passing over them, they, too, each became a small boiler and condenser combined, vapor being continually formed at the bottom of the bubble to be recondensed by its top and sides. This was of very far reaching importance, and was, he believed, the reason for the formation of steam pockets, especially in boilers with rapid circulation and where the plates are very thin; for he had found that circulation did not necessarily sweep these pockets away; on the contrary, the water giving up its heat and being continually cooled by evaporation (that was by the escape of its vapor through the water surface or through the disturbed surface), and being unable to respond quickly to the variation of plate temperature, the results was a very dangerous condition—a condition in which we had a plate evaporating and the cooling water condensing, on the respective sides of a more or less extensive bubble, the combination resulting in a presistent steam pocket, as had been shown.

The influence or circulation on evaporation was shown on Plate III., Fig. 3, where it would be seen the water diminished the volume of the escaping bubble or maintained those on the heating surface at constant volume by abstracting some of the heat of the enclosed steam, some only of this heat being given up to surface evaporation. No boiling was entirely distinct and apart from evaporation and must be the main thing depended upon in generators for the supply of steam, because evaporation, as he had defined it, might become a danger, and under any circumstance it was practically no use, the quanitity of steam thus formed being so small. Boiling or ebullition was the sudden explosion of small molecules of water on the heating surface, as sufficient heat passed through the plates; thus, if we took a boiler under a pressure of 150 lbs. per sq. inch we should have an increase in volume from water to vapor of 170 times—that was, one cubic inch of water would become 170 cubic inches of steam, but the heat to produce this conversion was the latent heat of evaporation, which being applied suddenly to a certain volume of the water molecules, its action must of necessity be rather that of an explosive than that of an evaporate agent. This action was well shown by dropping water into hot oil, where the temperature of the oil was higher than the boiling point of the water—the drop of water seemed to hesitate for a moment then exploded with a loud report; the pause was that which was sufficient to raise the water to the boiling point and to a minute degree greater when the explosion occurred.

It might appear presumptious to criticise such men as Professors Reynolds and Perry, but he could not help thinking that the experiments of the former were far from applicable to steam generators. True, the passage of heat through a plate would depend on the difference in temperature between the two sides, and as long as they were taking the heat away as sensible heat, and the cooler the water was kept (by circulation or by any other method) the more heat would be passed through, and the more "scrubbing" the water did the better. But the conditions were ntirely different when they passed the heat through the plate, and converted it into an explosive on the other side.

His experiments with water at boiling point lead him to believe that the best effects were obtained with quiet water, for thus the heat was allowed to work its explosive effect to more purpose. He must confess it was not quite possible to explain it, but there was an instinctive feeling that it was so. He was not altogether certain either that this analogy was a good one. Suppose they had a hot plate and it were possible to move a piece of guncotton over it rapidly, it was conceivable that the guncotton might just absorb the heat but not explode it, whereas if the same explosive were pressed down on the plate the rapid passage of heat would produce an explosion. Similarly, if the water was allowed to lie quietly on the plate, the plate would form a reservoir of heat, gradually increasing in temperature till the critical boiling point was reached, then with a slight local increase above that point the explosion would occur, and the quieter the water was allowed to remain the better.

In observing water as it approached boiling point, he found that comparatively little convection went on, probably due to the condensation of the vapor bubbles as they escaped from the heating surface, this action seeming to check the previous tendency of the water to circulate (it was this fact that made it so difficult to warm up a boiler uniformly), but just as the water bursted into boiling a very violent circulation was commenced, and the magnitude of the energy required to keep up this motion must be very great. It seemed to be produced not so much by direct convection but by much of the explosive energy of the latent heat exhausting itself in giving motion to the water. If circulation was allowed, many of the bubbles formed would be at once recondensed. The heat was thus lost in this production of motion, or conversion of heat into Kinetic energy. The excessive disturbance of boiling was perhaps due more to inertia of the water than to the velocity of the circulation, for he found this was very much greater as the water was deeper.

A peculiar phenomenon, which was, he believed, first observed by Yarrow (and apparently a contradiction of a previous statement) was that when the water was boiling (that was of comparatively uniform temperature throughout) the bubbles as they rose enlarged, and from careful observation he concluded that this was due not so much to the lessening of hydraulic head as to the evaporative area offered by the internal surface of these bubbles as they ascended, for the water being hot enough to give off vapour, yet lacked the surface of escape thus offered. Moreover containing, as they must, very dry steam, they for this reason also became readily absorbent of vapor, the result being that the greater depth of water they rose from the larger they became.

This was shown on Plate IV., Fig. 4, wherein was also shown the ideal condition (quiet water). The influence of circulation was shown in Fig. 5.

It was surprising to him how much had been made of recent years of circulation, and how the fallacy of its benefits had lèd to the expenditure of thousands of pounds in design and construction of so-called water-tube and other boilers, yet without any of the improvements in efficiency one would naturally expect from their apparent advantages.

The great loss of efficiency arising from circulation was that it gave a ready medium of transfer and retransfer of heat; necessarily a wasteful process, for however much we might think of the scientific platitude about heat and work being mutually convertable, and however grandoise was the simile of the stone thrown into the water with the ever widening eddies going on for ever, yet, if the heat was a motion, its transfer from one part of a liquid body to another, or to the liquid body at all must be wasteful from the fact that we must first overcome the inertia of the water molecules.

Though it be a far cry from a locomotive to a molecule, his meaning would be more apparent if he illustrated what he meant by the starting of a locomotive. The energy lost (and he did say it advisedly) in starting the engine was a calculable quantity, being more as the speed was developed in a lesser time, and similarly was our heat lost in transfer, the faster the temperature was increased in the receiving body the more heat we lost.

Water was a bad conductor mainly because of the inertia of its molecules, and circulation and convection were simply the reception of heat from the heating surface, and the transfer of this heat partly to other molecules of water, but largely, of course, to the escaping steam of evaporation at the surface, the water being thereby cooled, to descend and again receive heat from the heating surface. This transfer must be a wasteful process, and might be entirely avoided by stopping or checking circulation, for all that was really necessary in a boiler was that, as the bubbles of vapor were formed by explosion on the heating surface, sufficient depth of water should exist to ensure a steady water pressure, and to keep the plates covered with water.

The question of a large or small volume of water in a boiler was of great importance, and apart from the question of rapid steam raising we had the more important question of steam reserve, and—he said it unreservedly—that the modern water-tube boiler, and any boiler wherein the quantity of water was small, was an entire mistake in this respect, for, given the one condition of large evaporative surface to prevent priming, a large volume of still water was by far the most scientific, efficient and reliable steam reserve. For if we had a large body of water, say, at a temperature of 379° Fah., the normal pressure would be 195 lbs. absolute, and if a sudden call for power reduced the pressure, say, 5 lbs. per square inch, the boiling temperature would be 377° Fah., with the result that, independent of furnace temperature, this body of water being 2° above the normal boiling point would immediately commence boiling and, giving off a quantity of steam, would thus maintain the supply until the furnaces were able to respond.

In the above case 1000 lbs. of water would give off $2\frac{1}{2}$ lbs. weight of steam or 5·4 cubic feet before the boiling ceased. The action was shown on Plate IV., Fig. 7. This would mean that a boiler containing 1000 cubic feet of water under the above condition of pressure and temperature would on a reduction of 5 lbs. in pressure give off, roughly, 337 cubic feet of steam without any further heat being applied. Hence, it would be seen what an enormous benefit the marine type of boiler contained in its large volume of water.

It was an elementary principle in physics that convection, so-called, or the natural movements of gases or liquids within the