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Steam Boilers

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The design of the steam boiler is a problem in construction which involves much more than the mere application of chemical and physical principles and the calculation of grate areas and heating surfaces.

The first step in solving the problem is the choice of type of boiler. That best adapted for the special case is determined by the conditions of location and purpose; as whether stationary, portable or locomotive; by the pressure and quantity of steam demanded by the facilities for repairing; by the character of the feed water, and the cost of obtaining it.

The principal types of stationary boilers are the plain cylindrical, the cornish, and the tubular. The plain cylindrical boiler consists of a cylindrical shell with plain or domed heads. This type is chosen wherethe cost of fuel is low, and the character of the feed water is bad. The objections to the use of these boilers are many; for example, liability to explosions, the small amount of heating surface in proportion to the grate surface, and therefore the considerable waste of fuel in heating the water, also the poor circulation of the water, which causes unequal heating and therefore great strains, resulting often in ruption of the shell.

The cornish boiler consists of a plain, cylindrical shell through which extends a large flue with a diameter of about one-half that of the outer shell. These boilers are not common in this country but are in general use in Great Britain.

The tubular boiler is the one most used here. This type is divided into two classes; the water-tube, often called the sectional boiler, and the fire-tube. The latter is made up of a cylindrical shell with fifty or sixty tubes extending from head to head, through which the smoke and heated gases must pass t o the chimney. The water-tube boiler consists of many small tubes connected with a large cylinder, which serves as a steam space.

In this type the hot gases pass around among the tubes and not through them as in the fire-tube boiler.

Water-tubes and fire-tubes have their own special advantages and disadvantages, and these vary in importance in the different classes of these boilers. It has been demonstrated that the water-tube boiler is more economical than the fire-tube, and excels in the perfection of its circulation, and the readiness with which it can be freed from incrustation. On the other hand, the cost of the fire-tube is much less than the water-tube of the same power.

Water-tubes are always set either vertically or steeply inclined; for if they are horizontal, they are liable to rapid destruction, because of the defective water circulation. The fire-tube may be used in any position; but is usually placed horizontally.

The general experience of engineers has been such as to lead them to adopt the Water-tube in the safety class of boilers and the fire-tube in all others. For it has been demonstrated that it is practicallyimpossible to burst the water-tube boiler, so as to occasion destruction to life and property.

In the safety boilers the water tubes are usually set at an angle of thirty degrees with the horizontal.

As constructed by the best known builders, the water tube is expected to do about twenty per cent more work than the fire-tube of the same area. The water-tube is much safer than the fire-tube; since the water level can be carried a considerable distance below the top of the tube without endangering it, while low water in the fire-tube is alwaysdangerous

The marine fire tubular boiler has now almost universally been brought to a very definate standard of form and proportion. It consists of a cylindrical shell with plain heads traversed with large flues and small tubes, the furnaces being in the flues.

Those designed for sea-going steamers are made very large and very heavy boiler plate to withstand the great pressures which often exceed ten atmospheres, or one hundred fifty pounds per square inch. In ordinary practice, the heating surface of these boilers is from thirty to forty times the grate surface. The evaporation ranges from eight to eleven pounds per pound of good coal consumed; i. e. every pound of coal consumed converts eight to eleven pounds of water into steam providing the water is at 212 degrees to begin with.

The design of the water-tube boiler involves but little calculation of strength, as the tubes and connections are always much stronger than is absolutely necessary for a mere matter of supporting the steam pressure. Some special precautions however are demanded in designing this type of boiler to avoid serious difficulties which may arise from the comparatively small amount of water and steam carried by it. This type should also be so constructed that all joints shall be kept out of the fire, the furnace tubes should not be exposed unnecessarily to sudden draughts of cold air; cold feed water should never be delivered directly into the furnace tubes, ample space should be provided for both steam and water, to prevent the water being thrown out on the sudden opening of a steam or safety valve; also great care should be exercised to provide against the flame taking a short cut to the chimney and impinging against the tubes containing only steam, and lastly the tubes should be placed at such an angle with the fire grate as to secure the best possible circulation. This last is the most important point in the designing of steam boilers; for incrustation, rupture of the pipes and shell caused by unequal heat, explosions and priming are often due to faulty circulation.

In order to secure good circulation various types of boilers have been designed but the one that has so far met this requirement is the common water tube or sectional boiler. Perhaps the circulation will be made clearer by the aid of these drawings.

This drawing is a sketch of an ordinary kettle in which the circulation is the same as in a plain cylindrical boiler. Now on the application of heat to this class of vessels, currents are immediately started; and the tendency seems to be for them to rise next the walls of the vessel and to descend in the center. These currents are indicated by means of the arrows; but as the water becomes warmer and more heat is applied, ascending currents start in the center of the vessel, and on meeting the descending one a commotion is immediately started, which is commonly known as boiling. Now water boils in an plain cylindrical boiler just as it does in an ordinary kettle, only the agitation is a great deal more violent and the water is thrown much higher into the space reserved for steam, because of the great pressure and heat to which the water is subjected.

This diagram represents a cross section of a fi re-tube boiler. The small circles are cross sections of the tubes through which the hot gases pass to the chimney. Now, heat can be applied to this class of boilers much more uniformly than to the plain-cylindrical because the water receives heat both from the shell and the numerous tubes extending through it. The currents in this class of boilers do not have anyfixed path; but their tendency seems to be to rise vertically among the tubes and descend next the walls of the vessel. These currents are indicated by means of the arrows, showing the general direction which the currents have among the tubes.

The last sketch represents a longitudinal section of a system of glass tubes, the plan of which is the same as that of a water tube boiler. In this class of boilers, the heat must always be applied at the part marked,G. This rule is imperative; for if the heat were applied at the point marked,F, a part of the water would ascend through E, while the rest would ascend through the tubes marked A and the circulation would be as complex as in the other types of boilers. But when heat is applied at the end G, there aan be but one current which must pass up through the tube C. The circulation is indicated by means of the arrows, and one can readily see that it is perfect.

The efficiency of a steam boiler is measured by the ratio, in common and definate terms, of a result produced to the cost of its production.

This efficiency may be defined as the ratio of the total quantity of heat utilized in the production of work to that set free in the combustion of the fuel. It has as the maximum limit unity, and is a function of area of heating surface, and of factors depending upon the character of the fuel and its combustion; and also upon the design of the boiler. The commercial efficiency is measured by the cost of steam per pound or per cubic foot at the required pressure. This efficiency is a maximum; the cost is a minimum.

It often happens that the engineer designing a boiler finds himself called upon to determine the efficiency that it will be economical to secure, and then to calculate the proportions necessary to secure that efficiency, or, he may know the proportions of a boiler already built, and be required to estimate the quantity of steam which will be generated per pound of coal consumed. In solving this problem, a simple formula deduced by Rankine is often used. It assumes that fuel of a known calorific value is used. The formula is as follows;

$$E' = \frac{BE}{1 + \frac{ay}{\delta}},$$

in which E is the theoretical evaporative power of the fuel per pound, E' the actual; for example in a boiler in which F is the weight of fuel burned on the unit of area of the grate surface, and S is the unit of heating surface per unit of the same area, A and B are coefficients of the heat which is utilized. The lowest and best values of A are obtained when using a minimum needed air supply. The value of B depends upon the character of the boiler, being greater as the design and construction are improved.

The commercial efficiency may be classed under two heads.

I. The cost of operation which is dependent upon the quantity of steam made and the kind and amount of fuel consumed.

II. The cost of the boiler and its maintenance, which depends upon the the size and the character of the boiler itself and its attachments.

The explosions of steam boilers are among the worst of the many kinds of accidents. They have increased in frequency with increasing steam pressures, until to-day the amount of available energy stored in some boilers is sufficient to raise it 1000 or 2000 feet into the air, the fluid having a total energy pound for pound comparable only with that of gun powder.

The rupture of a boiler is due to the expansive force common at the moment to the steam and water, both being at a temperature higher than the boiling point. As soon as the steam escapes and thus diminishes the compressive force upon the water, a new issue of steam takes place from the water and thereby reduces its temperature. When this escapes and further diminishes the compressive force a third issue of steam of a lower elastic force takes place, reducing the temperature still more; and so on until the water has reached a temperature of 212 degrees. Thus it is to the enormous quantity of steam which is produced from the water in so short a space of time, that the destructive effect of steam-boiler explosions is due. The action of the steam which may happen to be in the boiler at the moment of rupture is considered unimportant.

The causes of steam-boiler explosions are many. Among the most common are incrustation, low water, defective circulation, the admission of cold feed water, the dissolving of the plate resulting from the impurities in the water, and lastly a greater pressure than the boiler was designed for. Incrustation is due to the impurities in the water, and so great care should be exercised to keep the boiler clean. The water tube boiler is often preferred for the reason that in it there is a receptacle to receive all the sediment. Low water is generally the result of ignorance or carelessness on the part of the attendant.

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