FURNACE DESIGN

Good efficiency and proper boiler performance are dependent on correct furnace design embodying sufficient volume for burning the particular fuel at hand, for permitting of thorough mixing of air and gases, for permitting a velocity low enough to allow sufficient time for combustion to take place and for permitting the maintenance of a sufficiently high temperature to produce combustion.

Proper and efficient combustion depends on a furnace volume so designed as to permit sufficient time for proper mixing and one that can at the same time be maintained at a temperature high enough to produce complete burning of all of the volatile gases. If the air and products of combustion do not thoroughly mix, stratification is likely to develop. In the burning of liquid or powdered fuel, the air should be so introduced as to set up a turbulent action in order that the small atomized particles may be entirely surrounded with air for supporting combustion.

Combustion must take place before the gases are cooled by the boiler heating surface, and the volume of the furnace must be sufficient for this purpose. The brick-set boiler is particularly convenient in this respect since almost any desired furnace volume may be obtained. The furnace temperature must be maintained sufficiently high to produce complete combustion, thus resulting in a higher CO_2 content and the absence of CO. Hydrocarbon gases ignite at temperatures varying from 1000 to 1500 F. A higher unburned gas content will result from a furnace having a small combustion space than from one having a large combustion space. The efficiency obtained from the large combustion space will therefore be higher. For further information on furnace design, see p. 280.

BOILER HEATING SURFACE

Boiler heating surface essentially is that surface which is exposed to fire or hot gases of combustion on one side and water or steam on the other side. In fire-tube and water-tube boilers most of the heating surface is in the tubes.

In horizontal return tubular boilers the bottom half of the shell and heads up to point where the setting corbels in, is effective heating surface. Likewise in a water-tube boiler the bottom side of the shell and the inner side of the tube headers provide active heating surface.

In the past, a heating surface area of 10 to 12 sq ft was required per boiler horsepower, based on the observation that the rate of evaporation of water at the most economical fuel consumption was about 3 lb of water per square foot of boiler heating surface. In modern boiler design, rates of evaporation from 4½ to 6 lb of water are practical with a small loss in economy which is justified by the reduction in investment in boilers and boiler space. Such rates of evaporation are, of course, only possible with boilers set with adequate furnace volume to permit complete combustion, and with means for directing the gas passage so that all heating surface is contacted. Adequate provision for the burning of the fuel and for the draft necessary to support combustion, are also required.

BOILER OUTPUT

The output of a *power* boiler is stated in terms of *boiler horsepower*. A boiler horsepower (*A.S.M.E.* standard) is equal to the evaporation of 34.5 lb of water per hour *from and at 212 F;* that is, a boiler receiving the feed water at 212 F must furnish the necessary heat to generate 34.5 lb of steam at this temperature and atmospheric pressure from water at the same temperature and pressure per hour. In other words, the boiler must supply the latent heat of vaporization (971.7 Btu) to each pound of water to develop steam at atmospheric pressure (14.7 lb per square inch, absolute) or it must furnish 971.7 × 34.5 = 33,523.7 Btu per hour to the water per boiler horsepower. Therefore, one boiler horsepower = 33,523.7 Btu per hour. The horsepower developed by a boiler in operation is determined by first finding the Btu received per hour by the water and steam from the boiler and dividing this quantity by the Btu equivalent of one boiler horsepower.

The output of *heating* boilers is usually stated in terms of *Btu per hour* or equivalent heating surface (radiation). Since one square foot of equivalent heating surface (steam) has an emission of 240 Btu per hour, a boiler horsepower is equal to about 140 sq ft of equivalent steam heating surface. It is common practice to allow one boiler horsepower for each 100 sq ft of equivalent steam heating surface (radiation), the additional 40 sq ft being intended to provide for secondary losses from mains, risers and returns.

EQUIVALENT EVAPORATION

It is customary to reduce the actual evaporation of a boiler to a standard set of conditions in order to make comparisons. This standard is the amount of water that would have been evaporated into dry steam *from and at 212 F* for the same heat expenditure. In practice, the feed water is usually below this temperature and the evaporation actually takes place at some higher temperature than 212 F. Hence, to find the rate of equivalent evaporation it is necessary to make use of the following relation:

$$E = FP \tag{1}$$

The *factor of evaporation* (F) is the ratio of the heat required to generate one pound of steam for the given condition (at the boiler pressure and temperature and feed-water temperature) to the amount of heat required to generate one pound of dry steam *from and at 212 F*. Therefore:

$$F = \frac{h_w + xh_{fg} - h_f}{971.7} \text{ (for wet steam)} \tag{2}$$

$$= \frac{h - h_f}{971.7} \text{ (for dry steam)} \tag{3}$$

$$= \frac{h + c\,(t_s - t)}{971.7} \text{ (for superheated steam)} \tag{4}$$

where

c = mean specific heat of superheated steam for the given range of temperature and pressure.
E = equivalent evaporation *from and at 212 F* in pounds per pound of fuel burned.
F = factor of evaporation.