METHOD OF ASCERTAINING WHAT PORTION OF THE FEED-WATER ADMITTED TO A BOILER IS ENTRAINED IN THE FORM OF SPRAY BY THE ESCAPING STEAM.

By Chief Engineer ISHERWOOD, U. S. Navy.

In making tests of the evaporative efficiency of boilers, it is desirable to know what fraction of the feed-water admitted to the boiler during an experiment is vaporized, and what fraction in the form of spray is mingled with and entrained by the steam.

This problem is very difficult to solve correctly, requiring costly apparatus; precise measurements of large quantities of water; thermometers absolutely accurate, for a very slight error in the temperatures would be equivalent to a very considerable error in the two fractions of the feed-water to be ascertained; and boilers perfectly free of leakage under the pressure employed.

The apparatus needed is a tank for the measurement of the feed-water previous to admission in the boiler; a condenser, in which all the steam generated in the boiler is condensed, and the temperature of the resulting water together with that of the water entrained in the form of spray, is reduced to the temperature of the feed-water; and a tank for the measurement of the condensing water previous to its use in the condenser. The condenser and the steam-pipe connecting it with the boiler, are to be covered with felt or other non-conducting substance, and placed in a temperature midway between that of the steam and that of the condensing water after use, as any heat lost or received by the steam and entrained water after leaving the boiler, would vitiate the results. Placing the condenser and steam-pipe in a temperature midway between that of the steam entering and that of the condensing water leaving the condenser, neutralizes, as nearly as possible, the effect of external temperature; and clothing them, additionally, with a non-conducting substance, reduces this effect to a minimum.

The pressure under which the generation and condensation of the steam take place must be identical, and the initial temperature of the feed-water must also be identical with the final temperature of the condensing water, in order to eliminate the transformation of heat into work which would otherwise be caused by the displacement of different pressures, due to the difference of bulks resulting from the difference of temperatures.

The principle of the investigation is simply a comparison of the quantity of heat that would have been imparted to the feed-water in the boiler, had all the feed-water been vaporized, with the quantity of heat (experimentally ascertained) imparted to the condensing water by the condensation of the steam and the reduction of the temperature of the resulting water, together with that of any water which may have been entrained in the form of spray, to the initial temperature of the feed-water.

Let w be the weight of feed-water admitted to the boiler ;

t^0 , the temperature of the feed-water ;

t^1 , the temperature of the steam ; and

h , the heat of vaporization above the temperature t^0 . Also,

let W be the weight of condensing water used ;

T^0 , the temperature of the condensing water before use ; and

T^1 , the temperature of the condensing water after use. Finally,

let w be the weight of feed-water in the form of spray, having the temperature t^0 entrained by the steam ; then

$w - w$ is the weight of feed-water vaporized.

$$\text{And } (w - w) \times h + w \times (t^1 - t^0) = W \times (T^1 - T^0).$$

$W \times (T^1 - T^0)$ represents the total quantity of heat, experimentally ascertained, imparted to the feed-water in the boiler, which quantity is composed of the unknown quantity $(w - w) \times h$, consumed in vaporizing the weight $w - w$ of feed-water, and of the unknown quantity $w \times (t^1 - t^0)$, consumed in raising the temperature of the weight w of feed-water from t^0 to t^1 . The determination of the values of w and of $w - w$ in fractions of w is the object of the following process.

The specific heat of the water is supposed to be constant at all its temperatures, which is not quite true ; the correction, however, would be so insignificant that it has been omitted, to avoid unnecessary complication. It can be easily made, if required, by simply multiplying the weights of water at the different temperatures by the respective specific heats and taking the products as the weights in place of the original weights of water.

It is obvious that the quantity $W \times (T^1 - T^0)$, as experimentally found, will equal $w \times h$ in the case in which all the feed-water is vaporized. It can never be greater than $w \times h$, but may easily be

less by the entrainment of part of the feed-water with the steam, and less in proportion as the quantity so entrained is greater. This results from the fact that the heat of vaporization of a given weight of feed-water is much greater than that which is required to raise its temperature from t° to t^1 .

In the single case in which the temperature of the feed-water is the same as that of the steam entraining a portion of it in the form of spray, the fraction vaporized of the feed-water is the fraction which the experimental quantity $W \times (T^1 - T^0)$ is of the quantity $w \times h$; that is, this fraction will be the quotient of $\frac{W \times (T^1 - T^0)}{w \times h}$, the remaining fraction of the feed-water having been entrained in the form of spray, but, not having had any heat imparted to it in the boiler, does not enter as a factor in the computation. For example: Suppose the temperature t° of the feed-water and t^1 of the steam to be 212° Fahrenheit; the heat h of vaporization, 965.7 Fahrenheit units; the weight w of the feed-water admitted to the boiler, 1 pound; the weight W of condensing water, 5 pounds; the temperature T^0 of the condensing water before use, 50° Fahrenheit; and its temperature T^1 after use, 212° Fahrenheit. Then $\frac{5 \times (212^\circ - 50^\circ)}{1 \times 965.7} = 0.83877$ = the fraction vaporized of the feed water, while the fraction entrained in the form of spray by the steam is $(1.00000 - 0.83877 =) 0.16123$.

But in all other cases of the entrainment of feed-water, in which its temperature is less than that of the steam, the experimental quantity of heat $W \times (T^1 - T^0)$ is composed of two unknown quantities $w \times (t^1 - t^\circ)$ and $(w - w^1) \times h$, the first being the quantity of heat imparted to the entrained water, and the last being the quantity of heat imparted to the vaporized water. Hence, considering the entire weight w of feed-water admitted to the boiler as unity,

$$\frac{(w \times h) - W \times (T^1 - T^0)}{h - (t^1 - t^\circ)} = w^1 = \text{the fraction of the entire feed-}$$

water admitted to the boiler, which has been entrained in the form of spray by the steam. Consequently, $w - w^1 = 1 - w^1$ = the fraction of the entire feed-water admitted to the boiler, which has been vaporized.

From the above formula may be derived the following rule for ascertaining the proposed results: From the quantity of heat which would have been imparted to the feed-water admitted to the boiler, had it *all* been vaporized, deduct the quantity of heat which was imparted as experimentally given by the increased temperature of the weight of condensing water used, and divide the remainder by the latent heat of the steam; the quotient will be the portion, in terms of the unit of weight employed, of the feed-water entrained in the form of spray by the steam. The subtraction of this quotient from the weight of feed-water admitted to the boiler gives the portion, in terms of the unit of weight employed, of the feed-water vaporized.

The above formula is based on the following reasoning: $w \times h$ is the quantity of heat that would have been imparted to the feed-water had it all been vaporized. $W \times (T^1 - T^0)$ is the quantity of heat that was imparted to the feed-water as experimentally ascertained. The latter quantity subtracted from the former leaves the quantity of heat due to the non-vaporization of a portion of the feed-water, which had been heated, however, to the temperature of the steam. The division of this remainder by the latent heat of the steam gives the weight of water, in terms of the unit employed, which was not vaporized, and which, consequently, was entrained in the form of spray by the escaping steam. The expression $h - (t^1 - t^0)$ is the latent heat of the steam. The following is a numerical application of the formula:

Suppose, for example, the entire weight w of feed-water admitted to the boiler to be 1 pound; the heat h of vaporization above the temperature t^0 of the feed-water to be 1078·5 Fahrenheit units; the weight W of the condensing water to be 19·637 pounds; the temperature T^0 of the condensing water before use to be 50° Fahrenheit; and its temperature T^1 after use to be 100° Fahrenheit; the temperature t^0 of feed-water to be 100° Fahrenheit; and the temperature t^1 of the steam to be 212° Fahrenheit. Then

$$\frac{(1 \times 1078.5) - 19.637 \times (100^\circ - 50^\circ)}{1078.5 - (212^\circ - 100^\circ)} = 0.1 = \text{the fraction of the entire feed-water admitted to the boiler which has been entrained in the form of spray by the escaping steam.}$$

Consequently $1 - 0.1 = 0.9$ = the fraction of the entire feed-water admitted to the boiler which has been vaporized.