a *heat balance*. Various components of this balance are generally expressed in terms of Btu per pound of fuel burned, or as a percentage of its calorific value. Components of special interest are listed as items 1 to 7 inclusive.

1. Useful heat transferred to heating medium, usually computed by determining the rate of flow of the heating fluid through the heating device, and the change in enthalpy of the fluid (heat added) between the inlet and outlet.

2. Heat loss in the dry chimney gases.

$$h_1 = w_g c_p (t_g - t_a) \tag{12}$$

3. Heat loss in water vapor formed by the combustion of hydrogen.

$$h_2 = \frac{9H_2}{100} (1091.8 + 0.455 (t_g - t_a) \tag{13}$$

4. Heat loss in water vapor in the air supplied for combustion.

$$h_3 = 0.455\, M\, w_a (t_g - t_a) \tag{14}$$

5. Heat loss from incomplete combustion.

$$h_4 = 10143\, C \left(\frac{CO}{CO_2 + CO} \right) \tag{15}$$

6. Heat loss from unburned carbon in the ash or refuse.

$$h_5 = 14600^* \left(\frac{C_u}{100} - C \right) \tag{16}$$

7. Radiation and all other unaccounted for losses.

Radiation and convection losses from a heating appliance are not usually determined by direct measurement. For this reason they, together with any other losses not measured, are determined by subtracting the total of items 1 to 6 from the heat of combustion of the fuel. If the heating appliance is located within the heated space, however, radiation and convection losses may be considered as useful heat rather than lost heat. They may, therefore, be omitted from calculations of heat losses, or added to item 1. If there is *CO* in the flue gases, small amounts of unburned hydrogen and hydrocarbons will probably also be present. The small loses due to incomplete combustion of these latter gases would also be included in item 7.

Symbols used in Equations 12 to 16 inclusive are:

h_1 = heat loss in the dry chimney gases, Btu per pound of fuel.
h_2 = heat loss in water vapor from combustion of hydrogen, Btu per pound of fuel.
h_3 = heat loss in water vapor in combustion air, Btu per pound of fuel.
h_4 = heat loss from incomplete combustion of carbon, Btu per pound of fuel.
h_5 = heat loss from unburned carbon in the ash, Btu per pound of fuel.
w_g = weight of dry flue gas per pound of fuel (from Equation 10), pounds.
c_p = mean specific heat of flue gases at constant pressure (c_p ranges from 0.242 to 0.254 for flue gas temperatures from 300 F to 1000 F)[2], Btu per pound.
t_g = temperature of flue gases at exit of heating device, Fahrenheit.
t_a = temperature of combustion air, Fahrenheit.
H_2 = percentage of hydrogen in fuel by weight from ultimate analysis of fuel burned.
1091.8 = enthalpy of saturated water vapor at a temperature of 70 F, Btu per pound.
M = humidity ratio of combustion air, pounds of water vapor per pound of dry air.

* A value of 14600 applies in calculating ash pit loss; in calculating heat of formation of carbon compounds use 14093 Btu per lb.

w_a = weight of combustion air per pound of fuel used, pounds, from Equations 2, 4, 5, 6, 7 and 8.
CO, CO_2 = percentages of CO, CO_2 in flue gases by volume.
C = weight of carbon burned per pound of fuel corrected for carbon in ash, pounds.

$$C = \frac{WC_u - W_a C_a}{100\, W} \tag{17}$$

where

C_u = percentage of carbon in the fuel by weight from the ultimate analysis.
W_a = weight of ash and refuse, pounds.
C_a = percent of combustible in ash by weight (combustible in ash is usually considered to be carbon).
W = weight of fuel used, pounds.

Flue gas losses for solid and liquid fuels, listed as items 2, 3 and 4 of the heat balance, may be determined with sufficient precision for most purposes from curves shown in Fig. 6[2], if CO_2 content and temperature of flue gases are known. Values of the losses plotted for fuel oil were computed from the ultimate analysis of a typical fuel oil used in domestic burners, while those presented for the several ranks of coal were computed from the typical ultimate analyses shown in Table 1. The curves for medium volatile bituminous coal may be used for high volatile bituminous coal with negligible error.

Utilization of gaseous fuels, for numerous reasons, is generally a more simple process than is the case with either solid or liquid fuels. Accordingly, the determination of a practical heat balance is also a more simple procedure in that items 5 and 6 do not generally apply to gas installations. A series of typical alignment charts has been combined in Fig. 7 for use in determining flue losses of items 2, 3 and 4 from common types of gas burning appliances. To determine flue losses place a straight edge extending from the corrected temperature reading to the percent CO_2 recorded. Percent flue loss is indicated where the straight edge interesects the flue loss column. The operating efficiency of a gas appliance can then be computed with sufficient precision by application of Equation 18.

$$\text{Percent Combustion Efficiency} = \frac{\left(\begin{matrix}\text{Gross Btu of fuel} \\ \text{gas per cubic foot}\end{matrix}\right) - \left(\begin{matrix}\text{total flue losses per} \\ \text{cubic foot fuel gas)}\end{matrix}\right)}{\text{Gross Btu of fuel gas per cubic foot}} \times 100 \tag{18}$$

Reference to Table 9 will show that ultimate CO_2 percentage values of fuel gases vary. While personal errors involved in CO_2, temperature, and chart determinations, would doubtless more than offset any inaccuracies due to universal use of the alignment charts shown, precise laboratory work may require a more exact method. For more complete information the reader is referred to *Combustion*, 3rd Edition, and *Gaseous Fuels*, (published by *American Gas Association*) and particularly to tables covering various properties of different commercial gases included in these publications.

CONDENSATION AND CORROSION

Sulfur dioxide or sulfur trioxide, formed by the combustion of sulfur in fuels, are the principal corroding substances in flue gases. They become active whenever sufficient moisture is present for the formation of sulfurous or sulfuric acid,[22] and they lower the dew points of flue gases appreciably.