Representative values of CO_2 for complete combustion of several fuels are given in Table 8.

To produce heat efficiently with any of the common fuels, the following requirements must be observed: (1) adequate heat absorbing surface is necessary; (2) the heat transfer surfaces must be clean; (3) a minimum of excess air should be used; (4) the combustion air and the combustible gases produced by the fuel must be well mixed; and (5) the quantity of combustible gases escaping to the stack must be kept small.

If insufficient heating surface is provided in a heating appliance, or if the heat transfer surfaces are covered with soot, ash or scale, the flue gas temperature will be excessive, and the amount of sensible heat passing up the stack will be unnecessarily large. Too much excess air dilutes the flue gases excessively and increases the sensible flue gas loss, while a deficiency of air will cause some combustible gases to pass out of the appliance unburned. The highest combustion efficiency is not always obtained by supplying enough excess air to reduce the incomplete combustion loss to zero, but the incomplete combustion loss should be kept small. If the secondary air is not well mixed with the combustible gases, some incomplete combustion may still occur. Unnecessary secondary air also dilutes the flue gases, and increases the sensible heat escaping up the chimney. Some excess air is always required in the practical operation of heating plants. It is considered good practice, under usual operating conditions, to supply from 25 to 50 percent excess air, depending upon the fuel used.

HEAT BALANCE

In analyzing the performance of a heating appliance, it is frequently desirable to make an accounting, insofar as possible, of the disposition of all the heat units in the fuel used. Such an accounting is sometimes called a *heat balance*. The several components of the heat balance may be expressed either in terms of Btu per pound of fuel used, or as a percentage of the calorific value of the fuel. The components of the heat balance are listed in items 1 to 7.

1. Useful heat transferred to heating medium and usually evaluated 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.**

$$h_1 = w_g c_p (t_g - t_a) \quad (11)$$

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

$$h_2 = \frac{9H_2}{100}(1091.8 + 0.455 (t_g - t_a)) \quad (12)$$

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

$$h_3 = 0.455\, M\, w_a (t_g - t_a) \quad (13)$$

5. **Heat loss from incomplete combustion.**

$$h_4 = 10143\, C\left(\frac{CO}{CO_2 + CO}\right) \quad (14)$$

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

$$h_5 = 14600^{*}\left(\frac{C_u}{100} - C\right) \quad (15)$$

7. **Radiation and all other unaccounted for losses.**

Since the radiation and convection losses from a heating appliance are not usually determined by direct measurement, they, together with any other losses not measured, are determined by subtracting the total of items 1 to 6, inclusive, from the heat of combustion of the fuel. Frequently, when there is CO in the flue gases, there also will be small amounts of unburned hydrogen and hydrocarbon gases in the products of combustion. The loss represented by these unburned gases may easily be as large as that resulting from the presence of carbon monoxide. In this event, item 7 of the heat balance would also include this unmeasured loss.

Symbols used in Equations 11 to 15 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 6), 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 degrees.
t_a = temperature of combustion air, Fahrenheit degrees.
H_2 = percentage of hydrogen in fuel by weight from ultimate analysis of fuel as fired.
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.
w_a = weight of combustion air per pound of fuel used, pounds, from Equations 1, 2, 8, and 9.
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.

$$C = \frac{WC_u - W_a C_a}{100\,W} \quad (16)$$

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.

The flue gas losses listed as items 2, 3, and 4 of the heat balance may be determined with considerable accuracy from the curves shown in Fig. 1[2] in many cases. The 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 plotted 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. Fig. 2 may be used to determine the flue losses when burning manufactured or natural gases.

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