

Since the calculation is usually made from Orsat analysis, Equation 9 will be found to be a convenient statement of this relationship.

$$\text{Per cent excess air} = \frac{100 \left(O_2 - \frac{CO}{2} \right)}{N_2 \times 0.264 - \left(O_2 - \frac{CO}{2} \right)} \quad (9)$$

In this formula the symbols represent volumetric percentages of the flue gas constituents as determined by analysis.

Due to the different carbon-hydrogen ratios of the different fuels the maximum CO_2 attainable varies. Representative values for complete combustion of several fuels are given in Table 9.

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.
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 per cent 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

TABLE 9. REPRESENTATIVE MAXIMUM CO_2 VALUE

FUEL	THEORETICAL CO_2	CO_2 USUALLY ATTAINED IN PRACTICE
Coke	21.00	12-14
Anthracite	20.20	12-14
Bituminous Coal	18.20	13
No. 2 Fuel Oil	15.00	10.5
No. 6 Fuel Oil	16.50	13.5
Natural Gas	12.00	9.7
Coke Oven Gas	11.00	8.5

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 either be expressed 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.

$$h_1 = w_g c_p (t_g - t_a) \quad (10)$$

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

$$h_2 = \frac{9H_2}{100} (1091.8 + 0.455 t_g - t_a) \quad (11)$$

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

$$h_3 = 0.455 M w_a (t_g - t_a) \quad (12)$$

5. Heat loss from incomplete combustion.

$$h_4 = 10143 C \left(\frac{CO}{CO_2 + CO} \right) \quad (13)$$

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

$$h_5 = 14093 \left(\frac{C_u}{100} - C \right) \quad (14)$$

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 10 to 14 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), 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.