in the literature and the details of Orsat manipulation need not be considered in this discussion. (See Chapter 11.)

The weight of dry flue gas per pound of fuel burned is used in combustion loss calculations and may be determined by Equation 6.

$$\text{Pounds dry flue gas per pound fuel} = \frac{11\ CO_2 + 8\ O_2 + 7\ (CO + N_2)}{3\ (CO_2 + CO)} \times C \qquad (6)$$

Values for CO_2, O_2, CO, and N_2 are percentages by volume from the flue gas analysis and C is the weight of carbon burned per pound of fuel corrected for carbon in the ash.

EXCESS AIR

Since one measure of the efficiency of combustion is the relation existing between the amount of air theoretically required for *perfect* combustion and the amount of air actually supplied, a method of determining the latter factor is of value. Equation 7 will give reasonably accurate results, for most solid and liquid fuels, for determining the amount of air supplied per pound of fuel.

$$\text{Pounds dry air supplied per pound of fuel} = \frac{3.04\ N_2}{(CO_2 + CO)} \times C \qquad (7)$$

Values for CO_2, CO, and N are percentages by volume from the flue gas analysis and C is the weight of carbon burned per pound of fuel corrected for carbon in the ash.

The difference between the air actually supplied for combustion and the theoretical air required is known as excess air.

$$\text{Per cent excess air} = \frac{\text{Air supplied} - \text{Theoretical air}}{\text{Theoretical air}} \qquad (8)$$

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

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

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.

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

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 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.

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

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

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

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

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

5. Heat loss from incomplete combustion.

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

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

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