

this is what is ordinarily meant when the heating value of a fuel is specified. In burning the fuel, however, the products of combustion are not cooled to the dew-point and the higher heating value cannot be utilized.

When combustion is complete, the carbon in the fuel unites with oxygen to form carbon dioxide, CO_2 , the hydrogen unites with oxygen to form water vapor, H_2O , and the nitrogen, being inert, passes through the reaction without change. When combustion is incomplete, some of the carbon may unite with oxygen to form carbon monoxide, CO , and some of the hydrogen and hydrocarbon gases may not be burned at all. When carbon monoxide or other combustible gases are present in the flue gases, there is a loss of heat produced per unit of fuel consumed, and a lower combustion efficiency is obtained. Incomplete combustion may result from any or all of the following three conditions: (1) inadequate air supply; (2) insufficient mixing of air and gases; and (3) a temperature too low to produce ignition or maintain combustion.

AIR REQUIRED FOR COMBUSTION

The weight of air required for perfect combustion of a pound of fuel may be determined by use of the ultimate analysis of the fuel as applied to Equations 1 and 2. The various elements are expressed in percentages by weight.

Solid and Liquid Fuels:

$$\text{Pounds air required per pound fuel} = 34.56 \left[\frac{C}{3} + \left(H - \frac{O}{8} \right) + \frac{S}{8} \right] \quad (1)$$

For Gaseous Fuels:

$$\begin{aligned} \text{Pounds air required per pound fuel} = & 2.47 CO + 34.34 H_2 + 17.27 CH_4 + 16.12 \\ & C_2H_6 + 15.70 C_3H_8 + 15.49 C_4H_{10} + 13.30 C_2H_2 + 14.81 C_2H_4 + 6.10 H_2S - 4.32 O_2 \end{aligned} \quad (2)$$

When the analysis is given on a volumetric basis the equation is expressed as follows:

$$\begin{aligned} \text{Cubic feet air required per cubic foot gas} = & 2.39 (CO + H_2) + 9.53 CH_4 + \\ & 16.68 C_2H_6 + 23.82 C_3H_8 + 30.97 C_4H_{10} + 11.91 C_2H_2 + 14.29 C_2H_4 + \\ & 7.15 H_2S - 4.78 O_2 \end{aligned} \quad (3)$$

Equations 4 and 5 may be used as approximate methods of determining the theoretical air requirement for any fuel.

$$\text{Pounds air required per pound fuel} = 0.755 \times (\text{Btu per pound}) \div 1000 \quad (4)$$

$$\text{Cubic feet air required per unit fuel} = (\text{Btu per unit}) \div 100 \quad (5)$$

Approximate values for the theoretical air required for different fuels are:

1. *Solid Fuel* (Pounds air per pound fuel). Anthracite, 9.6; Semi-Bituminous, 11.2; Bituminous 10.3; Lignite 6.2; and Coke 11.2.
2. *Fuel Oil* (Pounds air per gallon): Commercial Standard No. 1, 102.6; No. 2, 105.5; No. 5, 112; No. 6, 114.2.
3. *Gaseous Fuel* (Cubic feet of air per cubic foot): Natural, 10.0; Mixed Natural and Manufactured, 8.0; Manufactured, 5.2; Butane, 31.0; Propane, 23.8.

It is customary to make use of the analysis of the products of combustion to determine the amount of flue gas produced and the actual amount of air supplied for combustion. The analysis of flue gases has been well described in various publications of the *U. S. Bureau of Mines* and in the literature, and the details of Orsat manipulation need not be considered in this discussion. (See Chapter 49.)

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

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

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 has reasonable precision, for most solid and liquid fuels, for determining the amount of air supplied per pound of fuel.

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

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. See Equation 8 in which the symbols represent volumetric percentages of the flue gas constituents as determined by analysis.

$$\text{Percent excess air} = \left(\frac{\text{Air supplied} - \text{Theoretical air}}{\text{Theoretical air}} \right) \times 100 \quad (8)$$

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

$$\text{Percent excess air} = \frac{100 (O_2 - CO/2)}{N_2 \times 0.264 - (O_2 - CO/2)} \quad (9)$$

Due to the different carbon-hydrogen ratios of the different fuels, the maximum CO_2 attainable varies. The theoretical maximum CO_2 attainable may be calculated from the flue gas analysis by the use of Equation 10.

$$\text{Maximum theoretical \% } CO_2 = \frac{\% CO_2 \text{ in flue gas sample} \times 100}{100 - \left(\frac{O_2 \text{ in same sample}}{0.21} \right)} \quad (10)$$

TABLE 8. 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