combustion are not cooled to the dew-point and the higher calorific value cannot be obtained.

FLAME

The appearance of the flame or products of combustion may serve as an approximate measure of the temperatures developed in the combustion process. The luminosity of a flame is caused by the heating to incandescence of unconsumed particles of combustible matter in the gases and the higher the temperature of these particles the whiter the flame. Table 2 gives some approximate flame temperature data.

AIR AND COMBUSTION

The weight of air required for the perfect combustion of a pound of fuel may be determined by use of the ultimate analysis of the fuel as applied to Formulae 3 to 5. The various elements are expressed in percentages by weight.

TABLE 2. FLAME TEMPERATURE DATA

APPEARANCE OF FLAME	TEMPERATURE DEG F
Red, visible in daylight	975
Light red	1832
Orange-red	2012
Orange-yellow	2192
Yellow-white	2372
Bright white	2550

Solid and Liquid Fuels:

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

Gaseous Fuels:

$$\text{Pounds air required per pound fuel} = 2.46\ CO + 34.56\ H_2 + 17.28\ CH_4 + 13.29\ C_2H_2 + 14.81\ C_2H_4 + 16.13\ C_2H_6 + 6.10\ H_2S - 4.32\ O_2 \qquad (4)$$

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

$$\text{Cubic feet air required per cubic foot gas} = 2.39\ (CO + H_2) + 9.56\ CH_4 + 11.98\ C_2H_2 + 14.35\ C_2H_4 + 16.74\ C_2H_6 - 4.78\ O_2 \qquad (5)$$

Formulae 6 and 7 may be used as approximate methods of determining the theoretical air requirement for any fuel.

$$\text{Pounds air required per pound fuel} = 0.755 \times \frac{\text{Calorific value (Btu per pound)}}{1000} \qquad (6)$$

$$\text{Cubic feet air required per unit fuel} = \frac{\text{Calorific value (Btu per unit)}}{100} \qquad (7)$$

Approximate values for the theoretical air required for different fuels are given in Table 3.

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 *Bureau of Mines* and in the literature and the details of Orsat manipulation need not be considered in this discussion. (See Chapter 45.)

The weight of dry flue gas per pound of fuel burned is used in combustion loss calculations and may be determined by Formula 8.

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

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.

TABLE 3. THEORETICAL AIR REQUIREMENTS

SOLID FUEL	POUNDS AIR PER POUND FUEL
Anthracite	9.6
Semi-bituminous coal	11.2
Bituminous coal	10.3
Lignite	6.2
Coke	11.2
FUEL OIL	**POUNDS AIR PER GALLON FUEL**
Commercial Standard No. 1	102.6
Commercial Standard No. 2	104.5
Commercial Standard No. 3	106.5
Commercial Standard No. 5	112.0
Commercial Standard No. 6	114.2
GASEOUS FUELS	**CUBIC FEET AIR PER CUBIC FOOT GAS**
Natural gas	10.0
Mixed, natural and water gas	4.4
Carbureted water gas	4.4
Water gas, coke	2.1
Coke oven gas	5.2

EXCESS AIR

Because the real 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. Formula 9 will give reasonably accurate results, for most solid and liquid fuels, for determining the amount of air supplied per pound of fuel.

$$\text{Pounds dry air supplied per pound of fuel} = \frac{3.036\ N_2}{(CO_2 + CO)} \times C \qquad (9)$$

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.