tion efficiency is not always obtained when sufficient excess air is supplied to eliminate incomplete combustion entirely, because the air supply must not only be adequate but also be properly mixed with the combustible gases. Even with appliances connected to an effective flue every reasonable precaution should be taken to insure as complete combustion as possible at all times. This is of vital importance in unvented equipment such as a gas space heater, for example. It is considered good practice to supply from 20 to 50 percent excess air, the exact amount depending on the kind of fuel burned and especially on the type of equipment in which it is utilized.

Flue Gas Analysis

As radiation, convection, and conduction losses from common types of central heating appliances are largely employed in heating occupied spaces, flue gas losses logically become the item of principal concern. Another reason for their importance is the fact that they are usually larger than all other heat losses combined. These important considerations and others indicate not only the desirability but absolute necessity of a reasonably accurate method for determining flue losses if it is desired to compute even approximate operating efficiencies.

Customary procedure in arriving at flue gas losses is to make an analysis of a representative sample of flue gases and to measure their temperature. This information will enable the observer to compute the amount of flue gases produced, the excess air, the actual quantity of air supplied for combustion, and the flue losses. While the analysis of flue gases has been well described in several governmental and other scientific publications, the subject is of such importance that it warrants brief repetition here. Carbon dioxide and oxygen content are of principal interest in determining flue losses. Either or both of these values may be employed in such calculations. While the former constituent is probably most commonly employed, special considerations may make the latter of greater interest. Fortunately, both can be determined readily by use of an Orsat gas analysis apparatus, a device of reasonably simple construction and design. For field testing and burner adjustment, simple portable devices are available for determining carbon dioxide only. See Chapter 52 for details regarding the operation of the Orsat apparatus.

The weight of dry flue gas per pound of fuel burned is widely used in combustion loss calculations. For solid fuels this item may be determined by application of Equation 10.

$$\text{Pounds dry flue gas per pound fuel} = \frac{11\,CO_2 + 8\,O_2 + 7\,(CO + N_2)}{3\,(CO_2 + CO)} \times C \qquad (10)$$

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.

Total dry gas volumes of flue gases resulting from the combustion of one cubic foot of gaseous fuels for various percentages of CO_2 may be determined by application of Equation 11:

$$\text{Cubic feet dry flue gases per cubic foot fuel gas} = \frac{\text{Cubic feet } CO_2 \text{ produced per cubic foot of gas burned} \times 100}{\text{Percent } CO_2 \text{ by analysis.}} \qquad (11)$$

After obtaining the quantity of flue gases from Equations 10 or 11, the excess air quantity may be determined by subtracting the quantity of dry flue gases which would result from perfect combustion. Computations of flue losses are described in the next section on Heat Balance.

Application of the preceding equations and tables are illustrated by *Examples 1* and *2*.

Example 1: The analysis of the flue gases resulting from the burning of a natural gas is 10.0 percent CO_2, 3.1 percent O_2, and 86.9 percent N_2 by volume. The analysis of the fuel is 90 percent CH_4, 5 percent N_2, and 5 percent C_2H_6 by volume. Find U the maximum theoretical percent CO_2 and the percent excess air.

Solution: From Equation 9:

$$U = \frac{(10.0)(100)}{100 - \left(\frac{3.1}{0.21}\right)} = 11.8\%\ CO_2$$

From Equation 8,

$$\text{Percent Excess Air} = \frac{(11.8 - 10.0) \times 90}{10} = 16.2$$

Example 2: For the analyses in *Example* 1 find, per cubic foot of fuel gas, the cubic feet of dry air required for combustion, the cubic feet of each constituent in the flue gases, and the total volume of dry and wet flue gases.

Solution: From Equation 3 (or Table 7) the volume of dry air required for combustion is: $(9.53)\ (CH_4) + (16.68)(C_2H_6) = 9.53 \times 0.90 + 16.68 \times 0.05 = 9.41$ cu ft/cu. ft gas.

From Table 7, the constituents per cubic foot of gas are:

Nitrogen, N_2:

From methane = $(0.9\ CH_4)(9.53 - 2.0) = 6.78$
From ethane = $(0.05\ C_2H_6)(16.68 - 3.0) = 0.68$
Nitrogen in fuel = 0.05
Nitrogen in excess air = $0.791 \times .162 \times 9.41 = 1.20$

Total Nitrogen 8.71 cu ft

Oxygen, O_2:
Oxygen in excess air = $0.209 \times .162 \times 9.41 = 0.32$ cu ft

Carbon dioxide, CO_2:
From methane = $(0.9\ CH_4)(1.0) = 0.90$
From ethane = $(0.05\ C_2H_6)(4.0/2.0) = 0.10$

Total Carbon Dioxide 1.00 cu ft

Water vapor, H_2O (does not appear in Orsat analysis):
$(0.9\ CH_4)(2.0) = 1.8$
$(0.05\ C_2H_6)(6.0/2.0) = .15$

Total water vapor = 1.95 cu ft

Total volume of dry gas per cubic foot of gas:

$$8.71 + 0.32 + 1.00 = 10.03 \text{ cu ft}$$

Total volume of wet gases per cubic foot of gas (neglecting water vapor in combustion air):

$$10.03 + 1.95 = 11.98 \text{ cu ft}$$

The cubic feet of dry flue gas per cubic foot of fuel gas may also be computed from Equation II as follows:

$$\frac{(1.00)\ (100)}{10.0} = 10.0 \text{ cu ft}$$

HEAT BALANCE

The usual practice in analyzing the performance of heating appliances is to make an accounting, insofar as possible, of the disposition of all heat units available in the quantity of fuel burned. This accounting is called