The relationship of the air supplied, as determined from the previous formula, to the theoretical air required indicates the per cent of excess air supplied.

A formula that may be used to determine directly the per cent of *excess air* is expressed:

$$\text{Per cent excess air} = \frac{100\left(O_2 - \frac{CO}{2}\right)}{N_2 \times 0.264 - \left(O_2 - \frac{CO}{2}\right)} \qquad (10)$$

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

The amount of excess air in its relation to the percentage of CO_2 is shown by the curves in Fig. 1 for several fuels. These are approximate values. It should be noted that in hand-fired furnaces with long periods between firings the combustion goes through a cycle in each period and the quantity of excess air present varies.

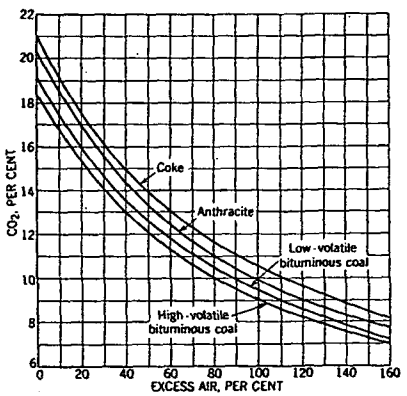

FIG. 1. RELATION BETWEEN CO_2 AND EXCESS AIR IN GASES OF COMBUSTION

Due to the different carbon-hydrogen ratios of the different fuels the maximum CO_2 attainable varies. Representative values for perfect combustion of several fuels are given in Table 4.

In considering the factor of excess air it should be noted that a deficiency of air supply will result in combustible products passing to the stack unburned. An excess of air absorbs heat from the products of combustion and results in a greater loss of sensible heat to the stack. An excess of air is usually required, however, to eliminate combustible losses occasioned by poor mixing of the fuel and air. It is considered good practice, under usual operating conditions, to supply from 25 to 50 per cent excess air, dependent upon the fuel utilized.

SECONDARY AIR

When a solid fuel is hand-fired in a furnace the volatile matter in the fuel distills off leaving coke on the grate. The product of combustion of

the coke is CO_2 and under certain conditions some CO may arise from the bed. The combustion of the volatile matter and the CO may amount to the liberation of from 40 to 60 per cent of the heat in the fuel in the combustion space over the fuel bed.

The air that passes through the fuel bed is called *primary air* and the air that is admitted over the fuel bed in order to burn the volatile matter and CO is called secondary air.

TABLE 4. MAXIMUM CO_2 VALUES

FUEL	PER CENT CO_2
Coke	21.0
Anthracite	20.2
Bituminous coal	18.2
Oil	15.5
Natural gas	11.5
Coke oven gas	9.25

This process of combustion is illustrated in Fig. 2[2]. The free oxygen of the air passes through the grate and the ash above it and burns the carbon in the lower three or four inches of the fuel bed forming carbon dioxide. This layer noted as the oxidizing zone is indicated by the symbols CO_2 and O_2. Some of the carbon dioxide of the oxidizing zone is reduced to carbon monoxide in the upper layer of the fuel bed noted as the reducing zone and indicated by the symbols CO_2 and CO. The gases leaving the fuel

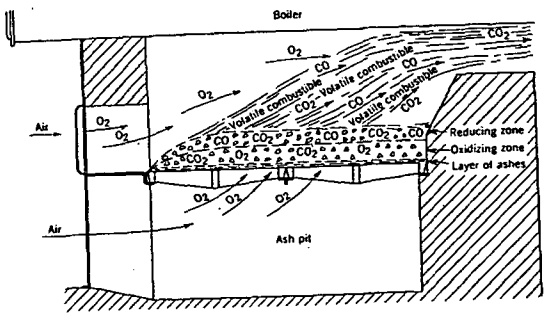

FIG. 2. COMBUSTION OF FUEL IN A HAND-FIRED FURNACE

bed are mainly carbon monoxide, carbon dioxide, nitrogen and very little free oxygen. Free oxygen is admitted through the firing door to burn carbon monoxide and the volatile combustible distilled from the freshly fired fuel.

The division of the total into primary and secondary air necessary to produce the same rate of burning and the same excess air depends on a number of factors which include size of fuel, depth of fuel bed, and size of firepot. The ratio of the secondary to the primary air increases with

[2]From *Bureau of Mines Technical Paper* No. 80.