T_c = temperature of flue gas, Fahrenheit, absolute.

W = flue gas flow rate, pounds per second.

f = coefficient of friction.

L = length of friction duct (approximately equal to H), feet.

D = minimum diameter of round chimney, feet.

x and y = length and width of cross-section of rectangular chimney, feet.

The following notes facilitate the use of Equations 3 and 4:

1. The *barometric pressure*, represented by B_o, is the actual pressure at the site of the chimney and not the pressure reduced to sea level datum.

In general, the barometric pressure decreases approximately 0.1 in. Hg per 100 ft increase in elevation.

2. The *unit weight of a cubic foot* of chimney gases at 0 F and sea level barometric pressure is given by the equation:

$$W_c = 0.131CO_2 + 0.095O_2 + 0.083N_2 \qquad (5)$$

In this equation CO_2, O_2 and N_2 represent the percentages of the parts by volume of the carbon dioxide, oxygen and nitrogen content, respectively, of the gas analysis. For ordinary operating conditions, the value of W_c may be assumed at 0.09.

The density effect on the chimney gases, due to superheated water vapor resulting from moisture and hydrogen in the fuel, or due to any air infiltration in the chimney proper, is disregarded. Though water vapor content is not disclosed by Orsat analysis, its presence tends to reduce the actual weight per cubic foot of chimney gases.

3. The *atmospheric temperature* is the actual observed temperature of the outside air at the time the analysis of the operating chimney is made. The mean atmospheric temperature in the temperate zone is approximately 62 F.

4. The *chimney gas temperature* decreases from the breeching connection to the top of the stack. This drop in temperature depends upon the material and construction of the stack, its tightness or freedom from leaks, its area, its height, and the velocity of the gases through it. The same chimney will suffer different temperature losses depending upon the capacity under which it is working, and the variable atmospheric conditions. No general equation covering all these variables has been suggested, but from observations on chimneys varying in diameter from 3 to 16 ft, and in height from 100 to 250 ft, Equation 6 was deduced:[2]

$$T_c = \frac{3.13T_1\left[\left(\frac{H_b}{3}\right)^{0.96} - 1\right]}{H_b - 3} \qquad (6)$$

where

T_1 = temperature at the center of the connection from the breeching, Fahrenheit degrees, absolute.

H_b = the height of the stack above center line connection to breeching, feet.

5. The *coefficient of friction* between the chimney gases and a sooted surface has been taken by many workers in this field as a constant value of 0.016 for the conditions involved. This value, of course, would be less for a new unlined steel stack than for a brick or brick-lined chimney, but in time the inside surface of all chimneys, regardless of the materials of construction, becomes covered with a layer of soot, and thus the coefficient of friction has been taken the same for all types of chimneys and generally constant for all conditions of operation. For reasons of simplicity and convenience to the reader, this constant value of 0.016 has been employed in the development of the various special equations and charts shown in this chapter.

In important large chimney design, especially when the construction or the materials are unusual, it is recommended that use be made of the Reynolds number[3] in determining the friction factor, f.

The following problem illustrates the use of Equation 3:

Example 1: Determine the available draft of a natural draft chimney 200 ft in height and 10 ft in diameter, operating under the following conditions: atmospheric temperature, 62 F; chimney gas temperature, 500 F; sea level atmospheric pressure, B_o = 29.92 in. Hg; atmospheric and chimney gas density, 0.0863 and 0.09, respectively; coefficient of friction, 0.016; length of friction duct, 200 ft. The chimney discharges 100 lb of gases per second.

Solution: Substituting these values in Equation 3 and reducing,

$$D_a = 2.96 \times 200 \times 29.92 \times \left(\frac{0.0863}{522} - \frac{0.09}{960}\right) - \frac{0.00126 \times 100^2 \times 960 \times 0.016 \times 200}{10^5 \times 29.92 \times 0.09}$$

$$= 1.27 - 0.14 = 1.13 \text{ in.}$$

Fig. 2 shows the variation in the available draft of a typical 200 ft by 10 ft chimney operating under the general conditions noted in *Example 1*. When the chimney is under static conditions and no gases are flowing, the available draft is equal to 1.27 in. of water, the theoretical intensity. As

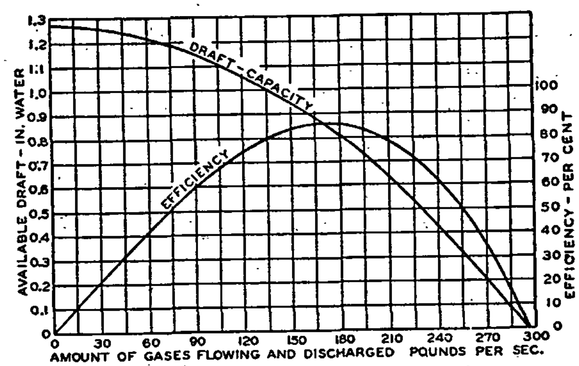

FIG. 2. TYPICAL SET OF OPERATING CHARACTERISTICS OF A NATURAL DRAFT CHIMNEY

the amount of gases flowing increases, the available draft decreases until it becomes zero at a gas flow of 297 lb per second, at which point the draft loss, due to friction, is equal to the theoretical intensity. The point of maximum draft and zero capacity is called shut-off draft, or point of impending delivery, and corresponds to the point of shut-off head of a centrifugal pump. The point of zero draft and maximum capacity is called the wide open point, and corresponds to the wide open point of a centrifugal pump. A set of operating characteristics may be developed for any size chimney operating under any set of conditions by substituting the proper values in Equation 3, and then plotting the results in the manner shown in Fig. 2.

Fig. 3 is a typical chimney performance chart giving the available draft for various gas flow rates and sizes of chimney. This chart is based on an atmospheric temperature of 62 F, a chimney gas temperature of 500 F, a unit chimney gas weight of 0.09 lb per cu ft, sea level atmospheric pressure, a coefficient of friction of 0.016, and a friction duct length equal to the height of the chimney above the grate level. These curves may be used for general operating conditions. For specific conditions, a new chart may be prepared from Equations 2 or 4.