can be dropped from the foregoing illustration. The manometer reading will be the same if its free connection is left open to the atmosphere.

These considerations in conjunction with those of barometric pressure and the difference in density of flue gases from that of air lead to the following formula:

$$D_t = 2.96\ HB_o\left(\frac{W_o}{T_o} - \frac{W_c}{T_c}\right) \tag{1}$$

where

H = height of chimney, feet.
B_o = existing barometric pressure, inches of mercury.
W_o = density of air at 0 F and 1 atmosphere pressure, pounds per cubic foot.
W_c = density of flue gas at 0 F and 1 atmosphere pressure, pounds per cubic foot.
T_o = temperature of air surrounding the chimney, degrees Fahrenheit absolute.
T_c = average or effective temperature of the gases in the chimney, degrees Fahrenheit absolute.

The quantity D_t, yielded by the formula, is the pressure difference between the gas inside and air outside of the chimney, in inches of water, when no flow occurs in the chimney. The quantity is variously known as the theoretical draft, the static draft or the computed draft. It is very useful in predicting and analyzing chimney performance, but it is seldom if ever attained in an actual chimney on account of the friction incident to gas flow, wind effects, etc.

AVAILABLE DRAFT

The available draft, D_a, *for large chimneys and stacks* has been estimated with apparent satisfaction in the past by means of formulae which in effect deduct an estimated friction loss from a theoretical draft determined as in Equation 1. The friction loss can be estimated by means of one of the formulae available for ducts, such as the Fanning equation. This procedure results in formulae for the available draft as follows:

For a *cylindrical* stack:

$$D_a = 2.96\ HB_o\left(\frac{W_o}{T_o} - \frac{W_c}{T_c}\right) - \frac{0.00126\,W^2T_cfL}{D^5B_oW_c} \tag{2}$$

and for a *rectangular* stack:

$$D_a = 2.96\ HB_o\left(\frac{W_o}{T_o} - \frac{W_c}{T_c}\right) - \frac{0.000388\ W^2\ T_cfL\ (x+y)}{xy^3\ B_o\ W_c} \tag{3}$$

where

D_a = available draft, inches, water gage.
H = height of chimney above grate, feet.
B_o = existing barometric pressure, inches of mercury.
W_o = density of air at 0 F, 1 atmosphere pressure.
W_c = density of flue gas at 0 F, 1 atmosphere pressure.
T_o = temperature of atmosphere, degrees Fahrenheit absolute.
T_c = temperature of flue gas, degrees Fahrenheit absolute.
W = flue gas flow rate, pounds per second.
f = coefficient of friction.
L = length of friction duct (= H approximately), feet.
D = minimum diameter of round chimney, feet.
x and y = length and width of cross-section of rectangular chimney, feet.

The following notes are intended to facilitate the use of Equations 2 and 3.

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:

$$W_c = 0.131CO_2 + 0.095O_2 + 0.083N_2 \tag{4}$$

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 infiltrations in the chimney proper are 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 the following equation was deduced[1]:

$$T_c = \frac{3.13\ T_1\left[\left(\frac{H_b}{3}\right)^{0.96} - 1\right]}{H_b - 3} \tag{5}$$

where

T_1 = absolute temperature at the center of the connection from the breeching, degrees Fahrenheit.
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 in general 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 chimney design, especially when the construction or the materials are unusual, it is recommended that use be made of Reynolds' number[2] in determining the friction factor, f.

To illustrate the use of Equation 2, the following problem is solved by its use.

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 tempera-

[1]Notes on Power Plant Design, by E. F. Miller and James Holt (*Massachusetts Institute of Technology*, 1930).

[2]For more complete discussion see Flow of Fluids in Closed Conduits, by R. J. S. Pigott (*Mechanical Engineering*, August, 1933).