economizers and recuperators are used, when the temperature will vary between 300 F and 450 F. If a chimney has been properly constructed, properly lined and has no air infiltration due to open joints, the temperature of the gases throughout the chimney will not differ appreciably from the foregoing figures. In most up-to-date heating plants, the temperature may be read from instruments or ascertained from a pyrometer. The analysis of this section is predicated on the assumption of constant gas temperature and no air infiltration throughout the height of the chimney.

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

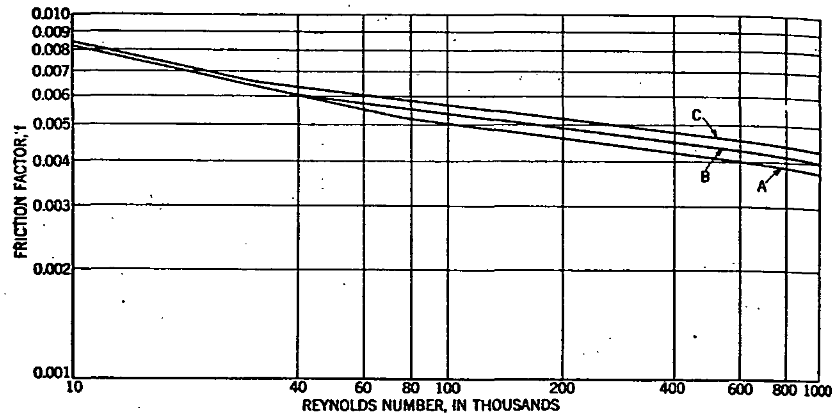

FIG. 5. VARIATION OF FRICTION FACTOR f WITH REYNOLDS NUMBER

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.

However, much to be recommended as an alternate method is the practise of separately determining duct friction factors as a function of the flow conditions, specifically as a function of the Reynolds number and the relative duct roughness. The Reynolds criterion is based on the physical properties of the gas, the duct dimensions, and the gas velocity. The gas velocity for a chimney is usually well above the critical velocity. It is likely that this procedure of using a separately determined variable friction factor for chimney flow will give results that are to be preferred over those based on a set constant.

The Reynolds number, a dimensionless ratio, may be stated as follows:

$$C_r = \frac{DV\rho}{\mu} \tag{4}$$

where

D = chimney diameter, feet.
V = velocity of hot gas, feet per second.
ρ = mass density of the chimney gas per cubic foot.
μ = viscosity of the gas in pounds-second per square foot taken at the gas temperature.

In another form:

$$C_r = \frac{1.27\,W}{D\mu g} = \frac{0.0396\,W}{D\mu} \tag{5}$$

where

W = weight of gas passed per second.
g = acceleration of gravity.

The value of μ for chimney gases is usually taken as that of air or nitrogen, and for the variation of μ with temperature, the Sutherland equation may be employed as follows, giving μ in pounds-second per square foot:

$$\mu = \mu_o \left[\frac{273 + C}{T_c + C}\right] \left[\frac{T_c}{273}\right]^{1.5}$$

where

T_c = chimney gas temperature, degrees Centigrade.
μ_o = gas viscosity at O C.
C = constant for specific gas.

Using International Critical Table values, for air $\mu_o = 35.6 \times 10^{-8}$; $C = 124$; for nitrogen $\mu_o = 34.5 \times 10^{-8}$; and $C = 110$.

Values for the viscosity of air and of nitrogen (the principal component of chimney gases) for the different temperatures follow, in which the values given in pounds-second per square foot are to be multiplied by 10^{-8}:

Temp. F	300	400	500	600	700	800
Air	49.7	54.5	58.5	62.5	66.7	70.5
Nitrogen	47.7	52.2	56.0	59.8	63.5	67.0

Example 2. To determine the Reynolds number C_r for a flow of 118 lb gas per second up a 12 ft diameter chimney at a temperature of 500 F. The gas may be assumed to have the same viscosity as nitrogen at 500 F. Using Equation 5:

$$C_r = 0.0396\,\frac{W}{D\mu} = \frac{0.0396 \times 118}{12 \times 56.0 \times 10^{-8}} = 698{,}000$$

The variation of the friction factor f with the Reynolds number is shown in Fig. 5[1]. Three curves are shown: A, B, and C, where the choice of the friction factor curve depends on the relative surface roughness, and this for usual chimney construction may be selected by size since surface conditions in service are always undeterminant. For sizes up to 3 ft in diameter, Curve C may be used; from 3 to 6 ft, Curve B; and from 6 ft upwards, Curve A. Thus for the previous example with $C_r = 698{,}000$ and 12 ft diameter, f would be taken from Curve A as 0.0039.

6. The *length of the friction duct* is the vertical distance between the bottom of the breeching opening and the top of the chimney. Ordinarily this distance is approximately equal to the height of the chimney above the grate level.

7. Assuming no air infiltration the *amount of gases flowing and being discharged* is, of course, equal to the amount of gases generated in the combustion chamber of the boiler. The total products of combustion in pounds per second for a grate fired boiler may be computed from the equation:

$$W = \frac{C_g G W_{tp}}{3600} \tag{6}$$

where

C_g = pounds of fuel burned per square foot of grate surface per hour.
G = total grate surface of boilers, square feet.
$C_g \times G$ = total weight of fuel burned per hour.
W_{tp} = total weight of products of combustion per pound of fuel.

A similar computation may be made in the case of gas, oil, or stoker-fired fuel.

[1]See also Flow of Fluids in Closed Circuits, by R. J. S. Pigott (*Mechanical Engineering*, August, 1933).