respectively. These charts were developed by the ASHAE Research Laboratory.[1]

The charts, Figs. 2 and 3, were constructed from the basic flow equation for the pressure loss in circular ducts (see Chapter 4):

$$H_f = f\left(\frac{l}{D}\right)H_v \qquad (4)$$

where

H_f = head loss due to friction, inches of water.
f = a nondimensional friction coefficient, which for air-conditioning work depends upon Reynolds number and the relative roughness of the conduit. Approximate values of f were taken from the work of Moody[2] where e = 0.0005 ft. (See Chapter 4, Fig. 4, Relation Between Friction Factor and Reynolds number.) It is numerically equal to the reciprocal of the number of duct diameters required to cause a pressure loss equivalent to one velocity pressure.
l = length of conduit, feet.
D = inside diameter of conduit, feet.
H_v = velocity pressure of mean velocity, inches of water.

The air friction chart is based on standard air with a density of 0.075 lb per cu ft, flowing through average, clean, round, galvanized metal ducts having approximately 40 joints per 100 ft. Fig. 2 should not be used to obtain values below the charts by extrapolation, because critical flow would occur in this region and values so obtained would be unreliable.

Variations in air temperature of the order of ±20 deg from 70 F affect duct friction very little. Figs. 2 and 3 can therefore be used for all air systems with temperatures from 50 F to 90 F.[1] For systems carrying air at much higher temperatures, however, the values found in the charts must be corrected.[3] To determine the friction loss in such systems, the *actual* flow rate or velocity existing at the nonstandard conditions must be used.

Changes in humidity, or the usual changes in barometric pressure or in the pressures required to circulate the air through the systems, have little influence on duct friction and can be disregarded in calculating friction losses in ordinary air-flow systems.[1] For unusual conditions, the friction values obtained from Figs. 2 and 3 must be corrected.[3]

For ordinary applications, an excellent approximation for nonstandard temperatures is

$$h_a = K h_c \qquad (5)$$

where

h_a = friction loss under actual operating conditions, inches of water.
h_c = friction loss obtained from Figs. 2 and 3 using the actual flow rate or velocity existing under the nonstandard conditions, inches of water.
K = friction loss correction factor, obtained from Fig. 4, dimensionless.

For ducts of other than standard sheet-metal construction, correction factors may be obtained from Figs. 5 and 6. The correction factors shown in Fig. 5 were computed for the value of ε, the roughness in feet, shown in Table 1.[3] Most ductwork today is fabricated from galvanized-iron or aluminum sheet metal, or flexible tubing. Fig. 6 presents in graphical form the recommended correction factors for aluminum

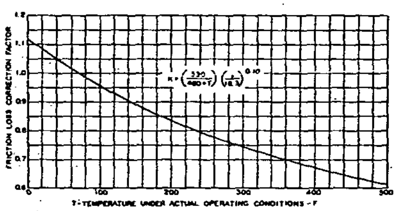


Fig. 4 .... Correction Factors for Density and Viscosity

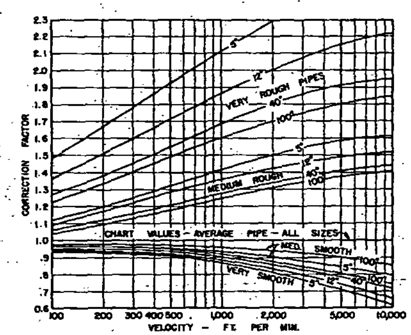
ductwork.[4] The correct friction loss for ducts of other than standard sheet-metal construction may be determined by multiplying the losses obtained from Figs. 2 and 3 by the factors found in Figs. 5 and 6.

Accurate experimental data on the absolute roughness for flexible tubing are not yet available. There is also little information on the friction loss in ducts lined with acoustical material. Until definite information is available, it is recommended that the correction factor for very rough pipes be used for uncovered soft material, and the factor for medium roughness be used for material behind perforated metal.

Example 1 illustrates the use of Fig. 3 to determine friction loss in a galvanized sheet-metal duct. *Examples 2, 3,* and *4* illustrate the use of Figs. 4, 5, and 6 in applying correction factors for ducts of other than sheet-metal construction and for air at high temperature.

Example 1: Determine the friction loss when circulating 10,000 cfm of air at standard density through 75 ft of 24-in. diameter galvanized duct.

Solution: Find 10,000 cfm on the left scale of Fig. 3 and move horizontally right to the diagonal line marked 24 in. The other intersecting diagonal shows that the velocity in the pipe is 3200 fpm. Directly below the intersection it is found that the friction per 100 ft is 0.50 in.; then for 75 ft the friction will be 0.75 × 0.50 = 0.38 in. In a like manner, any two variables may



To correct for pipe roughness multiply friction loss obtained from Figs. 2 and 3 by correction factor obtained from Fig. 5.

Fig. 5 .... Correction Factors for Pipe Roughness

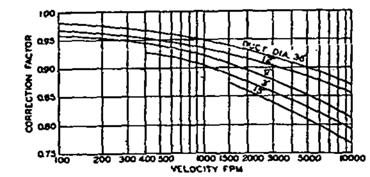


Fig. 6 .... Correction Factors for Aluminum Duct

be determined by the intersection of the lines representing the other two variables.

Example 2: If the duct in *Example 1* is very rough, instead of galvanized, with 40 joints per 100 ft, find the total friction.

Solution: On Fig. 5 find (by interpolation between 12-in. and 40-in. pipe) the intersection of the 24-in. *very rough* pipe line and the 3200 fpm velocity ordinate, and at the left margin read a correction factor of 2. The friction loss in the rough duct is therefore 2 × 0.38 = 0.76 in.

Example 3: If the duct in *Example 1* is made of aluminum, instead of galvanized iron, find the total friction.

Solution: On Fig. 6 find (by interpolation between 12-in. and 36-in. pipe) the intersection of the 24-in. line and the 3200-fpm velocity ordinate, and at the left margin read a correction factor of 0.91. The friction loss in the aluminum duct is therefore 0.91 × 0.38 = 0.35 in.

Example 4: Determine the friction loss in the duct of *Example 1*, if the temperature of the air transmitted through the duct is 200 F.

Solution: For t = 200 F, the density of the air is ρ_a = 0.060 lb per cu ft. Hence, the actual air-flow rate in the duct is

$$Q_c = \frac{10{,}000 \times 0.075}{0.060} = 12{,}500 \text{ cfm}$$

and the actual velocity

$$V = \frac{Q_c}{A} = \frac{12{,}500}{3.14} = 4{,}000 \text{ fpm}$$

With Q_c = 12,500 and D = 24 in., find h_c = 0.77 in. of water per 100 ft in Fig. 3 and K = 0.835 in Fig. 4. The friction loss under actual operating conditions is:

$$h_a = 0.835 \times 0.77 = 0.64 \text{ in. per 100 ft.}$$

The friction loss for 75 ft is then 0.75 × 0.64 = 0.48 in.

CIRCULAR EQUIVALENTS OF RECTANGULAR DUCTS

An air-handling system is usually sized first for round ducts. Then, if rectangular ducts are desired, their sizes are selected to provide flow rates equivalent to those of the round ducts originally selected.

A comprehensive study at the ASHAE Research Laboratory proved that for most practical purposes rectangular ducts of aspect ratios not exceeding 8:1 will have the same friction pressure loss for equal lengths and mean velocities of flow as a circular duct of the same hydraulic diameter. When duct sizes are expressed in terms of hydraulic diameter, and when equations for friction loss in round and rectangular ducts are equated for equal flow rate and equal length, Equation 6 giving the circular equivalent of a rectangular duct is obtained.[5]

Table 1 .... Values of Roughness ε for Different Pipes*

Pipe	*Degree of Roughness*	*ε Roughness in Feet*
Drawn Tubing..................	Very smooth	0.0000015
New Steel or Wrought Iron Pipe..	Medium smooth	0.00015
Galvanized Iron................	Average	0.0005
Average Concrete...............	Medium rough	0.003
Average Riveted Steel..........	Very rough	0.01

* Used in computing values for Fig. 5.

$$d_e = 1.30\,\frac{(ab)^{0.625}}{(a+b)^{0.250}} = 1.30\,\sqrt[8]{\frac{(ab)^5}{(a+b)^2}} \qquad (6)$$

where

a = length of one side of rectangular duct, inches.
b = length of adjacent side of rectangular duct, inches.
d_e = circular equivalent of a rectangular duct for equal friction and capacity, inches.

Table 2 gives the circular equivalents of rectangular ducts for equal friction and flow rate for aspect ratios not greater than 11.7:1 based on Equation 6.[5] Note that the mean velocity in a rectangular duct will be *less* than in its circular equivalent.

Multiplying or dividing the length of each side of a duct by a constant is the same as multiplying or dividing the equivalent round size by the same constant. Thus, if the circular equivalent of an 80 x 24 in. duct is required, it will be twice that of a 40 x 12 in. duct, or 2 x 23.0 = 46.0 in.

DYNAMIC LOSSES

Wherever eddying flow is present, brought about by sudden changes in the direction or magnitude of the velocity of the air flowing, a greater loss in pressure takes place than would occur in a steady flow through a similar length of straight duct having a uniform cross-section. The amount of this loss, in excess of straight-duct friction, is termed *dynamic loss.* Although dynamic losses may be assumed to be caused by changes in area actually occupied by the air flow, for convenience they are divided into two general classes: (1) those caused by *changes in direction* of the duct and (2) those caused by *changes in cross-sectional area* of the duct.

Dynamic losses vary substantially as the square of the mean velocity of the air, and are therefore conveniently expressed as a fraction of the velocity head:

$$H_d = C\left(\frac{V}{4005}\right)^2 \qquad (7)$$

where

H_d = dynamic pressure loss, inches of water.
V = mean velocity of air flow, feet per minute.
C = an experimentally determined constant (dynamic loss coefficient).

Where different areas are involved, subscripts are used to denote the area to which the coefficient applies, as C_1 for inlet area, C_2 for outlet area, and C_o for orifice area.

The dynamic loss coefficient C is dimensionless and represents the number of velocity heads lost at the conduit transition or bend. Values of the dynamic loss coefficient for elbows