therefore,

$$V = 1096.5\sqrt{\frac{h_v}{d}} \quad (1)$$

where

V = velocity, feet per minute.
h_v = velocity head or pressure, inches of water.
d = weight of air, pounds per cubic foot.

For dry air (70 F and 29.921 in. *Hg* barometer) $d = 0.07492$ lb per cubic foot[1]. Substituting this value in Equation 1:

$$V = 1096.5\sqrt{\frac{h_v}{0.07492}} = 4005\sqrt{h_v} \quad (2)$$

The relation of air velocity and velocity head expressed in Equation 2 is shown diagrammatically in Fig. 1 for air at 70 F and 29.92 in. *Hg* barometer.

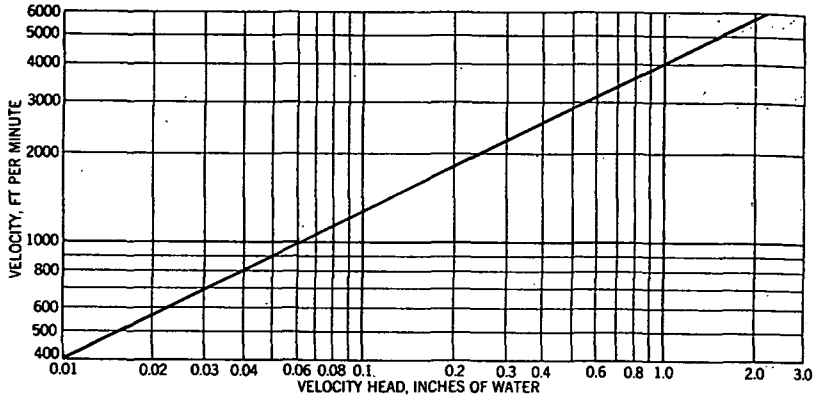

FIG. 1. RELATION BETWEEN VELOCITY AND VELOCITY HEAD FOR DRY AIR

The drop in pressure in air distributing systems is due to the *dynamic* losses and the *friction* losses. The friction losses for turbulent flow (which occur in all practical air flow problems) are due to the friction of air against the sides of the duct and to internal friction between air molecules. The dynamic losses are those due to the change in the direction or in the velocity of air flow.

Dynamic losses occur principally at the entrance to the piping, in the elbows, and wherever a change in velocity occurs. The entrance loss is the difference between the actual pressure required to produce flow and the pressure corresponding to the flow produced; it may vary from 0.1 to 0.5 times the velocity head. The pressure loss in elbows must also be allowed for in the design.

FRICTION LOSSES

Theoretically friction losses vary directly as the length of the duct, directly as the square of the velocity, and inversely as the diameter.

[1]See Chapter 46 for definition of standard air.

Since length is a fixed quantity for any system, the factors subject to modification are the area and the velocity, which determine the relation between the first cost of the duct system and the cost of the power for overcoming friction.

The friction between the moving air and pipe surface and internal friction between air molecules causes a loss of head which is numerically equal to the pressure required to maintain a given velocity, and is expressed in the following modification of Fanning's formula:

For round pipe and dry air at 70 F and 29.921 in. *Hg* barometer

$$h_L = f\frac{L}{D}h_v = \frac{L}{CD}\left(\frac{V}{4005}\right)^2 \quad (3)$$

For rectangular ducts

$$h_L = fL\left(\frac{a+b}{2ab}\right)h_v = \frac{L}{C}\left(\frac{a+b}{2ab}\right)\left(\frac{V}{4005}\right)^2 \quad (4)$$

where

h_L = loss of head, inches of water.
$h_v = \left(\frac{V}{4005}\right)^2$ = velocity head, inches of water.
V = velocity of air, feet per minute.
L = length of pipe
D = diameter of pipe
a, b = sides of rectangular duct
} all in feet.
f = coefficient of friction, or friction factor.
$C = \frac{1}{f}$ = length of pipe in diameters for one head loss.

For all practical purposes C varies only with the nature of the pipe surface: $C = 60$ for perfectly smooth pipe; $= 55$ for pipe as used in planing mill exhaust systems; $= 50$ for heating and ventilating ducts; $= 45$ for smooth and 40 for rough conduits of tile, brick or concrete. However, Fritzsche states (and numerous tests check very closely) that f varies inversely as the 2/7 power of the pipe diameter, and inversely as the 1/7 power of the velocity, or inversely as the 1/7 power of capacity, which is the same thing. Thus Formula 3 may be revised as follows, based upon a loss of one velocity head (at 2000 fpm) in a length equal to 50 diameters of 24 in. galvanized swedged pipe:

$$h_L = 1.1\frac{L}{CD^{9/7}}\left(\frac{V}{4005}\right)^{13/7} \quad (5)$$

The preceding formulae are based on dry air at 70 F, and for other conditions the friction varies directly as the air density or inversely (approximately) as the absolute temperature. The increase of friction due to increase of air viscosity with increased temperature is small and is generally neglected.

Friction Loss Chart

A convenient chart is given in Fig. 2 for determining the friction loss for various air quantities in ducts of different sizes. It has been in use for several years and has incorporated in it a factor of safety which should be adequate for any installation of good design. The general form of this chart is familiar, but it should be noted that it is corrected for changes in