and relative roughness in Table 18 to find the friction factor, f; (*5*) use f in the equation above to find the air-flow friction loss in inches of water per hundred feet of pipe.

TABLE 17

Roughness Measure (ϵ) for Various Kinds of Pipe[20]

Kind and condition of pipe	ϵ (ft.)
Perfectly smooth drawn tubing	0.0000015
Commercial steel or wrought iron, new	0.00015
Asphalted cast iron	0.0004
Galvanized iron (used for Figure 22)	0.0005
Cast iron	0.00085
Concrete, average roughness	0.003
Riveted steel, very rough	0.01

TABLE 18

Friction Factors (f) Based on Reynolds Number and Pipe Roughness[20] for Use with Friction Formula Above (page 337)

Relative roughness,[a] ϵ/D	Reynolds Number 10^4 10,000	10^5 100,000	10^6 1,000,000	10^7 10,000,000
0.00001	0.030	0.018	0.012	0.009
0.0001	0.031	0.0185	0.0135	0.012
0.0005	0.032	0.0205	0.0175	0.017
0.001	0.032	0.022	0.020	0.0195
0.005	0.038	0.031	0.030	0.030
0.01	0.043	0.038	0.038	0.038
0.03	0.060	0.057	0.057	0.057
0.05	0.074	0.072	0.072	0.072

[a] ϵ = roughness measure of pipe surface in feet and D = inside diameter of pipe in feet.

For kinds of pipe not listed in Table 17 the roughness measure can be selected for the material most likely to be similar in surface characteristics. In estimating the internal pipe roughness, consideration should be given to surface treatment of the pipe for corrosion resistance, and the possibility of surface modification by the accumulation of particulate matter, especially if hygroscopic or unusually electrostatic.

E. REYNOLDS NUMBER

The Reynolds Number used in fluid mechanics and required in the use of Table 18 is a "dimensionless" figure that may be computed from the following equation:

[20] L. F. Moody, *Trans. Am. Soc. Mech. Engrs.*, **66**, 671 (1944).

$$\text{Reynolds Number} = \frac{\text{(velocity in f.p.s.) (diam. in ft.)}}{\text{(kinematic viscosity in sq. ft./sec.)}}$$

A convenient, approximate form that applies to most air-flow conditions in ventilating systems, and is adjusted to the conventional units, is the following:

$$\text{Reynolds Number} = 8.5 \text{ (l.f.m.) (diam. in in.)}$$

The constant 8.5 in this equation is based on a kinematic viscosity for air at 70° F. and 29.92 inches Hg barometer of 0.000163 sq. ft. per second. For values of kinematic viscosity at high and low temperatures and high pressures, see the convenient chart presented by L. G. Miller.[21]

F. FLEXIBLE METAL, CANVAS, OR RUBBER DUCTS

The friction of air flow through flexible ducts is considerably higher than for straight sheet-metal pipes. If the inside surface is deeply corrugated, the friction loss may be two to four times the loss for smooth pipe of equal diameter. Furthermore, it is necessary to anticipate increased friction loss to a degree depending upon the amount of curvature to which the duct can or will be subjected.

Not all flexible ducts should be treated as unusually high-resistance material. Some natural or synthetic rubber ducts are so constructed that the inside is relatively smooth, while the corrugations due to metal reinforcement appear on the outside surface. Also, some metal flexible ducts are so rigidly constructed that sharp curvature is impossible. Field tests of friction loss should be made if its effect on air flow or power consumption is of serious consequence.

G. ADJUSTABLE DAMPERS OR FLOW REGULATORS

The tendency still exists to install in each branch of an exhaust or ventilating system some type of damper to make possible an initial or periodic variation in the amount or distribution of air flow. This practice has reached the ultimate in disfavor in connection with the handling of highly explosive dusts that may collect or settle out in the vicinity of dampers as a result of eddies or sudden changes of flow direction. A great many objections to dampers have been expressed among designers of exhaust systems, but the fact remains that in many cases their use has made possible the correction of air-flow distribution when the original design did not succeed in anticipating the best proportion of ventilation for each machine or process in the system. It is true that tremendous power has been wasted throughout the years by the work of dragging air through the constrictions imposed by dampers, and efforts to improve the accuracy of ventilation estimates and designs must be encouraged. Likewise, some attention must be given to the design of better flow-regulating devices to give the user the flexibility his operations may demand. Designs also can be, and have been, made to permit adjustments that cannot be disturbed by unauthorized persons without obvious damage or destruction.

[21] L. G. Miller, *Trans. ASHVE*, **43**, 71 (1937).