



FIG. 5. COMPARISON OF VELOCITY PROFILES FOR 3 DIFFERENT REYNOLDS NUMBERS BUT FOR SAME AVERAGE VELOCITY

factor in turbulent flow, is open to some conjecture; artificially roughened pipes, for instance, give results at variance with actual tests. The curves above the smooth pipe curve of Fig. 4 represent a summary of tests on rough pipe, each of them identified by a value of e/d , with e signifying the absolute roughness in feet. Values of e/d for different pipes are given in Table 1.

To find the friction loss for any pipe, follow the curve with the proper value of e/d , to the pertinent value of N_{Re} ; and from this point proceed horizontally to left margin to find the value of f to use in Equation 5.

Equation 5 is applicable to all liquids, and to gases when the pressure loss is less than 10 per cent of the initial pressure. When the loss in head is high, the formula to be used for gases is

$$\frac{p_1 - p_2}{p_1} = \frac{fLV_1^2}{gd p_1 v_1} \quad (9)$$

which may be rearranged to give the loss in pressure

$$p_1 - p_2 = p_1 \left[1 - \sqrt{1 - \frac{fLV_1^2}{gd p_1 v_1}} \right] \quad (10)$$

Pressure Loss In Non-Circular Pipes

The formulas for flow in pipes are based upon the use of pipes of circular cross-section. The formulas may be used with conduits of other shapes, and in conduits not flowing full, when the flow is turbulent, by using the hydraulic radius, R_H , which is really a ratio:

$$R_H = \frac{\text{area of cross-section}}{\text{wetted perimeter of cross-section}} \quad (11)$$

TABLE 1. VALUES OF e/d FOR DIFFERENT KINDS OF PIPE

TYPE OF PIPE	e/d
Smooth drawn tubing	0.000005
Commercial steel or wrought iron	0.00015
Asphalted cast-iron	0.0004
Galvanized iron	0.0005
Cast-iron	0.00085
Wood stave	0.0006 to 0.003
Concrete	0.001 to 0.01
Riveted steel	0.003 to 0.03

For instance, in a square duct, 1 ft on a side, handling air, the hydraulic radius is $\frac{1}{4}$ or 0.25. If the same duct is handling water, flowing 9 in. deep, the hydraulic radius is 0.75/2.5 or 0.30. Note in this latter case that the wetted perimeter does not include the distance across the free surface.

In the case of a round pipe

$$R_H = \frac{\pi d^2/4}{\pi d} = \frac{d}{4} \text{ or } d = 4R_H \quad (12)$$

Substituting Equation 12 in Equation 6,

$$N_{Re} = \frac{4R_H V \rho}{\mu} \quad (13)$$

and in the flow Equation 5,

$$h_f = \frac{fLV^2}{8gR_H} \quad (14)$$

and finally in the compressible fluid flow Equation 10,

$$p_1 - p_2 = p_1 \left[1 - \sqrt{1 - \frac{fLV_1^2}{4gR_H p_1 v_1}} \right] \quad (15)$$

Equations 13, 14, and 15 may be used to compute the flow in pipes and ducts of non-circular section and in any type of conduit not flowing full. They should not be used when the flow is laminar.

FLOW OF COMPRESSIBLE FLUIDS

The energy equation for the flow of compressible fluids, as represented by the gases, is derived from Equation 1. Assuming that no heat is transferred to the fluid, that no work is done, and that there is no difference in elevation, Equation 1 becomes

$$\frac{V_1^2}{2g} + J u_1 + p_1 v_1 = \frac{V_2^2}{2g} + J u_2 + p_2 v_2 \quad (16)$$

or, after rearrangement,

$$\frac{V_2^2 - V_1^2}{2g} = p_1 v_1 - p_2 v_2 + J(u_1 - u_2) \quad (17)$$

Since internal energy is dependent only on temperature,

$$u_1 - u_2 = c_v(T_1 - T_2) \quad (18)$$

where

c_v = the specific heat of the gas at constant volume,

T_1 and T_2 = the temperatures in Fahrenheit degrees at points 1 and 2, respectively.

Substituting Equation 18 in Equation 17,

$$\frac{V_2^2 - V_1^2}{2g} = p_1 v_1 - p_2 v_2 + J c_v(T_1 - T_2) \quad (19)$$

Now

$$c_v = \frac{R}{J(k-1)} \quad (20)$$