

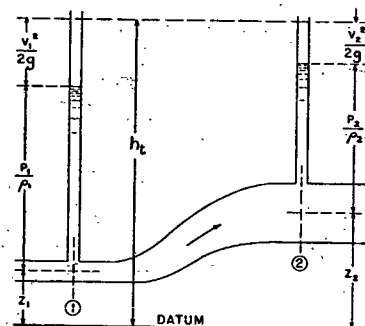


FIG. 1. RELATION OF VARIOUS FACTORS IN BERNOULLI EQUATION

its equivalent p/ρ in Equation 1, the result, after rearranging, will be:

$$\frac{V_1^2}{2g} + \frac{p_1}{\rho_1} + z_1 = \frac{V_2^2}{2g} + \frac{p_2}{\rho_2} + z_2 + [J(u_2 - u_1) - E - Jq] \quad (3)$$

In the case of flow through a pipe, no outside work is performed and, if the process is considered adiabatic, and if the change due to turbulence and friction is considered to be negligible, the bracketed expression in Equation 3 will disappear, leaving:

$$\frac{V_1^2}{2g} + \frac{p_1}{\rho_1} + z_1 = \frac{V_2^2}{2g} + \frac{p_2}{\rho_2} + z_2 \quad (4)$$

which is commonly called the Bernoulli equation, named after the Swiss mathematician and physician who first propounded the theory. $\frac{V^2}{2g}$ is

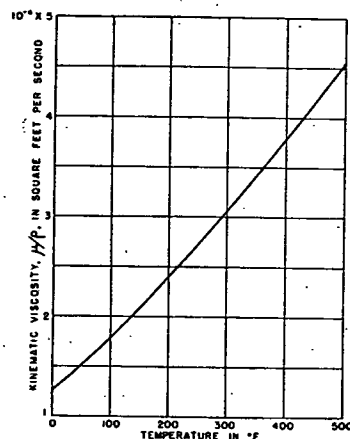


FIG. 2. RELATION OF KINEMATIC VISCOSITY TO TEMPERATURE OF AIR

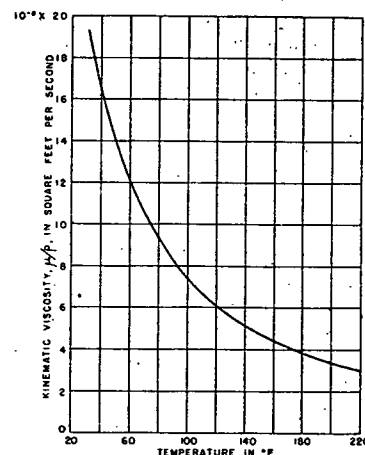


FIG. 3. RELATION OF KINEMATIC VISCOSITY TO TEMPERATURE OF WATER

known as the velocity head, $\frac{p}{\rho}$ is the pressure head, and z is the elevation head, all in feet of the fluid; the total head, h_t is the sum of the other three heads. Fig. 1 shows diagrammatically the relation of the various factors. The pressure at point 2 is lower than at point 1 because of the elevation of point 2 over point 1, and the velocity at point 2 is lower than at point 1 because of the larger pipe diameter at point 2. If the pipe diameter were the same throughout, the velocity, and consequently the velocity head, would be the same at both points, but the higher elevation at point 2 would still be responsible for a loss in pressure. The utility of the equation is evident, though it should be remembered that in it the effects of friction and turbulence are neglected, and that Fig. 1 represents ideal conditions. It should also be noted that the Bernoulli equation applies only to incompressible fluids.

Pressure Loss in Circular Pipes

The pressure loss in circular pipes is customarily expressed by the formula:

$$h_f = \frac{f l V^2}{2g d} \quad (5)$$

where

- h_f = the loss in head of the fluid under conditions of flow, in feet.
- l = the length of the pipe, in feet.
- V = the velocity, in feet per second.
- g = the acceleration due to gravity = 32.17 ft per (second) (second).
- d = the internal diameter of the pipe, in feet.
- f = a dimensionless friction coefficient.

The formula is generally known by the name of Darcy or Fanning, though it seems to have been originated by d'Aubisson de Voisins in 1834.

The factor f is a function of the Reynolds number

$$N_{Re} = \frac{d V \rho}{\mu} \quad (6)$$

where

- N_{Re} = Reynolds number.
- ρ = the density in pounds per cubic foot.
- μ = the absolute viscosity in pounds per foot-second.

Both f and the Reynolds number are dimensionless. To aid in computing the Reynolds number, values of $\frac{\mu}{\rho}$, the kinematic viscosity, are shown as a function of temperature for air in Fig. 2 and for water in Fig. 3.

Fig. 4 shows the relation between f and the Reynolds number, adapted from a review by Moody¹. The straight line sloping downward at the left of the chart supplies the values of f for laminar flow; it represents the formula

$$f = \frac{64}{N_{Re}} \quad (7)$$

With laminar flow, the velocity profile is a parabola, having the formula

¹Superior numbers refer to the references at the end of the chapter.