$$Q_s = A_2 \frac{1}{\sqrt{1 - \left(\frac{A_2}{A_1}\right)^2}} \sqrt{2gh_f} \qquad (44)$$

the central term on the right hand side of Equation 44 will be recognized as the *velocity of approach factor*, so that

$$Q_s = A_2 \frac{1}{\sqrt{1 - \beta^4}} \sqrt{2gh_f} \qquad (45)$$

Actual Flow Through Orifices and Nozzles

The actual rate of flow through an orifice, nozzle, or Venturi tube is rarely equal to the theoretical, and generally the actual rate is less than the theoretical. In the case of the nozzle and Venturi tube, this is due to losses from wall roughness, fluid friction, and turbulence during the expansion in the section following the throat. While wall roughness is not a factor in a sharp-edged orifice, fluid friction and turbulence are important, as is the fact that the discharge contracts to a degree variable with the ratio of outlet to inlet pressure after leaving the orifice, so that the limiting area is somewhat less than the opening in the orifice plate. Accordingly, Equation 45 must be modified by a correction factor, C. Usually, the velocity of approach factor is included with this correction factor, and, if

$$K = C \frac{1}{\sqrt{1 - \beta^4}}, \qquad (46)$$

$$Q_s = KA_2 \sqrt{2gh_f}. \qquad (47)$$

Multiplying by 3600 to convert from cubic feet per second to cubic feet per hour and converting area in square feet to diameter in inches, gives

$$Q_f = 3600\, K \frac{\pi D_2^2}{4 \times 144} \sqrt{2gh_f}$$

or

$$Q_f = 19.635\, KD_2^2 \sqrt{2gh_f} \qquad (48)$$

where

Q_f = rate of flow in cubic feet per hour.
D_2 = the diameter of the orifice or nozzle throat in inches.

Equation 48 is a general equation, expressing the flow of any fluid through an orifice or nozzle. Further use of it will be made as other types of flow are discussed.

The differential loss, h_f, is in terms of feet of the fluid flowing through the orifice or nozzle. In the case of a gas flowing, where it is customary to read the differential pressure in inches of water, feet of gas must be converted to inches of water. Since dry air at 32 F and 14.7 psi absolute pressure weighs 0.0807 lb per cubic foot, the weight of a cubic foot of any other kind of gas under the same conditions is 0.0807 G, where G is the specific gravity of the gas referred to air. Water weighs 62.37 lb per cubic foot at 60 F. Using also the relation of 12 in. in 1 ft,

$$h_f = \frac{h_w}{12} \times \frac{62.37}{0.0807G} \qquad (49)$$

in which h_w is the differential pressure in inches of water.

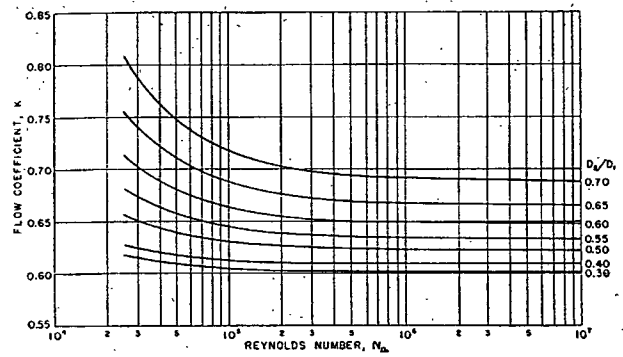

FIG. 7. FLOW COEFFICIENTS, K, FOR SQUARE-EDGED ORIFICE PLATES AND FLANGE TAPS IN SMOOTH PIPE
NOTE: From Table 6, Bibliography [H].

Also, since the gas flowing is not necessarily at 32 F and 14.7 psi, it is necessary to apply Charles' and Boyle's laws to the density of the gas and therefore:

$$h_f = \frac{h_w}{12} \times \frac{62.37}{0.0807G} \times \frac{14.7}{P_f} \times \frac{T_f}{492} \qquad (50)$$

in which P_f and T_f are the absolute pressure and temperature of the flowing gas. Substituting this in Equation 48, and combining the constants,

$$Q_f = 218.44 KD_2^2 \sqrt{\frac{h_w T_f}{P_f G}} \qquad (51)$$

Then, to correct the value of Q_f to any other standard conditions of pressure and temperature, using the gas laws,

$$Q_b = Q_f \times \frac{P_f}{P_b} \times \frac{T_b}{T_f} \qquad (52)$$

Equation 51 becomes

$$Q_b = 218.44 KD_2^2 \frac{T_b}{P_b} \sqrt{\frac{P_f h_w}{T_f G}} \qquad (53)$$

Finally, since gases expand under the conditions of reduced pressure downstream from the orifice or nozzle, an expansion factor, Y, must be added. The final formula, then, is

$$Q_b = 218.44 KYD_2^2 \frac{T_b}{P_b} \sqrt{\frac{P_f h_w}{T_f G}} \qquad (54)$$

In Equation 54, all the data must be observed at the time of measurement except K and Y. These must be obtained from charts, tables, or formulas, derived from or based on the results of a great many experiments, the results of which have been collected by a joint committee of the *American Gas Association* and the *American Society of Mechanical Engineers*[2,3]. The report of the two associations gives orifice coefficients as a function of the Reynolds number and of the ratio of orifice to pipe diameter, for pipes from 2 to 12 and 14 in. in diameter, and for four