where

ρ_l = the density of the fluid over the mercury in the manometer.
ρ_w = the density of water at 60 F.

Substituting Equations 60 and 67 in Equation 52 gives

$$Q_l = 44.764\, KD_2^2 \sqrt{h_w\left(\frac{1}{\rho_l} - 0.00118\right)} \tag{68}$$

Then, since liquids are generally measured in gallons instead of cubic feet, and since there are 7.4805 gal in 1 cu ft,

$$Q_w = 334.86\, KD_2^2 \sqrt{h_w\left(\frac{1}{\rho_l} - 0.00118\right)} \tag{69}$$

in which Q_w is the discharge or rate of flow, in gallons per hour.

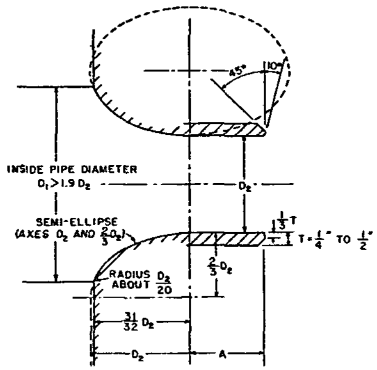

FIG. 14. SHAPE OF *ASME* LONG RADIUS NOZZLE WHEN RATIO OF THROAT TO PIPE DIAMETER IS 0.53 OR LESS

Since liquids, for practical purposes, are incompressible, no expansion factor is necessary. If circumstances demand, the factor P for the expansion of the orifice may be applied. Also, if it is necessary to correct the volumetric discharge to a base temperature, application of the known expansion characteristics of the liquid will enable the conversion to be made. Values of K again are obtainable from Figs. 7, 8, and 9, according to the type of pressure tap.

NOZZLE COEFFICIENTS AND EXPANSION FACTORS

Nozzles differ from orifices in that the flow is guided to the throat in such a way that contraction of the jet is suppressed, or, in other words, there is no vena contracta. Because of this fact, the coefficients are different from those of orifices, and are very close to unity before the velocity of approach factor is added. Also, the expansion factor may be deduced rationally, rather than empirically, as with orifices.

Two shapes of nozzles that have been under investigation by the *A.S.M.E.* for some time are shown in Figs. 14 and 15. They are referred

to as long-radius nozzles. Their contour is that of a semi-ellipse, and the contracting portion is followed by a cylindrical section of the same area as the throat. The shape shown in Fig. 14 is designed for use with ratios of throat to pipe diameter of 0.53 or less; that of Fig. 15 for ratios of 0.4 to 0.7. The most usual location of pressure taps is 1 pipe diameter upstream and ½ diameter downstream, both measured from the plane of the nozzle inlet. In addition, the *International Standards Association* has adopted still another shape of nozzle, which has a somewhat sharper approach than the *A.S.M.E.* nozzles, and which uses corner taps. Very little use of this nozzle has been made in this country.

The formulas already given for orifices apply equally to nozzles except for discharge coefficients, and for the expansion factor, when it is applied. Discharge coefficients for nozzles, as for orifices, vary with pipe size; they may either increase or decrease with decreasing size of pipes, depending on the sharpness of the approach curvature of the nozzle. For the *A.S.M.E.* nozzles, they tend to decrease. Generally speaking, too, the

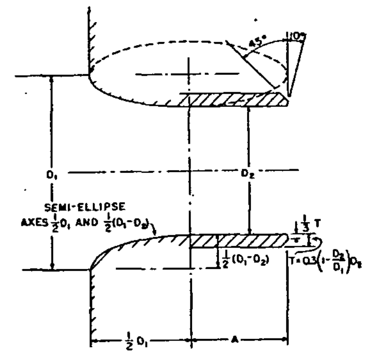

FIG. 15. SHAPE OF *ASME* LONG RADIUS NOZZLE WHEN RATIO OF THROAT TO PIPE DIAMETER IS 0.4 TO 0.7

coefficient for a given nozzle shape is higher if the finish of the surface is smoother.

Discharge coefficients, C, for pipes 2, 6, and 10 in. in diameter are given in Figs. 16, 17, and 18, as correlated by Bean, Beitler and Sprenkle,[5] as functions of the diameter ratio β and the Reynolds number N_{Re} (Equation 70) referred to the diameter of the throat in feet.

$$N_{Re} = \frac{D_2 V_2 \rho_1}{\mu_1} \tag{70}$$

Coefficients from these curves must be multiplied by $\frac{1}{\sqrt{1-\beta^4}}$, the velocity of approach factor, in accordance with Equation 50, to obtain the value of K to use in the various equations.

The expansion factor for nozzles, designated by φ, is obtained from a rational formula, as already noted: