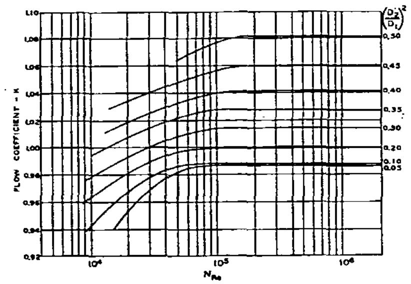

From Reference 3. Used by permission of ASME.

Fig. 12 .... Flow Coefficient for International Standards Association Flow Nozzle Shown in Fig. 8 as a Function of Area Ratio $(D_2/D_1)^2$ and the Reynolds Number $N_{Re}$

that published flow coefficients can be used for accurate determination of flow rates.

In measuring the flow of compressible fluids, the approximate Equations 52 and 53 must be corrected for density variations. The need for such correction is evident by comparing Equations 35 and 38 with Equation 47. Introducing a multiplicative correction factor $\phi$ the equation for flow with no loss becomes:

$$w = \frac{A_2\phi}{\sqrt{1-\beta^4}}\sqrt{2g\rho_1(p_1-p_2)} \qquad (54)$$

By comparison with Equation 35,

$$\phi = \sqrt{\frac{k}{2}\frac{p_2}{p_1}\frac{M_2^2(1-\beta^4)}{(p_1/p_2)-1}} \qquad (55)$$

From Equations 34 and 35,

$$M_1^2/M_2^2 = \beta^4(p_2/p_1)^{2/k} \qquad (56)$$

Hence, by Equation 38 for a small value of $M_1$,

$$\phi = \sqrt{(p_2/p_1)^{1/k}\left(\frac{k}{k-1}\right)\frac{(p_1/p_2)^{(k-1)/k}-1}{(p_1/p_2)-1}\cdot\frac{1-\beta^4}{1-\beta^4(p_2/p_1)^{2k}}} \qquad (57)$$

From Equations 37 and 56, if $M_2$ is not too large,

$$\frac{2}{k}\frac{1}{M_2^2}\left(\frac{p_1}{p_2}-1\right) \cong 1-\beta^4+\tfrac{1}{4}[1-2(k-2)\beta^4]M_2^2 \qquad (58)$$

so that, approximately,

$$\phi \cong -\frac{3}{8}\left[1+\left(1-\frac{2k}{3}\right)\beta^4\right]M_2^2 \qquad (59)$$

where to the same degree of approximation from Equation 36

$$M_2^2 = 2\frac{p_1-p_2}{kp_1} \qquad (60)$$

Values of $\phi$ are also given by Figs. 13 and 14.

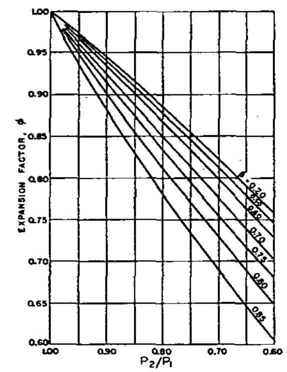

Fig. 13 .... Relation of Expansion Factor, $\phi$, for Nozzles to Diameter Ratio and Pressure Loss for Air and Other Diatomic Gases

While $\phi$ may be used for smooth nozzles and Venturi tubes, it is necessary in the case of orifices, where the departure from ideal flow is significant, to replace $\phi$ by an *empirical factor* $Y$ obtained by the equation

$$Y = 1 - (0.41 + 0.35\beta^4)\left(\frac{p_1-p_2}{p_1}/k\right) \qquad (61)$$

When this correction is used, the flow will be given by the equation

$$w = KA_2Y\sqrt{2g\rho_1(p_1-p_2)} \qquad (62)$$

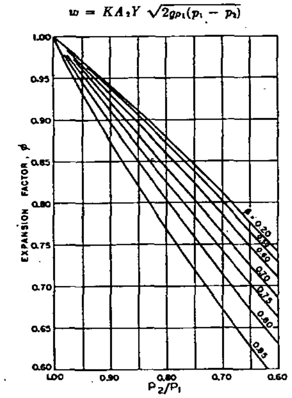

Fig. 14 .... Relation of Expansion Factor, $\phi$, for Nozzles to Diameter Ratio and Pressure Loss for Steam, Carbon Dioxide and Natural Gas



## Location of Head Meters and Pressure Taps

In the installation of Venturis, orifices, and nozzles, care must be taken in regard to upstream and downstream flow conditions. Recommended practice, with reference to fittings and valves, is shown by Fig. 15. If these conditions cannot be met, some flexibility is possible by introducing straightening vanes, as described more fully in References 2 and 5.

The static pressure difference across the head meter is measured by suitably located static pressure taps. For orifices, the different sets of pressure taps are called flange taps, radius taps, vena contracta taps, and pipe or full-flow taps. The relative locations of the first three of these are shown in Fig. 16.

The flow coefficients in Figs. 9, 10, and 11 apply only to measurements made with these pressure tap locations. The need for applying suitable coefficients to measurements obtained by means of the different taps, is indicated by the curve of change, in pressure of the flowing fluid, shown in the lower part of Fig. 16. Pipe taps are located 2½ pipe diameters upstream and 8 pipe diameters downstream (both distances being measured from the upstream face of the orifice plate) so that pressures are measured before the orifice plate has had any effect on the flow, and after the recovery in pressure has been completed. The use of pipe or full-flow taps has been limited to the metering of natural fuel gas in certain areas. As they are not suited to use in heating and ventilating work, no data for them are given in this chapter.

Still another type of pressure tap, the corner tap, is used in European practice. Pressures are taken from recesses in the flange connected to annular slits in the corners formed by the pipe wall and the orifice plate. Coefficients for these taps have been adopted by the *International Standards Association*, but are not used commercially in America.

It will be noted that the location of the downstream pressure tap of the vena contracta arrangement is variable. Vena contracta is the term applied to the minimum cross-section of the jet from the orifice, where the static pressure is at a minimum. Its location, and the location of the downstream vena contracta tap, vary with the ratio of orifice to pipe diameter, and with rate of flow, as shown in Fig. 17; the tap is generally located in accordance with the mean curve in the figure.

Similar precautions are required when using flow nozzles and Venturi tubes. In many cases, these will be supplied

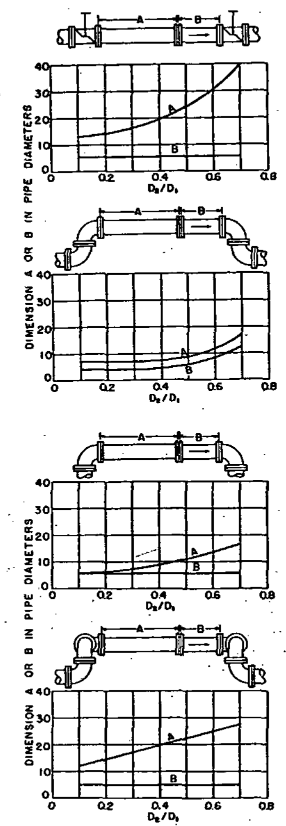

Fig. 15 .... Minimum Conditions to be Observed When Installing Orifices and Nozzles Between Fittings and Valves

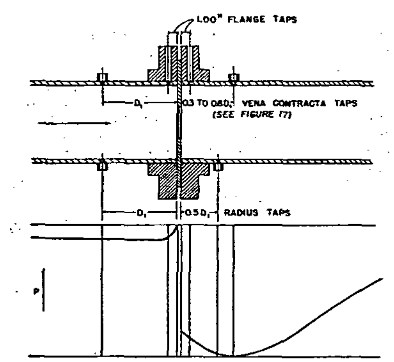

Fig. 16 .... Relative Location of Flange, Radius and Vena Contracta Taps