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

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

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

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

so that, approximately,

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

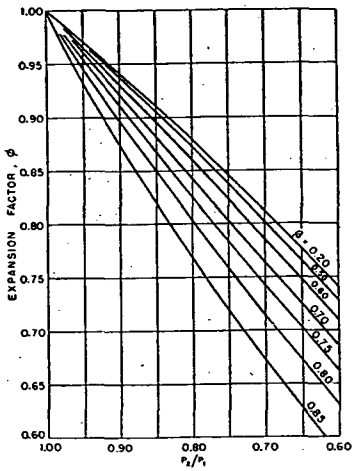

FIG. 14. RELATION OF EXPANSION FACTOR, ϕ, FOR NOZZLES TO DIAMETER RATIO AND PRESSURE LOSS FOR STEAM, CARBON DIOXIDE AND NATURAL GAS

where to the same degree of approximation from Equation 36

$$M_2^2 = 2\frac{p_1-p_2}{kp_1} \tag{60}$$

Values of ϕ are also given by Figs. 13 and 14.

While ϕ 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 ϕ by an empirical factor Y obtained by the equation

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

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

$$w = KA_2Y\sqrt{2gp_1(p_1-p_2)} \tag{62}$$

Installation of Head Meters

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 need for applying suitable coefficients to measure-

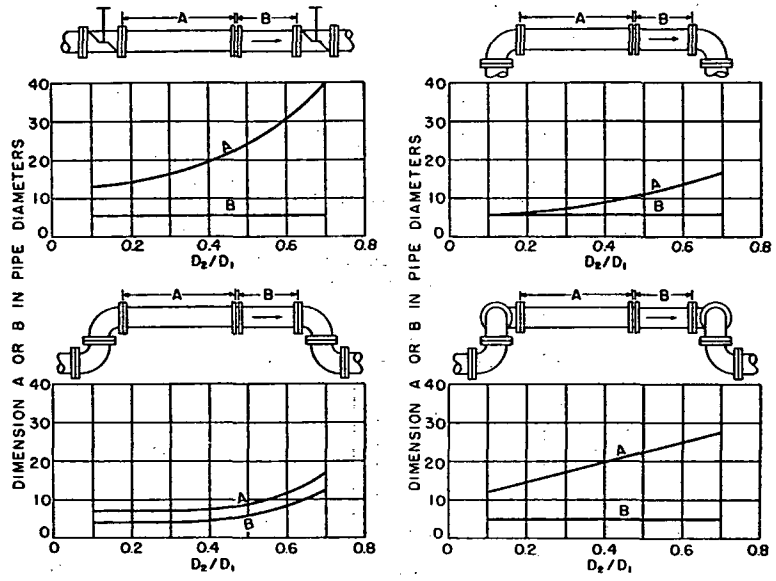

FIG. 15. MINIMUM CONDITIONS TO BE OBSERVED WHEN INSTALLING ORIFICES AND NOZZLES BETWEEN FITTINGS AND VALVES

ments 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 $2\frac{1}{2}$ 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.