FLUID MECHANICS FOR MECHANICAL ENGINEERING (ME 208F)

Section B:
Fluid Dynamics - III

- **Venturi, nozzle and orifice meters**

- The Venturi-, nozzle- and orifice-meters are three similar types of devices for measuring discharge in a pipe. The Venturi meter consists of a rapidly converging section, which increases the velocity of flow and hence reduces the pressure. It then returns to the original dimensions of the pipe by a gently diverging 'diffuser' section. By measuring the pressure differences the discharge can be calculated. This is a particularly accurate method of flow measurement as energy losses are very small.
- The nozzle meter or flow nozzle is essentially a Venturi meter with the convergent part replaced by a nozzle installed inside the pipe and the divergent part omitted. The orifice meter is a still simpler and cheaper arrangement by which a sharp-edged orifice is fitted concentrically in the pipe.
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- The working formulae are similar for the three devices. Let us for illustration show the one for the Venturi meter. Applying the Bernoulli equation along the streamline from point 1 to point 2 in the narrow *throat* of the Venturi meter, we have

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$$\frac{p_1}{\rho g}+z_1+\frac{V_1^2}{2g}=\frac{p_2}{\rho g}+z_2+\frac{V_2^2}{2g}$$

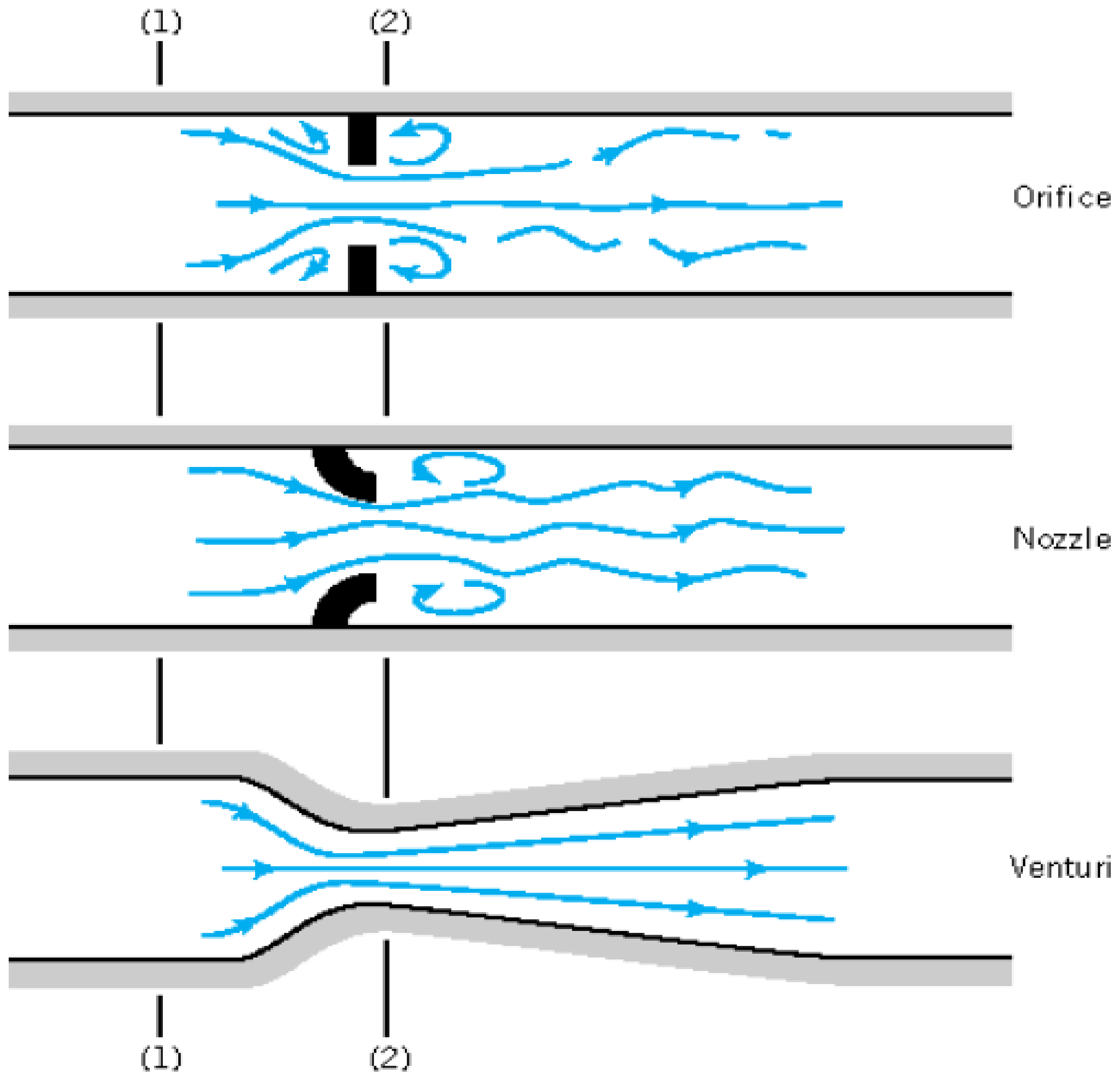
By using the continuity equation we can eliminate the velocity V_2, $Q = A_1V_1 = A_2V_2$ or $V_2 = A_1V_1 / A_2$.

Substituting this into and rearranging the Bernoulli equation we get

$$V_1=\sqrt{\frac{2g\left[\frac{p_1-p_2}{\rho g}+z_1-z_2\right]}{\left(A_1/A_2\right)^2-1}}$$

To get the theoretical discharge this is multiplied by the area. To get the actual discharge taking in to account the losses due to friction, we include a coefficient of discharge

$$Q_{\text{ideal}}=A_1V_1; \qquad Q_{\text{actual}}=C_dQ_{\text{ideal}}=C_dA_1V_1=C_dA_1\sqrt{\frac{2g\left[\frac{p_1-p_2}{\rho g}+z_1-z_2\right]}{\left(A_1/A_2\right)^2-1}}$$



(1)
(2)
Orifice
Nozzle
Venturi
(1)
(2)

To get the theoretical discharge this is multiplied by the area. To get the actual discharge taking in to account the losses due to friction, we include a coefficient of discharge

$$Q_{\text{ideal}} = A_1 V_1; \qquad Q_{\text{actual}} = C_d Q_{\text{ideal}} = C_d A_1 V_1 = C_d A_1 \sqrt{\frac{2g\left[\dfrac{p_1 - p_2}{\rho g} + z_1 - z_2\right]}{\left(A_1 / A_2\right)^2 - 1}}$$

Suppose a differential manometer is connected between (1) and (2). Then the terms inside the square brackets can be related to the manometer reading h as given by

$$p_1 + \rho g z_1 = p_2 + \rho_{man} g h + \rho g \left(z_2 - h\right) \Rightarrow \frac{p_1 - p_2}{\rho g} + z_1 - z_2 = h\left(\frac{\rho_{man}}{\rho} - 1\right)$$

Thus the discharge can be expressed in terms of the manometer reading:

- Notice how this expression does not include any terms for the elevation or orientation ($z1$ or $z2$) of the Venturi meter. This means that the meter can be at any convenient angle to function.
- The purpose of the diffuser in a Venturi meter is to assure gradual and steady deceleration after the throat. This is designed to ensure that the pressure rises again to something near to the original value before the Venturi meter. The angle of the diffuser is usually between 6 and 8 degrees. Wider than this and the flow might separate from the walls resulting in increased friction and energy and pressure loss. If the angle is less than this the meter becomes very long and pressure losses again become significant. The efficiency of the diffuser of increasing pressure back to the original is rarely greater than 80%.

$$Q_{\text{actual}} = C_d A_1 \sqrt{\frac{2gh\left[\frac{\rho_{man}}{\rho} - 1\right]}{(A_1 / A_2)^2 - 1}}$$