

Fluid Mechanics

Chapter 13

Flow Measurements

Measuring Velocity and Pressure

(Read Chapter 13.1-13.2)

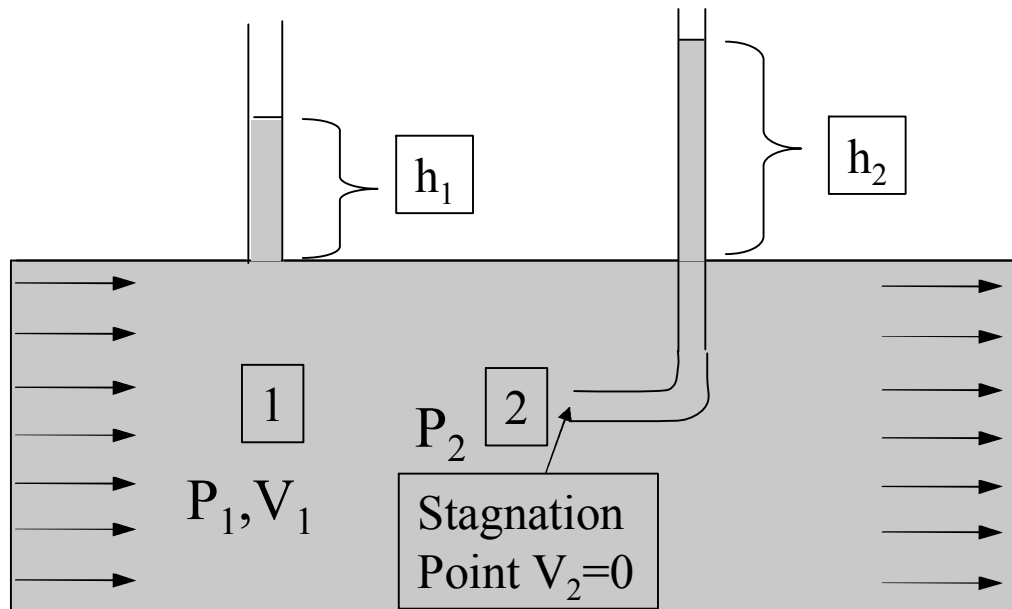
Flow Measurement

The Bernoulli equation can be applied to several commonly occurring situations in which useful relations involving pressures, velocities and elevations may be obtained.

A very important application in engineering is *fluid flow measurement*

- Measurement of velocity : Pitot-static tube
- Measurement of flow rate: Venturi meter
Orifice meter

The Pitot-Static Tube



Refer to Chapter 4 for a review

- P_1 is a **Static pressure**: It is measured by a device (static tube) that causes no velocity change to the flow. This is usually accomplished by drilling a small hole normal to a wall along which the fluid is flowing.
- P_2 is a **Stagnation pressure**: It is the pressure measured by an open-ended tube facing the flow direction. Such a device is called a Pitot tube.

Pitot-Static tube

Bernoulli equation (4.42) between 1 and 2: $(P_2 - P_1) + \frac{\rho(V_2^2 - V_1^2)}{2} = 0$

$$P_2 = P_1 + \frac{1}{2} \rho V_1^2$$

❖ Stagnation Pressure is higher than Static Pressure

(Recall that position 2 is a *stagnation* point: $V_2 = 0$)

$$V_1 = \left[\frac{2(P_2 - P_1)}{\rho} \right]^{1/2}$$

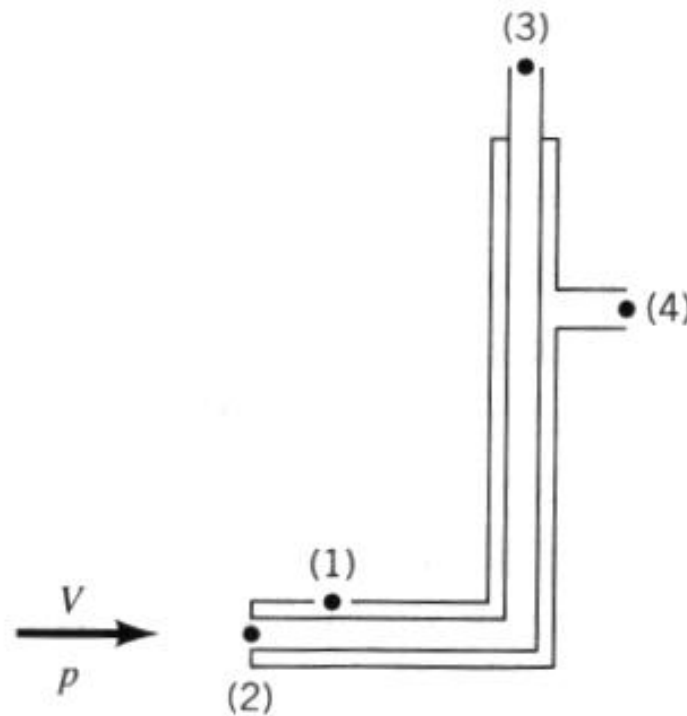
We can measure pressures P_1 and P_2 using hydrostatics:

$$P_1 = P_{\text{atm}} + \rho g h_1, \quad P_2 = P_{\text{atm}} + \rho g h_2$$

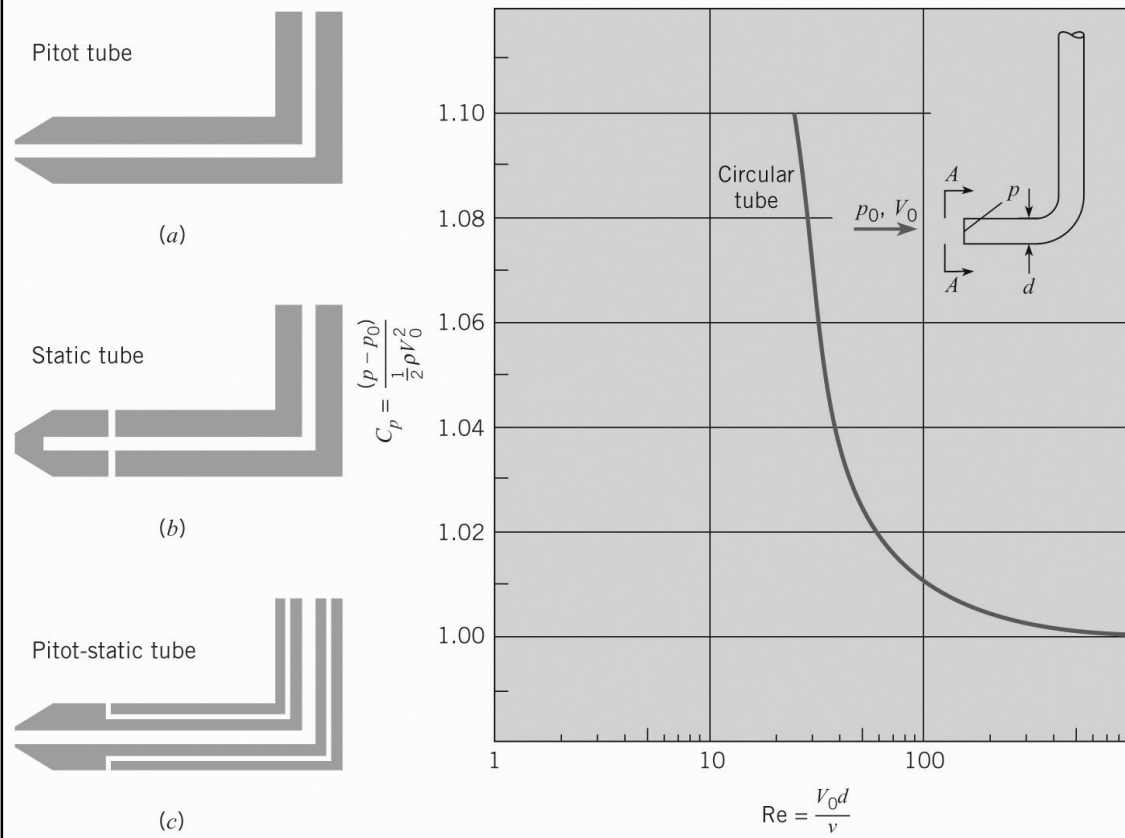
or using a Pressure Gauge

Pitot-static tube

The static and Pitot tube are often combined into the one-piece Pitot-static tube.



Pitot-static tube



- When we studied these in Chapter 4, we neglected viscous effects.
- In reality, you would need to look at a plot of the pressure coefficient (C_p – Chap. 4.7) vs Re to get an accurate velocity measurement

Fluid Mechanics

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Flow Measurements

Measuring Flow Rates (Discharge)

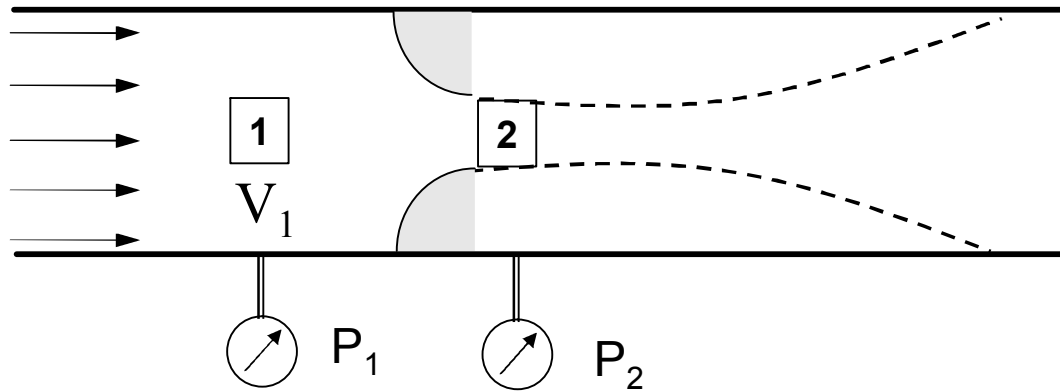
(Read Chapter 13.1-13.2)

Orifice, Nozzle and Venturi meters

Basic principle: Increase in velocity causes a decrease in pressure.

- Fluid is accelerated by forcing it to flow through a constriction, thereby increasing kinetic energy and decreasing pressure energy.
- The flow rate is determined by measuring the pressure difference between the meter inlet and a point of reduced pressure.
- Desirable characteristics of flow meters:
 - Reliable, repeatable calibration
 - Introduction of small energy loss into the system
 - Inexpensive
 - Minimum space requirements

Generalized flow obstruction in a pipe with ideal flow



Continuity equation between 1 and 2: $Q = A_1 V_1 = A_2 V_2$

Bernoulli equation between 1 and 2: $(P_2 - P_1) + \frac{\rho(V_2^2 - V_1^2)}{2} = 0$

$$V_{2,\text{ideal}} = \sqrt{\frac{2(P_1 - P_2)}{\rho [1 - (A_2 / A_1)^2]}}$$

Generalized flow obstruction in a pipe with real flow

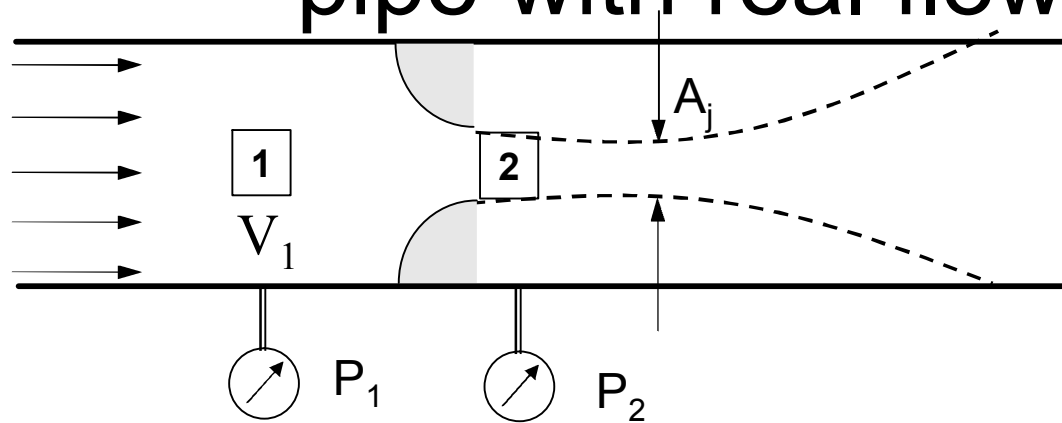
- In $V_{2, ideal}$ Eqn. frictional losses have not been taken into account
- To account for frictional losses we use a “discharge” coefficient, C_d :

$$V_2 = C_d V_{2, ideal}$$
$$V_2 = C_d \sqrt{\frac{2(P_1 - P_2)}{\rho [1 - (A_2 / A_1)^2]}}$$
$$V_2 = C_d \sqrt{\frac{2g(h_1 - h_2)}{[1 - (A_2 / A_1)^2]}}$$

- The volumetric flow rate can be easily calculated:

$$Q = V_2 A_2$$

Generalized flow obstruction in a pipe with real flow



- With any contraction, the contracted area of the jet is smaller than the opening: $A_j = C_c A_2$
- Therefore, a new term is introduced, K , which is the flow coefficient:

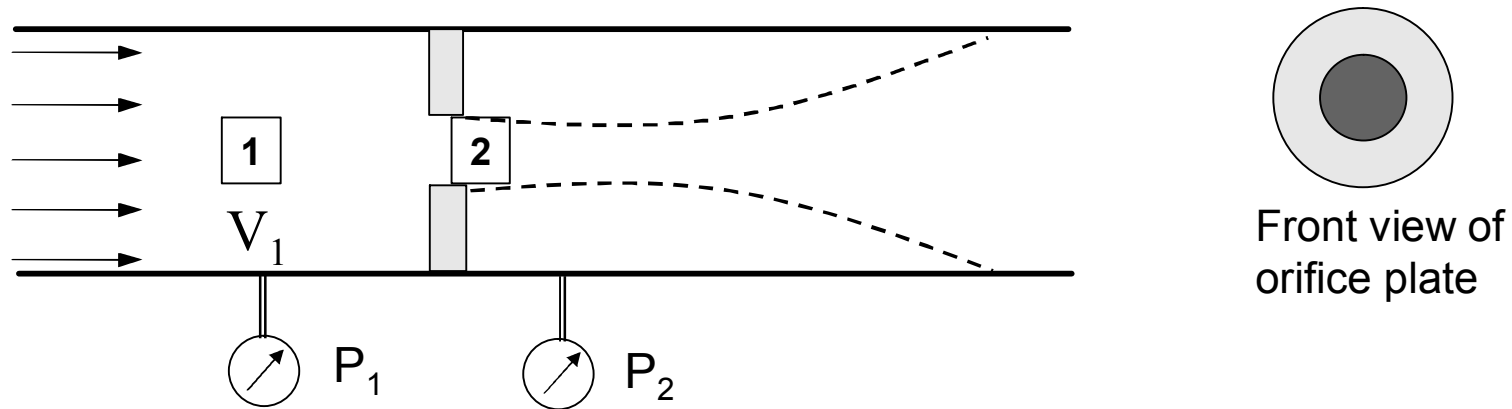
$$K = \frac{C_d}{\sqrt{[1 - (C_c^2 A_2 / A_1)^2]}}$$

- And: $V_2 = K \sqrt{2g(h_1 - h_2)}$

$$Q = V_2 A_2$$

Orifice Meter

This type of meter consists of a thin flat plate with a circular hole drilled in its center. It is very simple, inexpensive and easy to install, but it can cause significant pressure drops.

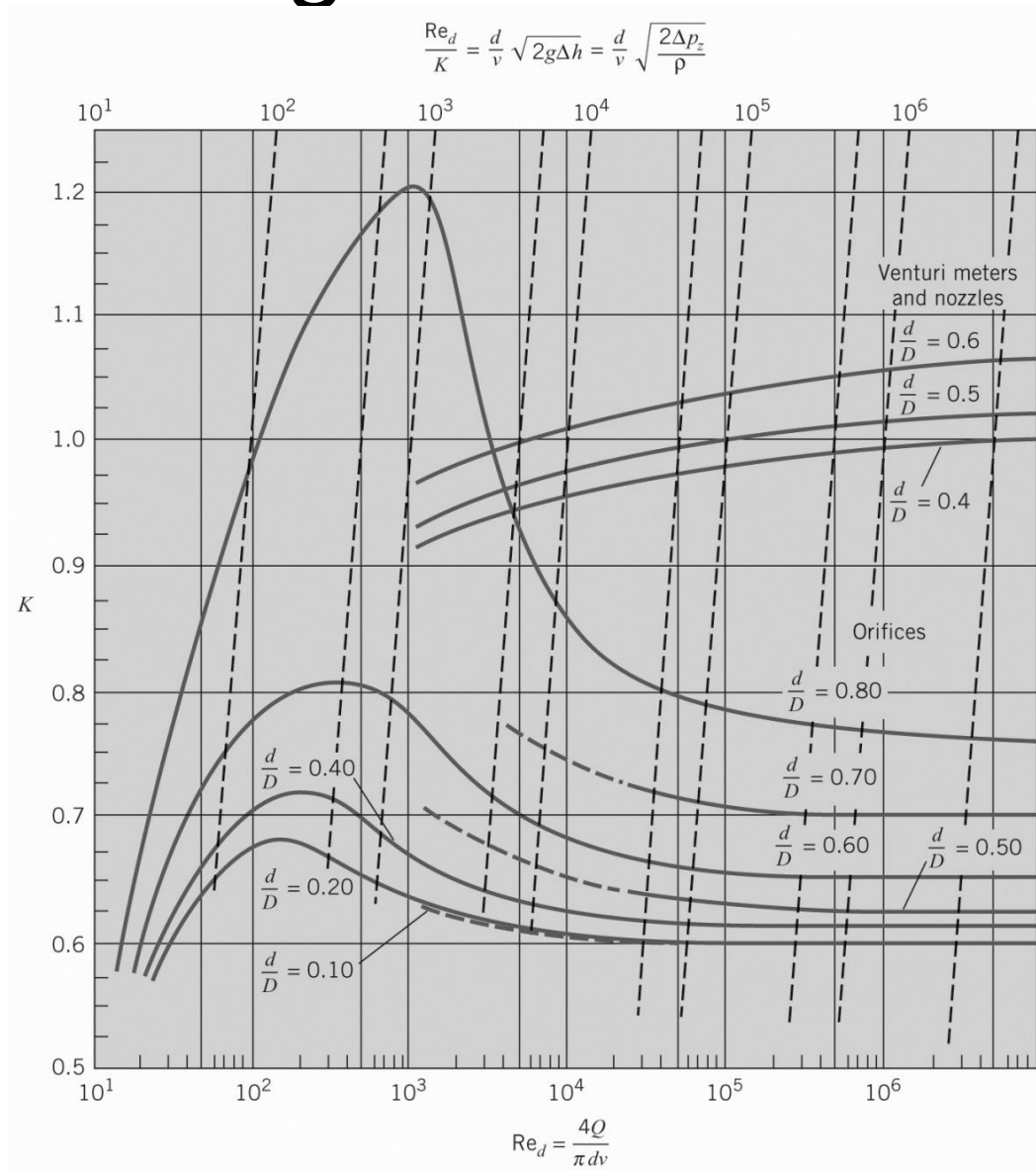


$$V_2 = K\sqrt{2g(h_1 - h_2)}$$

$$Q = V_2 A_2$$

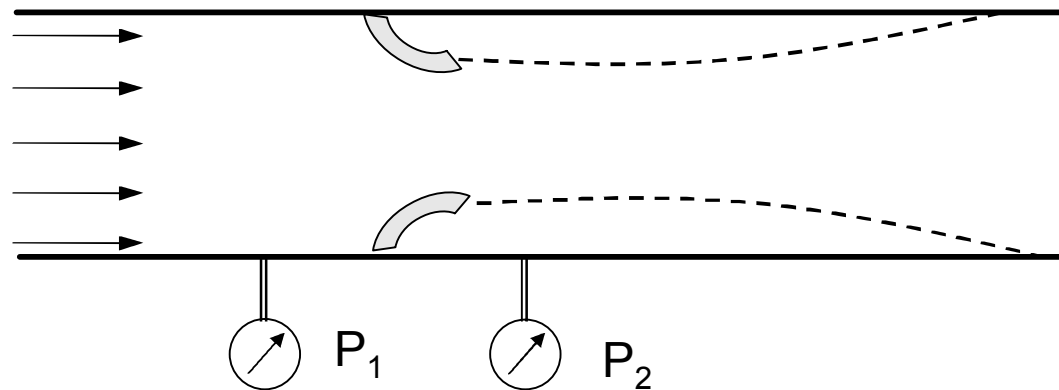
Where the discharge coefficient, $K = f(\text{Re}, D_2/D_1)$, can be found in Figure 13.14 of your textbook.

Figure 13.14



Nozzle Meter

The nozzle meter uses a contoured nozzle. The resulting flow pattern for the nozzle meter is closer to ideal.



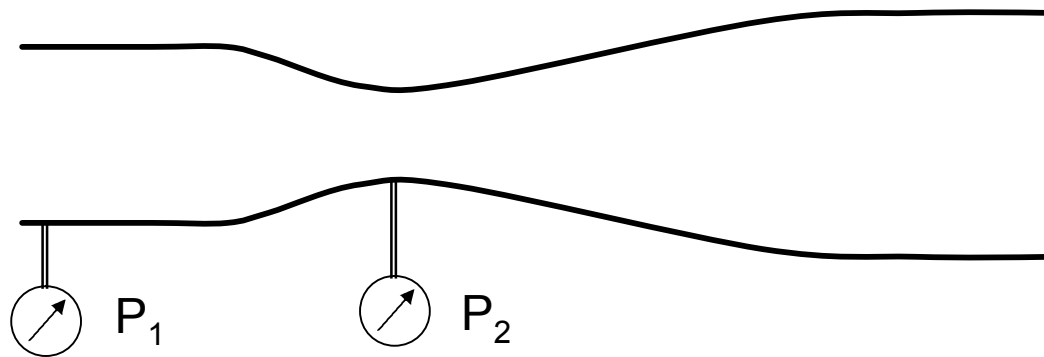
$$V_2 = K\sqrt{2g(h_1 - h_2)}$$

$$Q = V_2 A_2$$

Where the discharge coefficient, $K = f(\text{Re}, D_2/D_1)$, can be found in Figure 13.14 of your textbook.

Venturi Meter

This device consists of a conical contraction, a short cylindrical throat and a conical expansion. The fluid is accelerated by being passed through the converging cone. The velocity at the “throat” is assumed to be constant and an average velocity is used. The venturi tube is a reliable flow measuring device that causes little pressure drop. It is used widely particularly for large liquid and gas flows.



$$V_2 = K\sqrt{2g(h_1 - h_2)}$$

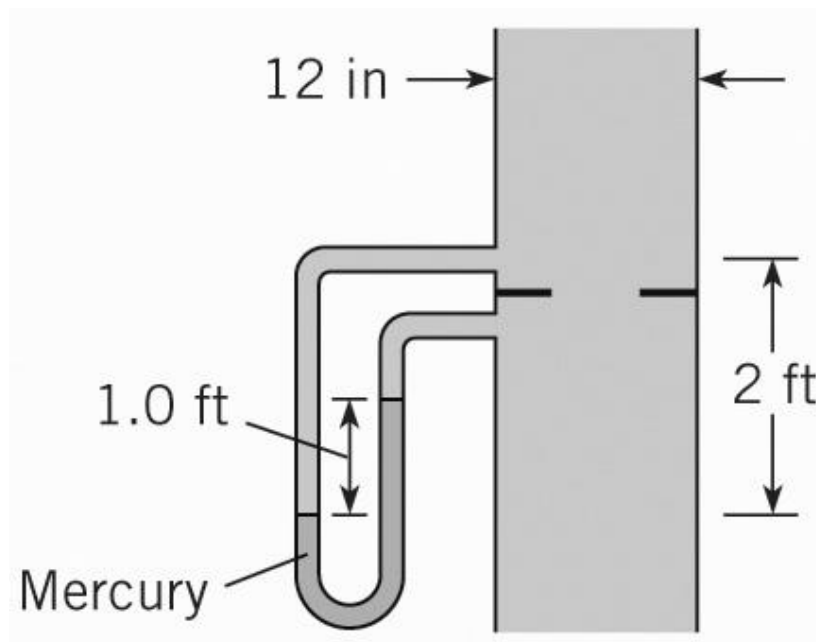
$$Q = V_2 A_2$$

Where the discharge coefficient, $K = f(\text{Re}, D_2/D_1)$, can be found in Figure 13.14 of your textbook.

Summary

- The Bernoulli equation can be applied with negligible error to almost all steady flows of liquids and for steady flows of gases at low velocities (incompressible, irrotational, inviscid).
- A large number of devices for the measurement of fluid velocity and flow rate are based on the conservation of energy. The Bernoulli equation can be conveniently used to make the appropriate calculations.

Example Problem 13.25

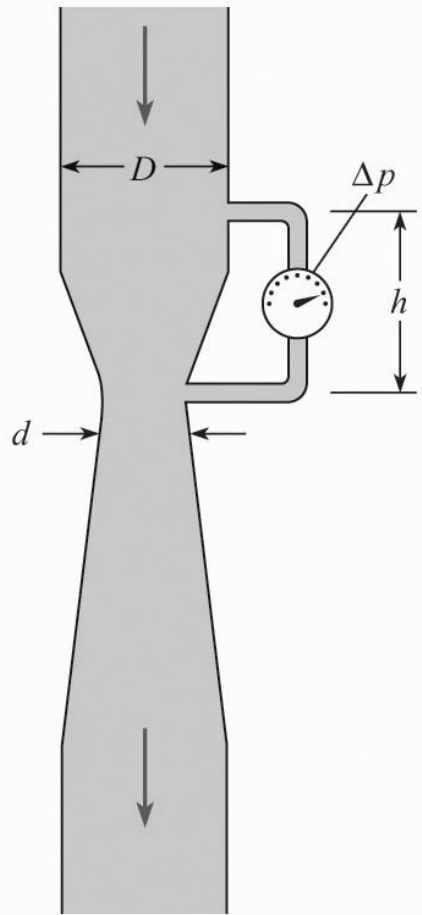


➤ Determine the discharge of water through this 6 in. orifice that is installed in a 12 in. pipe.

➤ Steps:

- Calculate head in mercury manometer
- Find K ($Re, d/D$)
- Calculate Q

Example Problem 13.47



- The differential-pressure gage on the venturi meter reads:
 - 45 kPa
 - $d = 20$ cm
 - $D = 40$ cm
 - $h = 80$ cm
- What is the discharge of gasoline ($S = 0.69$; $\mu = 3 \times 10^{-4} \text{ N} \cdot \text{s/m}^2$) in the system?