Both, friction and the formation of the vena contracta affect the discharge through the orifice. The estimate using the Bernoulli equation based on ideal fluid disregarding the contraction gives a rather higher value than the actual discharge. As before, to correct this over estimation, a correction factor is introduced. *Coefficient of discharge,* C_d is defined as the ratio between the actual and ideal discharges.

$$C_d = C_c \times C_v \tag{4.20}$$

Assume the discharge at the vena contracta to be Q.

$$Q = A_{vc} \times v_2 = C_c A_o \times C_v \sqrt{2hg}$$

$$= C_c C_v A_o \sqrt{2gh} = C_d A_o \sqrt{2gh}$$

Therefore the actual discharge through the orifice is given by

$$Q = C_d A_o \sqrt{2hg} \tag{4.21}$$

Coefficient of discharge for some nozzle types is shown in Figure 4.15. C_c, C_v and C_d are determined experimentally.

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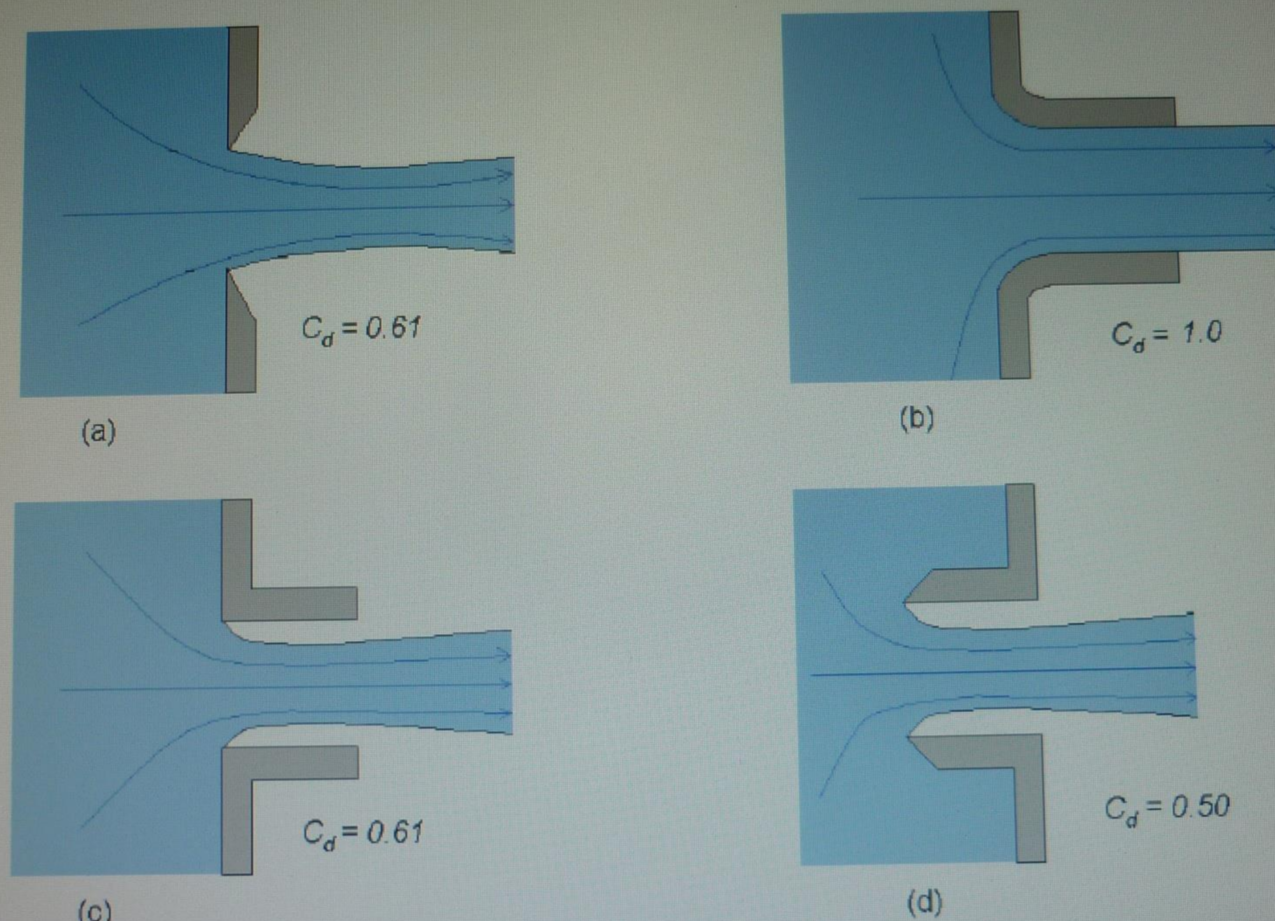
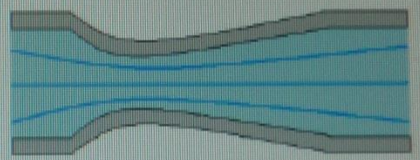
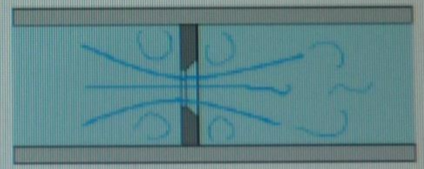


Figure 4.15 Discharge coefficients for some nozzle types

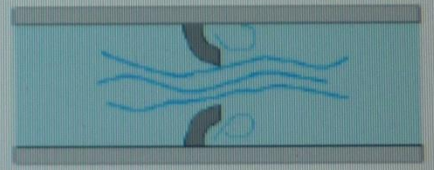
1. Venturi meter



2. Orifice meter



3. Flow nozzle



nturi meter

Example

Consider a fluid with density 800 kgm^{-3}.

1. This fluid is placed in a 5 mm gap between two parallel plates. Top plate is moved with a constant velocity 0.25 ms^{-1} over the fixed bottom plate. It is found that the top plate experience a force 0.125 Nm^{-2}. Determine the kinematic viscosity of the fluid.
2. Same fluid is flowing in a pipe. The pipe diameter is 200 mm. A Pitot tube with an external manometer is connected to the pipe. The manometer fluid is water. The height difference between the water levels in the two legs is 33 mm.

a) Calculate the volumetric flowrate in the pipe.

b) Calculate the Reynolds number of the pipe flow.

Answer

a) Calculate the volumetric flowrate in the pipe.

b) Calculate the Reynolds number of the pipe flow.

Answer

Determining the kinematic viscosity

Flow configuration described in the question is shown in figure Q4.2.

According to the Newton's law on fluid shear stress,

$$\tau = \frac{F}{A} = \mu \frac{du}{dy} \text{-------------------------} (1)$$

where μ is the viscosity and $\frac{du}{dy}$ is the velocity gradient.

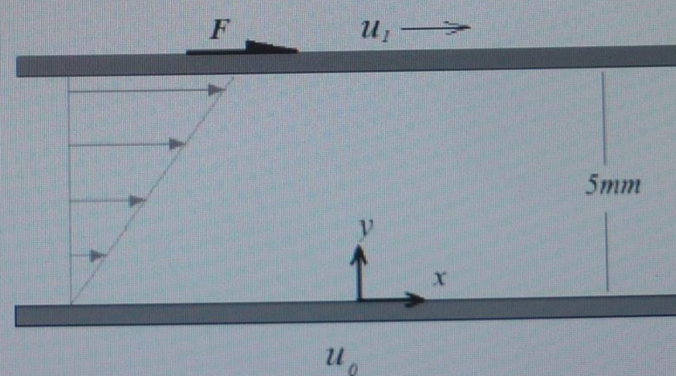


Figure Q4.21

Velocity gradient can be written as

$$\frac{du}{dy} = \frac{\Delta u}{\Delta y} = \frac{u_1 - u_0}{\Delta y} \quad (2)$$

Therefore $\tau = \frac{F}{A} = \mu\left(\frac{u_1 - u_0}{\Delta y}\right)$ (3)

It is given that

$\frac{F}{A} = 0.125\ N/m^2$

$u_1 = 0.25\ m/s$

$\frac{F}{A} = 0.125\ N/m^2$

$u_1 = 0.25\ m/s$

$u_0 = 0$

$\Delta y = 5\ mm$

Rearranging equation (3)

$\mu = \left(\frac{F}{A}\right)\left(\frac{\Delta y}{u_1}\right)$-------------------------- (4)

Substituting values given $\mu = 0.125 \times \left(\frac{5}{0.25}\right) = 2.5 \times 10^{-3} Pa \cdot s$

Kinematic viscosity $\nu = \frac{\mu}{\rho} = \frac{2.5\times10^{-3}}{800} = 3.125 \times 10^{-6}\ m^2/s$

2. (a) Calculating the volumetric flow rate

Diameter of the pipe D = 200 mm

The flow rate $Q = \frac{\pi D^2}{4} U$------------------------(5)

where U is the average velocity. U has to be determined using the Pitot tube information given.

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Applying the Bernoulli equation at planes defined by the Pitot tube openings

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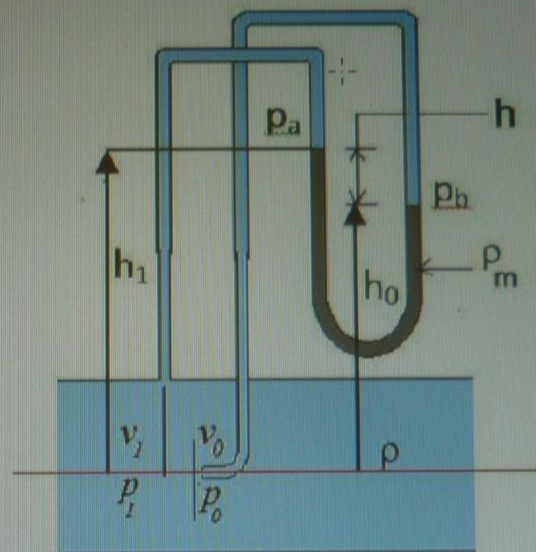

Figure Q4.3

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} = \frac{p_0}{\rho g} \qquad (6)$$

$$v_1^2 = \frac{2(p_0 - p_1)}{\rho} \qquad (7)$$

Using the diagram

$$p_b = p_0 - h_0 \rho g \text{------------------------(a)}$$

$$p_a = p_1 - h_1 \rho g \text{------------------------(b)}$$

From (a)-(b)

$$p_b - p_a = p_0 - p_1 + h_1 \rho g - h_0 \rho g$$

$$h \rho_w g = p_0 - p_1 + h \rho g$$

$$p_0 - p_1 = h \rho_w g \left[1 - \frac{\rho}{\rho_w}\right] \text{---------------(8)}$$

Therefore,

$$v_1 = \sqrt{2hg\left(\frac{\rho_w}{\rho} - 1\right)} \text{---------------- (9)}$$

Using equation (9)

$$v_1 = \sqrt{2 \times 0.033 \times 9.81 \left(\frac{1000}{800} - 1\right)} = 0.40\ m/s$$

7.6 Flow Control

When using pumps to move liquid between process vessels, flow rates has to be controlled. In some cases a certain flowrate has be achieved but finding a pump may be difficult. There may be instances where one has to increase the flowrate economically or achieve higher heads than an individual pump could provide. How to address these problems are explained below.

7.6.1 Throttling

Consider the system curve. The curve is dependent on the head losses. Therefore, by changing the pressure drop the steepness of the curve could be changed. As the pressure drop increases the steepness increases. This is achieved by opening or closing a valve downstream of the pump. Valve that is used to control the flow is called the throttle valve and controlling the head in such a manner is called throttling. This valve is shown immediately of the pump in Figure 10.

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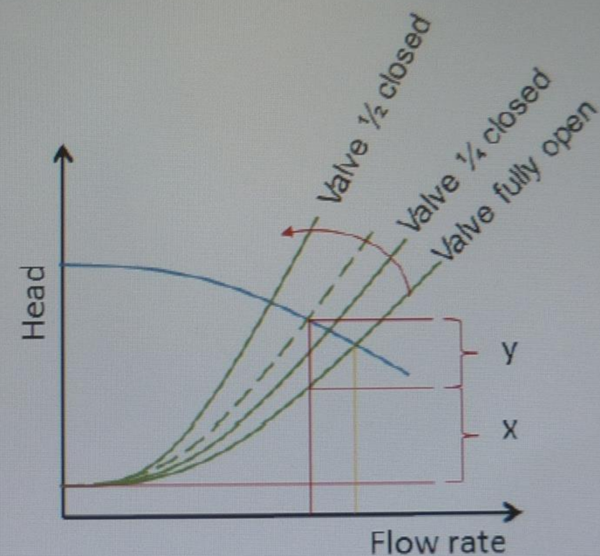

Figure 7.16. Impact of throttling on the system curve

When the throttle valve closes the point at which the system curve intersect the pump curve moves to the left as shown in the figure 7.16. The head is gained at the expense of the flow rate.

7.6.2 Varying pump speed

Flowrate can be increased by increasing the speed of the impeller. Variable speed pumps are normal centrifugal pumps fitted with variable speed motors. The speed of the motor is controlled through an inverter that controls the current to the motor.