# Production & Industrial Engineering

# General Engineering

## Vol. VI : Fluid Mechanics

Comprehensive Theory

*with* Solved Examples and Practice Questions

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**General Engineering : Vol. VI – Fluid Mechanics**



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## Fluid Mechanics



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VOLUME VI

# General Engineering

# Fluid Mechanics

## INTRODUCTION

**Fluid Mechanics** can be defined as the science which deals with the study of behaviour of fluids either at rest or in motion.

It can be divided into **fluid statics**, the study of fluids at rest; and **fluid dynamics**, the study of the effect of forces on fluid motion. It is a branch of continuum mechanics, a subject which models matter without using the information that it is made out of atoms; that is, it models matter from a **macroscopic** viewpoint rather than from **microscopic**. Fluid mechanics, especially fluid dynamics, is an active field of research, typically mathematically complex. Many problems are partly or wholly unsolved, and are best addressed by numerical methods, typically using computers. A modern discipline, called computational fluid dynamics (CFD), is devoted to this approach. Particle image velocimetry, an experimental method for visualizing and analyzing fluid flow, also takes advantage of the highly visual nature of fluid flow.

## 6.1 Fluid

A fluid is a substance which deforms continuously when subjected to external shearing forces. Following are some of the important characteristics of fluid :

1. It has no definite shape of its own, but conforms to the shape of the containing vessel.
2. Even a small amount of shear force exerted on a fluid will cause it to undergoes deformation which continues as long as the force continues to be applied.
3. It is interesting to note that a solid suffers strain when subjected to shear forces whereas a fluid suffers rate of strain i.e. it flows under similar circumstances.

### 6.1.1 Some Important Properties

1. **Mass Density :** Mass density (or specific mass) of a fluid is the mass which it possesses per unit volume. It is denoted by the Greek symbol $\rho$. In SI system, the unit of $\rho$ is kg/m$^3$.
2. **Specific Gravity :** Specific gravity ($S$) is the ratio of specific weight ( or mass density) of a fluid to the specific weight (or mass density) of a standard fluid. The standard fluid chosen for comparison is pure water at 4°C.

$$\text{Specific gravity of liquid} = \frac{\text{Specific weight of liquid}}{\text{Specific weight of water}} = \frac{\text{Specific weight of liquid}}{9810\ \text{N/m}^3}.$$

3. **Relative Density (R.D.) :** It is defined as ratio of density of one substance with respect to other substance.

$$\rho_{1/2} = \frac{\rho_1}{\rho_2}$$

where, $\rho_{1/2}$ = Relative density of substance '1' with respect to substance '2'.

4. **Specific Weight :** Specific weight (also called weight density) of a fluid is the weight it possesses per unit volume. It is denoted by the Greek symbol $\gamma$. For water, it is denoted by $\gamma_w$. In SI system, the unit of specific weight is N/m$^3$. The mass density and specific weight $\gamma$ has following relationship $\gamma = \rho g$ ; $\rho = \gamma / g$ . Both mass density and specific weight depend upon temperature and pressure.

5. **Specific Volume :** Specific volume of a fluid is the volume of the fluid per unit mass. Thus it is the reciprocal of density. It is generally denoted by *v*. In SI unit specific volume is expressed in cubic meter per kilogram, i.e., m$^3$/kg.

## 6.1.2 Ideal and Real Fluid

### 1. Ideal Fluid

An ideal fluid is one which has

- no viscosity
- no surface tension
- and incompressible

### 2. Real Fluid

A real fluid is one which has

- viscosity
- surface tension
- and compressible

Naturally available all fluids are real fluids.

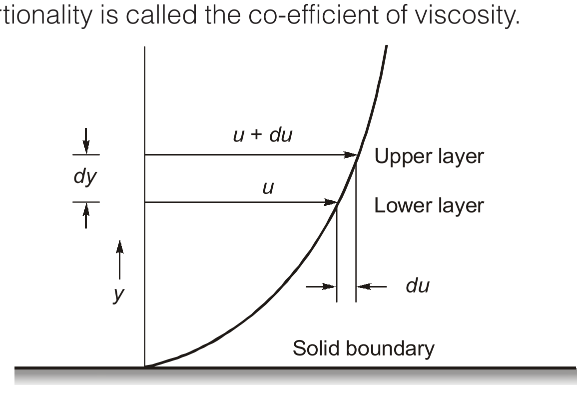
## 6.1.3 Viscosity

**Definition :** Viscosity is the property of a fluid which determines its resistance to shearing stresses.

**Cause of Viscosity :** It is due to cohesion and molecular momentum exchange between fluid layers.

**Newton's Law of Viscosity :** It states that the shear stress ($\tau$) on a fluid element layer is directly proportional to the rate of shear strain.

The constant of proportionality is called the co-efficient of viscosity.




**Velocity variation near a solid wall**

When two layers of fluid, at a distance '*dy*' apart, move one over the other at different velocities, say *u* and *u* + *du*.

$$\text{Velocity gradient} = \frac{du}{dy}$$

According to Newton's law

$$\tau \propto \frac{du}{dy}$$

or,
$$\tau = \mu \frac{du}{dy}$$

where μ = constant of proportionality and is known as co-efficient of viscosity or dynamic viscosity or simply viscosity.

As
$$\mu = \frac{\tau}{\left[\frac{du}{dy}\right]}$$

Thus viscosity may also be defined as the shear stress required, producing unit rate of shear strain.

**Units of Viscosity**

S.I. Units : Pa.s or N.s/$m^2$

C.G.S. Unit of viscosity is poise = dyne-sec/$cm^2$

One poise = 0.1 Pa.s

1/100 poise is called centipoise.

Dynamic viscosity of water at 20°C is approximate = 1 cP

**Effect of Temperature on Viscosity**

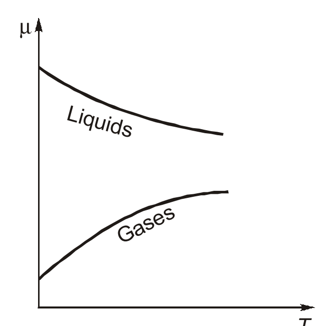
**Effect of Temperature on Viscosity**

- It is necessary to understand the factors contributing to viscosity to analyse temperature effect.
- In liquid, viscosity is caused by intermolecular attraction force which weaken as temperature rises so viscosity decreases.
- In gases, viscosity is caused by the random motion of particle/ molecules. Due to increase in temperature, randomness increases causing increase in viscosity.
- For liquids viscosity decreases with temperature and it is roughly exponential as

$$\mu = ae^{-bT}$$

where *a* and *b* are constant for a particular liquid.

For water $a = -1.94, \quad b = -4.80$



**Variation of Viscosity with Temperature**

**NOTE :** 1. Temperature responses are neglected in case of Mercury.
2. The lowest viscosity is reached at the critical temperature.

**Example 6.15** A wooden log of 0.6 m diameter and 5 m length is floating in river water. Find the depth of the wooden log in water when the specific gravity of the log is 0.7.

**Solution :**

Given :

Diameter of log = 0.6 m

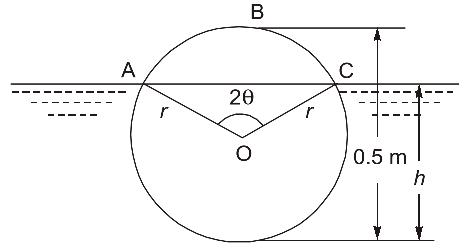
Length, $L = 5$ m

Specific gravity $S = 0.7$

∴ Density of log = 0.7 × 1000 = 700 kg/m$^3$

∴ Weight density of log, $w = \rho \times g = 700 \times 9.81$ N/m$^3$

Find depth of immersion or $h$




Weight of wooden log = Weight density × Volume of log

$$= 700 \times 9.81 \times \frac{\pi}{4}(D)^2 \times L$$

$$= 700 \times 9.81 \times \frac{\pi}{4}(0.6)^2 \times 5 \text{ N} = 989.6 \times 9.81 \text{ N}$$

For equilibrium,

Weight of wooden log = Weight of water displaced

= Weight density of water × Volume of WATER displaced

$$\therefore \quad \text{Volume of water displaced} = \frac{989.6 \times 9.81}{1000 \times 9.81} = 0.9896 \text{ m}^3$$

(∵ Weight density of water = 1000 × 9.81 N/m$^3$)

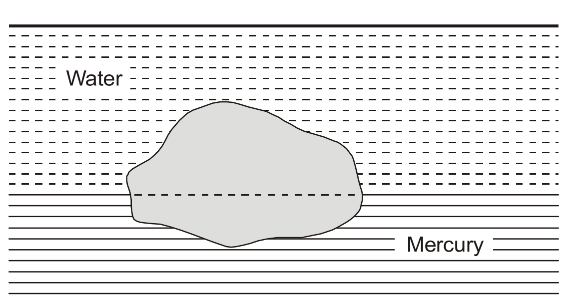
Let $h$ is the depth of immersion

∴ Volume of log inside water = Area of $ADCA$ × Length = Area of $ADCA$ × 5.0

But volume of log inside water = Volume of water displaced = 0.9896 m$^3$

**Example 6.16** Find the density of a metallic body which floats at the interface of mercury of sp. gr. 13.6 and water such that 40% of its volume is sub-merged in mercury and 60% in water.

**Solution :**



Let the volume of the body = $V$ m$^3$

Then volume of body sub-merged in mercury

$$= \frac{40}{100}V = 0.4\ V\ m^3$$

Volume of body sub-merged in water

$$= \frac{60}{100}\times V = 0.6\ V\ m^3$$

For the equilibrium of the body

Total buoyant force (upward force) = Weight of the body

But total buoyant force = Force of buoyancy due to water + Force of buoyancy due to mercury

Force of buoyancy due to water = Weight of water displaced by body

= Density of water × $g$ × Volume of water displaced

= 1000 × $g$ × Volume of body in water

= 1000 × $g$ × 0.6 × $V$ N

and Force of buoyancy due to mercury

= Weight of mercury displaced by body

= $g$ × Density of mercury × Volume of mercury displaced

= $g$ × 13.6 × 1000 × Volume of body in mercury

= $g$ × 13.6 × 1000 × 0.4 $V$ N

Weight of the body = Density × $g$ × Volume of body = $\rho \times g \times V$

where $\rho$ is the density of the body

∴ For equilibrium, we have

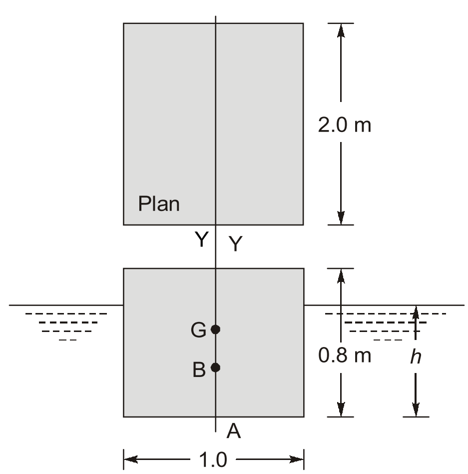
Total buoyant force = Weight of the body

$1000 \times g \times 0.6 \times V + 13.6 \times 1000 \times g \times 0.4\ V = \rho \times g \times V$

or $\rho$ = 600 + 13600 × 0.4 = 600 + 54400 = 6040.00 kg/m$^3$

∴ Density of the body = 6040.00 kg/m$^3$

**Example 6.17** A block of wood of specific gravity 0.7 floats in water. Determine the meta-centric height of the block if its size is 2 m × 1 m × 0.8 m.




**Solution :**

Given :

Dimension of block = 2 × 1 × 0.8

Let depth of immersion = $h$ m

Specific gravity of wood = 0.7

Weight of wooden piece = Weight density of wood* × Volume

$= 0.7 \times 1000 \times 9.81 \times 2 \times 1 \times 0.8$ N

Weight of water displaced = Weight density of water × Volume of the wood sub-merged in water

$= 1000 \times 9.81 \times 2 \times 1 \times h$ N

For equilibrium,

Weight of wooden piece = Weight of water displaced

$$\therefore \quad 700 \times 9.81 \times 2 \times 1 \times 0.8 = 1000 \times 9.81 \times 2 \times 1 \times h$$

$$\therefore \quad h = \frac{700 \times 9.81 \times 2 \times 1 \times 0.8}{1000 \times 9.81 \times 2 \times 1} = 0.7 \times 0.8 = 0.56 \text{ m}$$

∴ Distance of centre of Buoyancy from bottom, i.e.,

$$AB = \frac{h}{2} = \frac{0.56}{2} = 0.28 \text{ m}$$

and

$$AG = \frac{0.8}{2.0} = 0.4 \text{ m}$$

$$\therefore \quad BG = AG - AB = 0.4 - 0.28 = 0.12 \text{ m}$$

The meta-centric height is given by equation

$$GM = \frac{I}{\forall} - BG$$

where

$$I = \frac{1}{12} \times 2 \times 1.0^3 = \frac{1}{6} \text{ m}^4$$

$\forall$ = Volume of wood in water

$= 2 \times 1 \times h = 2 \times 1 \times 0.56 = 1.12 \text{ m}^3$

$$\therefore \quad GM = \frac{1}{6} \times \frac{1}{1.12} - 0.12 = 0.1488 - 0.12 = 0.0288 \text{ m.}$$

## 6.6 Conservation Equations in Fluid Mechanics

### 6.6.1 Moment of Momentum Equation

If a fluid particles of mass $m$ moves along a curved path such that its distance from the axis of rotation (i.e., fixed center) changes with time, then radial distance will be different at different positions of the particle. If the flow enters the control volume at a uniform velocity $v_1$ and at a steady rate, then

momentum of flow entering the control volume = $\rho Q v_1$

If this flow has a radius $r_1$, then moment of momentum of flow entering the control volume

$= \rho Q v_1 r_1$

Similarly, if $v_2$ and $r_2$ are the velocity and radius at the outlet of control volume, then

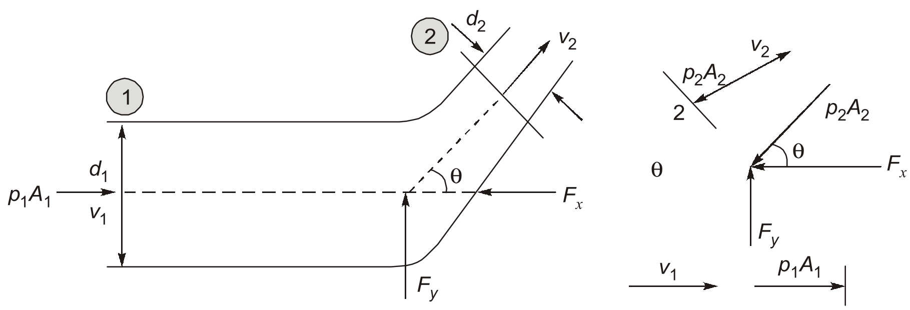
moment of momentum of (low leaving the control volume = $\rho Q v_2 r_2$

According to moment of momentum principal, the resulting torque is equal the time rate of change in moment of momentum, therefore,

$$T = \rho Q(v_2 r_2 - v_1 r_1)$$

**Application of Momentum Equation**

(1) Thrust on a Pipe Bend : The momentum equation is applied for the solution of pipe bend problems.




**Reducing bend**

A control volume selected includes the inlet and outlet sections (1) and (2) of the pipe bend.

Let the average velocity, pressure and the area of flow at sections (1) and (2) be $v_1$, $p_1$, $A_1$ and $v_2$, $p_2$, $A_2$ respectively.

Let $F_x$ and $F_y$ be the components of the force exerted on the fluid by the pipe bend in the $x$ and $y$ directions respectively, then the equations for the bend can be worked out in the following final form:

$$p_1A_1 - p_2A_2\cos\theta - F_x = \frac{\gamma Q}{g}(v_2\cos\theta - v_1)$$

$$F_x = \frac{\gamma Q}{g}(v_2 - v_2\cos\theta) + p_1A_1 = p_2A_2\cos\theta$$

and

$$F_y - p_2A_2\sin\theta = \frac{\gamma Q}{g}(v_2\sin\theta)$$

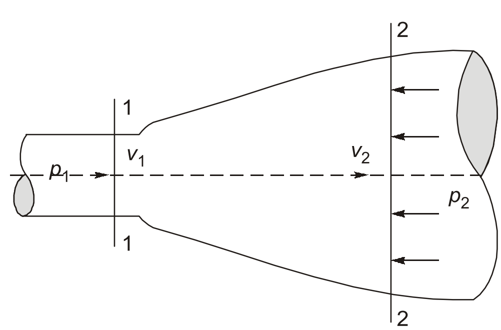
Resultant force,

$$F_R = \sqrt{F_x^2 + F_y^2} \text{ and } \theta = \tan^{-1}\frac{F_y}{F_x}$$

(2) **Mechanical energy loss due to sudden enlargement** Let the incompressible steady fluid flow securing in a pipe of area $A_1$ expands suddenly to area $A_2$. Let the mean velocities at sections 1 and 2 be $v_1$ and $v_2$ respectively.

Apply momentum equation between sections 1-1 and 2-2, we have

$$(p_1 - p_2) = \frac{\gamma v_2}{g}(v_2 - v_1)$$




Apply energy equation between sections 1-1 and 2-2, we have

$$\frac{p_1}{\gamma} + \frac{v_1^2}{2g} = \frac{p_1}{\gamma} + \frac{v_2^2}{2g} + h_L$$

or

$$h_L = \frac{p_1 - p_2}{\gamma} + \frac{v_1^2 - v_2^2}{2g} = \frac{v_2}{g}(v_2 - v_1) + \frac{v_1^2 - v_2^2}{2g}$$

## Student's Assignments 1

**Q.1** Which of the following device is used to measure the difference of low pressures between two points?
(a) U-tube differential manometer
(b) U-tube manometer
(c) Inverted U-tube differential manometer
(d) None of these

**Q.2** A bubble of radius '$R$' and surface tension '$\sigma$' explodes into 8 small bubbles of equal radius '$r$'. Then the energy released during the process is
(a) $\pi\sigma R^2$ (b) $2\pi\sigma R^2$
(c) $4\pi\sigma R^2$ (d) $8\pi\sigma R^2$

**Q.3** The difference between the total head line and the hydraulic grade line represents
(a) velocity head (b) pressure head
(c) elevation head (d) piezoelectric head

**Q.4** The shear stress distribution for a one dimensional viscous flow through pipe is
(a) Parabolic (b) Linear
(c) Cubic (d) None of these

**Q.5** What would be the shear stress distribution across the section of two fixed parallel plates kept at a distance $t$ apart and having a viscous flow?

(a) $\tau = -\frac{1}{2}\left(\frac{\partial P}{\partial x}\right)(t^2 - y^2)$

(b) $\tau = -\frac{1}{2}\left(\frac{\partial P}{\partial x}\right)(t - 2y)$

(c) $\tau = -\frac{1}{2}\left(\frac{\partial P}{\partial x}\right)(ty - y^2)$

(d) $\tau = -\frac{1}{2}\left(\frac{\partial P}{\partial x}\right)(y - ty)$

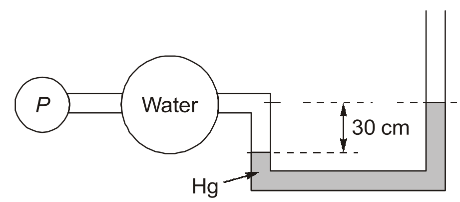
**Q.6** The pressure drop for a relatively low Reynolds number flow in a 600 mm, 30 m long pipe line is 70 kPa. The wall shear stress is __________ Pa.

**Q.7** A pitot tube is used to measure the velocity of water in pipe. The stagnation pressure head is 6 m and the static pressure head is 5 m. If the coefficient of tube is 0.98, then the velocity of flow is ________ m/s.

**Q.8** Consider a body with radius of gyration 2 m about its centre of gravity and metacentric height 1.5 m. If the body is floating in a liquid, then the time period of oscillation is ________sec.

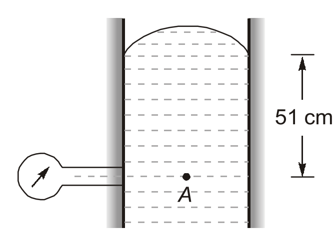
**Q.9** The surface tension of water in contact with air at 20°C is 0.0725 N/m. The pressure inside a droplet of water is to be 0.02 N/cm$^2$ greater than the outside pressure. The diameter of water droplet is _______ cm.

**Q.10** In the given figure pressure $P$ in kPa is




(a) 37 (b) 48
(c) 45.2 (d) 51.3

**Q.11** In a narrow though as shown above the gauge pressure at point '$A$' is 5.010 kPa. If surface tension of water is 0.075 N/m what will be radius of curvature of excess fluid at to P




(a) 21.74 mm (b) 105.43 mm
(c) 10.87 mm (d) 0.704 mm

**Q.12** The pressure drop for a relatively low Reynold's number flow in a 800 mm, 40 m long pipeline is 50 kPa, what is the wall shear stress?
(a) 300 Pa (b) 250 Pa
(c) 200 Pa (d) 150 Pa

**Q.13** A jet of water 50 mm diameter having a velocity of 25 m/s, strikes normally a flat smooth plate. The thrust on the plate if the plate is moving in the same direction as the jet with a velocity of 5 m/s is __________ N.

**Q.14** A vertical clean glass tube of uniform bore is to be used as a piezometer for measuring pressure of a liquid at a point. The liquid has a mass density of 1400 kg/m$^3$ and a surface tension of 0.07 N/m in contact with air. For the liquid the angle of contact with glass is zero. If the capillary rise in the tube is not to exceed 2 mm, then the required minimum diameter of the tube is

(a) 12 mm (b) 10 mm
(c) 6 mm (d) 8 mm

**Q.15** Given the $x$-component of the velocity $u = 6xy - 2x^2$, the $y$-component of the flow velocity is given by

(a) $6y^2 - 4xy$ (b) $-6xy + 2x^2$
(c) $6x^2 - 2xy$ (d) $4xy - 3y^2$

## Student's Assignments 2

**Q.16** Which of the following statements are correct in respect of steady laminar flow through a circular pipe?

1. Shear stress is zero at the centre
2. Discharge varies directly with the viscosity of the fluid
3. Velocity is maximum at the centre
4. Hydraulic gradient varies directly with the velocity

Select the correct answer using the codes given below:

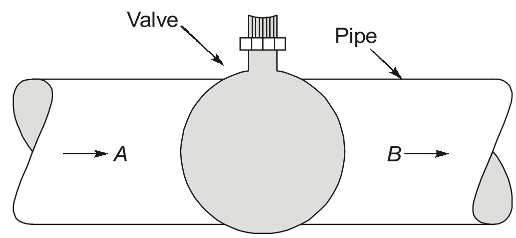
(a) 1, 2 and 4 (b) 1, 3 and 4
(c) 1 and 3 (d) 3 and 4

**Q.17** Water at 15°C flows between two large parallel plate at a distance of 1.6 mm apart. The shear stress at the walls of plate, if the average velocity is 0.2 m/s, is __________ N/m$^2$.
(The viscosity of water at 15°C is given as 0.01 poise)

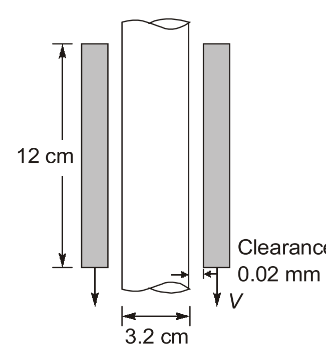
**Q.18** The boundary layer thickness at the trailing edge of a smooth plate of length 4 m and width 1.5 m, when the plate is moving with a velocity of 4 m/s in stationary air is ________ mm. (Take kinematic viscosity of air as $1.5 \times 10^{-5}$ m$^2$/s).

**Q.19** A vertical venturimeter is used to measure the discharge of a liquid of specific gravity 0.9. The flow is downwards and the pressure at the 30 cm inlet is found to be 150 kPa. The pressure at the throat, which has a diameter of 10.0 cm and is 10 cm below the inlet is measured as 90 kPa. If the head loss at the inlet is 2% of the difference in the piezometric head at the inlet and the throat, the discharge passing through the venturimeter is __________ litres/s. [Take density of water = 9.79 kN/m$^3$ and $C_d$ = 0.99]

**Q.20** $A$ and $B$ are at the same elevation of 2.8 m above datum in the valve and pipe line shown in the given figure. Velocity head of 0.8 m, head loss in valve of 0.5 m and pressure head of 2.8 m are the parameters at $A$. Piezometric head at $B$ is equal to __________.

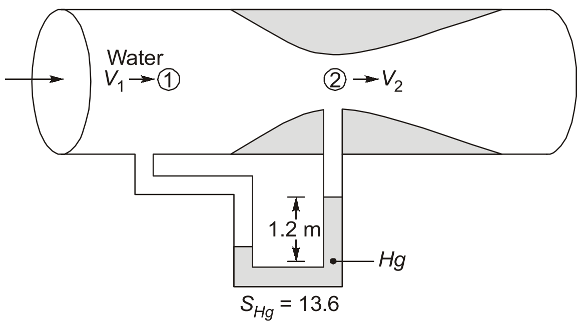



**Q.21** A sleeve 12 cm long encases a vertical metal rod 3.2 cm in diameter with a radial clearance of 0.02 mm. If when immersed in an oil of viscosity 6.0 poise, the effective weight of sleeve is 7.5 N. The sliding velocity of the sleeve down the rod will be (cm/s)________.



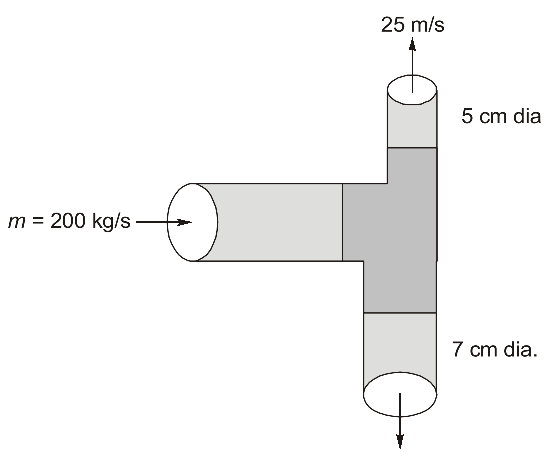

**Q.22** A water droplet of 2 mm diameter is atomized in to 200 equal spherical droplets. If surface tension of water is 0.073 N/m, the energy required to do so is ____________ $\times 10^{-6}$ J.

**Q.23** The venturimeter shown reduces the pipe diameter from 10 cm to a minimum of 5 cm. Assuming ideal conditions, the mass flow rate is




(a) 34.90 (b) 26.18
(c) 40.62 (d) 42.13

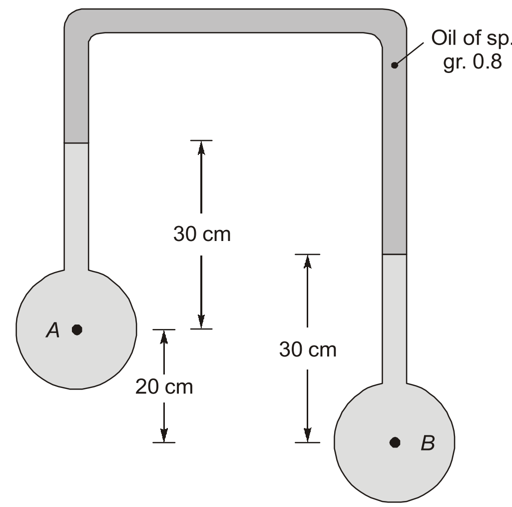
**Q.24** A pipe transports 200 kg/s of water. The pipe divides into a 5 cm diameter pipe and a 7 cm diameter pipe as shown in figure. If the average velocity in the smaller diameter pipe is 25 m/s, the flow rate in the larger pipe is




(a) 312 L/s (b) 151 L/s
(c) 418 L/s (d) 263 L/s

**Q.25** The water is flowing through a taper pipe of length 100 m having diameters 600 mm at the upper end and 300 mm at the lower end, at the rate of 50 litres/seconds. The pipe has a slope of 1 in 30. Find the pressure at the lower end if the pressure at the higher end is 19.62 N/cm$^2$.
(a) 21.623 N/cm$^2$ (b) 22.867 N/cm$^2$
(c) 24.621 N/cm$^2$ (d) 27.128 N/cm$^2$

**Q.26** An inverted differential manometer as shown in figure has a manometeric liquid of specific gravity 0.8. The manometer is connected to two pipes *A* and *B* which conveys water. The pressure difference $(p_B - p_A)$ is ____________N/m$^2$. (Assume $g$ = 10 m/s$^2$)




## ANSWERS

| | | | | |
|---|---|---|---|---|
| 1. (c) | 2. (c) | 3. (a) | 4. (b) | 5. (b) |
| 6. (350) | 7. (4.34) | 8. (3.28) | 9. (0.145) | 10. (a) |
| 11. (c) | 12. (b) | 13. (785.4) | 14. (b) | 15. (d) |
| 16. (b) | 17. (0.75) | 18. (92.2) | 19. (90.18) | 20. (5.1) |
| 21. (2.07) | 22. (4.45) | 23. (a) | 24. (b) | 25. (b) |
| 26. (1600) | | | | |

## HINTS

1. **(c)**
Inverted U-tube manometer uses a light manometer liquid, which is used to measure the difference of low pressures between two points.

2. **(c)**
From volume conservation,

$$\frac{4}{3}\pi R^3 = 8 \times \frac{4}{3}\pi r^3$$

$$R = 2r$$

Now, Energy released ($E$)

$$E = 8 \times \sigma \times 4\pi r^2 - \sigma \times 4\pi R^2$$

$$\therefore \quad E = 8\pi\sigma R^2 - 4\pi\sigma R^2 = 4\pi\sigma R^2$$

3. **(a)**

H.G.L. contains $\left(\frac{P}{\rho g} + z\right)$

T.E.L. contains $\left(\frac{P}{\rho g} + z + \frac{v^2}{2g}\right)$

15. (d)

The flow must satisfy continuity equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y} = 0$$

$$\frac{\partial v}{\partial y} = -\frac{\partial u}{\partial x} = -(6y-4x) = 4x-6y$$

On integrating, we get

$$v = 4xy - 3y^2$$

17. 0.75 (0.745 to 0.752)

Given, $t = 1.6 \text{ mm} = 0.0016 \text{ m}$

$\bar{u} = 0.2 \text{ m/s}$

$\mu = 0.01 \text{ poise} = 0.001 \text{ Ns/m}^2$

Now, pressure drop is given by,

$$P_1 - P_2 = \frac{12\mu\bar{u}L}{t^2}$$

$$\therefore \quad \frac{\partial P}{\partial x} = \frac{12\mu\bar{u}}{t^2} = \frac{12\times 0.001\times 0.2}{(0.0016)^2}$$

$$= 937.5 \text{ N/m}^2 \text{ per m.}$$

Shear stress at wall,

$$\tau_0 = \frac{1}{2}\left(\frac{\partial P}{\partial x}\right)\times t$$

$$= \frac{1}{2}\times 937.5\times 0.0016$$

$$\tau_0 = 0.75 \text{ N/m}^2$$

18. 92.2 (91.6 to 92.8)

Given,Length of plate,

$L = 4 \text{ m}$

Width of plate, $b = 1.5 \text{ m}$

Velocity of plate,

$U = 4 \text{ m/s}$

Kinematic viscosity,

$\nu = 1.5 \times 10^{-5} \text{ m}^2\text{/s}$

So, Reynold number,

$$\text{Re} = \frac{UL}{\nu}$$

$$= \frac{4\times 4}{1.5\times 10^{-5}} = 10.66\times 10^5$$

As the Reynold number is greater than $5 \times 10^5$, so the flow at the trailing edge is turbulent.

Boundary layer thickness,

$$\delta = \frac{0.37x}{(\text{Re}_x)^{1/5}}$$

At, $x = 4 \text{ m}$

$\text{Re} = 10.66 \times 10^5$

$$\delta = \frac{0.37\times 4}{(10.66\times 10^5)^{1/5}} = 0.0922 \text{ m}$$

$$\therefore \quad \delta = 92.2 \text{ mm}$$

19. (90.18)

Difference in the piezometric head between the inlet and the throat, by taking the throat as the datum,

$$\Delta h = \left(\frac{P_1}{\gamma}+z_1\right)-\left(\frac{P_2}{\gamma}+z_2\right)$$

$$= \left(\frac{150}{0.9\times 9.79}+0.10\right)-\left(\frac{90}{0.9\times 9.79}+0\right)$$

$$= 6.91 \text{ m}$$

Head loss, $H_2 = 0.02\,\Delta h$

From Bernoulli's equation;

$$\frac{P_1}{\rho g}+\frac{V_1^2}{2g}+Z_1 = \frac{P_2}{\rho g}+\frac{V_2^2}{2g}+0+0.02h$$

$$\therefore \quad h-0.02h = \frac{Q^2}{2g}\left[\frac{1}{A_2^2}-\frac{1}{A_1^2}\right]$$

$$\therefore \quad Q_{th} = \sqrt{\frac{2g(0.98h)}{A_1^2-A_2^2}}\times A_1A_2$$

$$\therefore \quad Q = C_d \cdot Q_{th} = 90.18 \ l\text{ps}$$

20. 5.1 (5.0 to 5.2)

Velocity is not reduced in a pipe flow (as area remains constant), so head loss will be due to pressure head loss only.

Piezometric head at $B$

= (Pressure head at $B$ + Elevation head at $B$)

= (Pressure head at $A$ + Elevation head at $A$) – Head loss in valve

= (2.8 + 2.8) – 0.5 = 5.1 m

21. 2.07 (1.98 to 2.20)

$$\text{Shear stress, } t = \mu\frac{du}{dy} = \mu\frac{V}{h} = 0.6\frac{V}{0.02\times 10^{-3}}$$

$$= 3\times 10^4 \text{ V}$$

At terminal velocity,

Shear force = Submerged weight of the sleeve

$$(2\pi rL)\times\tau = W_s$$

$$\Rightarrow \left(2\pi\times\frac{0.032}{2}\times 0.12\times 3\times 10^4\right)\text{V} = 7.5$$

$$\Rightarrow \quad V = 2.07 \text{ cm/s}$$

22. (4.45)(4.40 to 4.80)

Initial volume = final volume

$$\left(\frac{4}{3}\pi\right)\times\left(\frac{2}{2}\right)^3 = 200\times\left(\frac{4}{3}\pi\right)\times r^3$$

$$r = \left(\frac{1}{200}\right)^{1/3} \text{ mm}$$

$$r = 0.171 \text{ mm}$$

energy required,

$$E = \sigma\times\Delta A_{surface}$$
$$= 0.073\times 4\pi[200\times(0.171\times 10^{-3})^2-(1\times10^{-3})^2]$$
$$E = 4.447\times10^{-6}\text{ J}$$

23. (a)

Given data: $d_1 = 10 \text{ cm} = 0.1 \text{ m}$

$$\therefore \quad A_1 = \frac{\pi}{4}d_1^2 = \frac{3.14}{4}\times(0.1)^2$$
$$= 7.85\times10^{-3}\text{ m}^2$$
$$d_2 = 5 \text{ cm} = 0.05 \text{ m}$$
$$\therefore \quad A_2 = \frac{\pi}{4}d_2^2 = \frac{3.14}{4}\times(0.05)^2$$
$$= 1.965\times10^{-3}\text{ m}^2$$

Manometer reading : $x = 1.2$ m of $Hg$

$$h = x\left[\frac{\rho_{Hg}}{\rho_{water}}-1\right]$$
$$= 1.2\left[\frac{13600}{1000}-1\right]$$
$$= 15.12 \text{ m of water}$$

Applying continuity equation,

$$A_1V_1 = A_2V_2$$
$$7.85\times10^{-3}\ V_1 = 1.965\times10^{-3}\ V_2$$

or $\quad V_2 = 4V_1$

Applying Bernoulli's equation between sections 1 and 2.

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

or $$\frac{p_1-p_2}{\rho g} = \frac{V_2^2-V_1^2}{2g} \qquad [\because z_1 = z_2]$$

$$h = \frac{(4V_1)^2-V_1^2}{2g} = \frac{15V_1^2}{2g}$$

or $$V_1^2 = \frac{2gh}{15}$$

or $$V_1 = \sqrt{\frac{2gh}{15}} = \sqrt{\frac{2\times9.81\times15.12}{15}}$$

$$= 4.447 \text{ m/s}$$

Mass flow rate :

$$m = \rho A_1V_1$$
$$= 1000\times7.85\times10^{-3}\times4.447$$
$$= 34.90 \text{ kg/s}$$

24. (b)

Applying continuity equation

$$m = (m)_{smaller}+(m)_{larger}$$
$$m = (\rho AV)_{small}+(m)_{larger}$$
$$200 = 1000\times\frac{\pi}{4}(0.05)^2\times25+(m)_{larger}$$

or $\quad (m)_{larger} = 150.93$ kg/s

$$\therefore \quad (Q)_{larger} = \frac{(m)_{larger}}{\rho} = \frac{150.93}{1000}\text{ m}^3\text{/s}$$
$$= 0.151 \text{ m}^3\text{/s or 151 L/s}$$

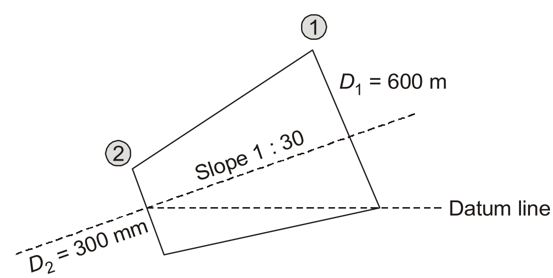
25. (b)

Given,length of pipe

$$L = 100 \text{ m}$$

Dia. at upper end

$$D_1 = 600 \text{ mm}$$




$$\therefore \quad A_1 = \frac{\pi D_1^2}{4} = \frac{\pi}{4}\times0.6^2$$
$$= 0.2827 \text{ m}^2$$
$$P_1 = \text{Pressure at upper end}$$
$$= 19.62 \text{ N/cm}^2$$
$$= 19.62\times10^4 \text{ N/m}^2$$

Dia. at lower end

$$D_2 = 300 \text{ mm}$$
$$\therefore \quad \text{Area } A_2 = \frac{\pi D_2^2}{4} = \frac{\pi}{4}\times0.3^2$$
$$= 0.07068 \text{ m}^2$$
$$Q = \text{Flow rate} = 50\ l/s$$
$$= 0.05 \text{ m}^3\text{/s}$$

Let the datum line passes through the centre of lower end.

Then, $\quad Z_2 = 0$

As slope is 1 in 30,

$$Z_1 = \frac{100}{30} = \frac{10}{3}\text{ m}$$

Also we know,

$$A_1V_1 = A_2V_2 = Q$$

$$V_1 = \frac{Q}{A_1} = \frac{0.05}{0.2827} = 0.177\text{ m/s}$$

$$V_2 = \frac{\theta}{A_2} = \frac{0.05}{0.07068} = 0.707\text{ m/s}$$

Applying Bernoulli's equation at sections (1) and (2), we have

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2$$

$$\frac{19.62\times10^4}{1000\times9.81} + \frac{0.177^2}{2\times9.81} + \frac{10}{3}$$

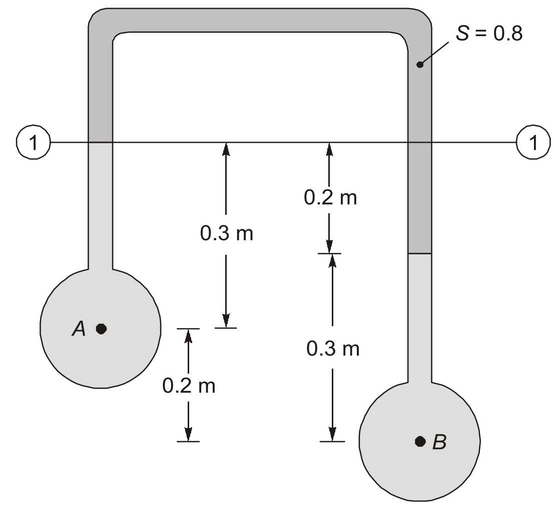
$$= \frac{P_2}{\rho g} + \frac{0.707^2}{2\times9.81} + 0$$

$$\frac{P_2}{\rho g} = 23.333 - 0.02388$$

$\therefore$ $P_2 = 228665.41\text{ N/m}^2$

$= 22.867\text{ N/cm}^2$

26. (1600)




Assume (1) – (1) be the datum line.

Pressure below the datum line (1) – (1) is same in left limb and in right limb.

$$p_A - \rho_w g \times 0.3 = p_B - \rho_w g \times 0.3 - \rho_{oil} g \times 0.2$$

or $$p_B - p_A = \rho_{oil} g \times 0.2 = 800 \times 10 \times 0.2$$

$$= 1600\text{ N/m}^2$$

■■■■