Production & Industrial Engineering

General Engineering
Vol. VI :
Fluid Mechanics

Comprehensive Theory
with Solved Examples *and* Practice Questions

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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 ρ. In SI system, the unit of ρ 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 γ. For water, it is denoted by γ_w. In SI system, the unit of specific weight is N/m^3. The mass density and specific weight γ 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.

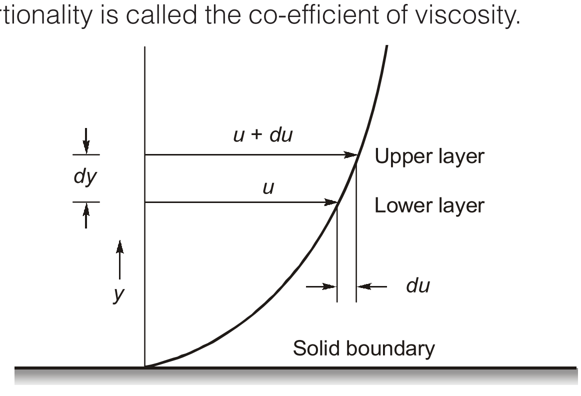
6.1.3 Viscosity

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 (τ) 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 = $dyne\text{-}sec/cm^2$

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

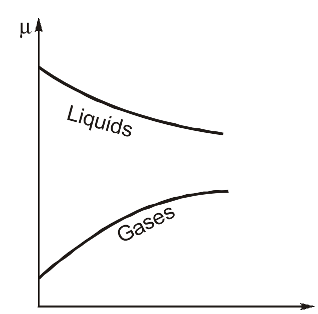
Effect of Temperature on Viscosity

- 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.

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

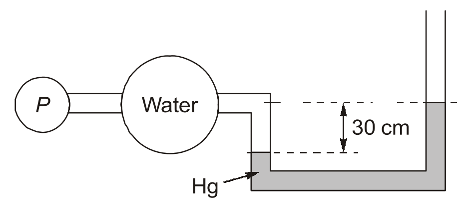
Q.6 The pressure drop for a relatively low Reynolds number flow in a 600 mm, 30 m long pipe line is 70 kPa. The wall shear stress is ________ Pa.

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.

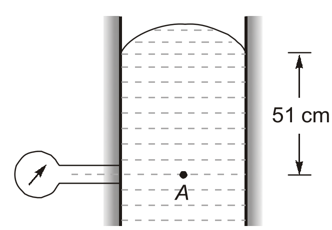
Q.9 The surface tension of water in contact with air at 20°C is 0.0725 N/m. The pressure inside a droplet of water is to be 0.02 N/cm^2 greater than the outside pressure. The diameter of water droplet is ________ cm.

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

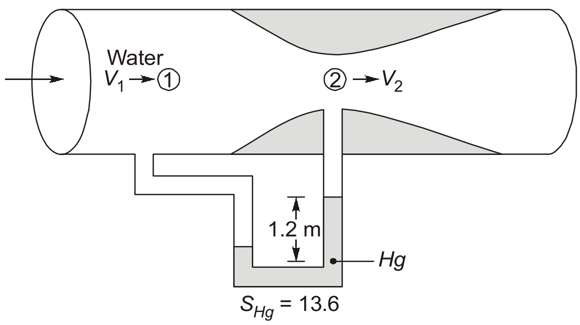


(a) 21.74 mm (b) 105.43 mm
(c) 10.87 mm (d) 0.704 mm

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

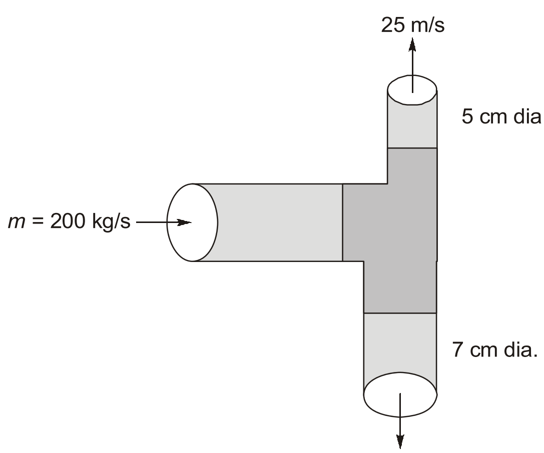
Q.13 A jet of water 50 mm diameter having a velocity of 25 m/s, strikes normally a flat smooth plate. The thrust on the plate if the plate is moving in the same direction as the jet with a velocity of 5 m/s is ________ N.

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



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

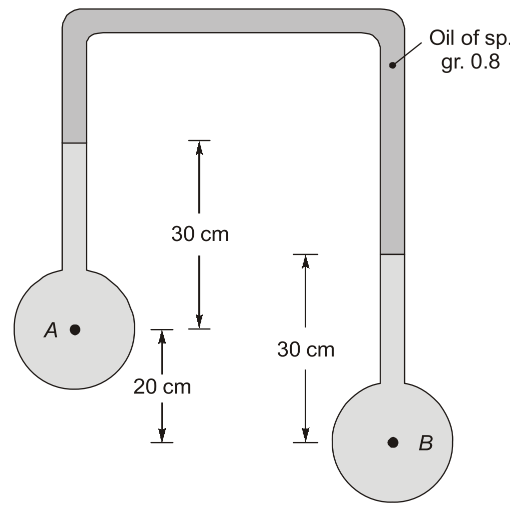
Q.24 A pipe transports 200 kg/s of water. The pipe divides into a 5 cm diameter pipe and a 7 cm diameter pipe as shown in figure. If the average velocity in the smaller diameter pipe is 25 m/s, the flow rate in the larger pipe is



(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 $\left(\frac{P}{\rho g} + z + \frac{v^2}{2g}\right)$