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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VOLUME VI

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 undergoma 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.

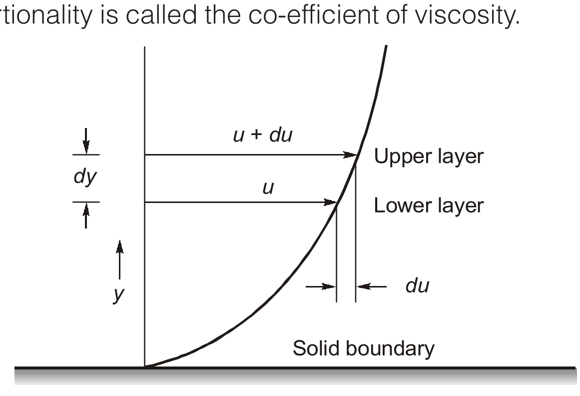
6.1.3 Viscosity

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-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

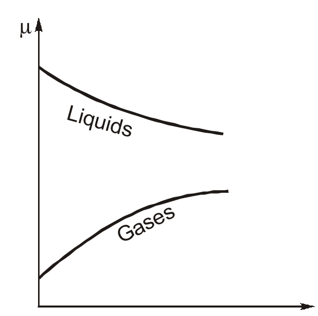
Effect of Temperature on Viscosity

- 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.

Effect of Pressure on Viscosity

Pressure has very little effect on viscosity. But if pressure increases intermolecular gap decreases then cohesion increases so viscosity would be increase.

6.1.4 Kinematic Viscosity

It is the ratio between the dynamic viscosity and density of fluid and denoted by ν.

Mathematically,
$$\nu = \frac{\text{dynamic viscosity}}{\text{density}} = \frac{\mu}{\rho}$$

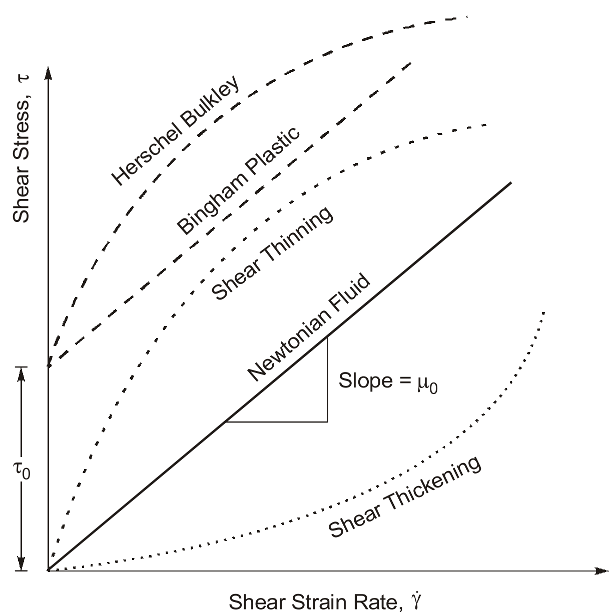
Units of Kinematic Viscosity

- S.I. units : m^2/s
- C.G.S. units : stoke = cm^2/s

  One stoke = 10^{-4} m^2/s

6.1.5 Classification of Fluid

1. Newtonian Fluids : These fluids follow Newton's viscosity equation. For such fluids viscosity does not change with rate of deformation.
2. Non-Newtonian Fluids : These fluids does not follow Newton's viscosity equation. Such fluids are relatively uncommon e.g. printer ink, blood, mud, slurries, polymer solutions.



Properties of these different types of fluids is summarized in following table :