

# FLUID MECHANICS

For

ME/CE

By



[www.thegateacademy.com](http://www.thegateacademy.com)

## Syllabus for Fluid Mechanics

Fluid Properties; Fluid Statics, Manometry, Buoyancy, Forces on Submerged Bodies, Stability of Floating Bodies; Control-Volume Analysis of Mass, Momentum and Energy; Fluid Acceleration; Differential Equations of Continuity and Momentum; Bernoulli's Equation; Dimensional Analysis; Viscous Flow of Incompressible Fluids, Boundary Layer, Elementary Turbulent Flow, Flow Through Pipes, Head Losses In Pipes, Bends and Fittings.

### Analysis of GATE Papers

Year	ME	CE
2015	7.33	5.00
2014	7.80	26.00
2013	6.00	7.00
2012	6.00	4.00
2011	5.00	7.00
2010	8.00	7.00
2009	8.00	7.00
2008	4.67	15.00
2007	10.00	16.00
2006	11.33	17.00
Overall Percentage	7.41%	11.10%

## Contents

Chapters	Page No.
<b>#1. Fluid Properties</b>	<b>1 – 13</b>
• Fluids	1
• Properties of Fluids	1 – 4
• Newton's Law of Viscosity	5
• Types of Fluids	5 – 6
• Solved Examples	7 – 9
• Assignment 1	10
• Assignment 2	11
• Answer Keys & Explanations	12 – 13
<b>#2. Fluid Statics</b>	<b>14 – 42</b>
• Fluid Pressure	14 – 16
• Measurement of Fluid Pressure	16 – 18
• Forces on Submerged Bodies	18 – 19
• Buoyancy	20
• Floating Bodies Stability	21 – 22
• Solved Examples	22 – 36
• Assignment 1	37 – 38
• Assignment 2	38 – 39
• Answer Keys & Explanations	40 – 42
<b>#3. Fluid Kinematics</b>	<b>43 – 59</b>
• Fluid Flow	43 – 48
• Continuity Equation	49 – 51
• Solved Examples	51 – 55
• Assignment	56 – 57
• Answer Keys & Explanations	58 – 59
<b>#4. Fluid Dynamics</b>	<b>60 – 77</b>
• Equations of Motion	60 – 61
• Euler's Equations of Motion	61
• Bernoulli's Equation	61 – 62

• Practical Applications of Bernoulli's Theorem	63 – 66
• Solved Examples	66 – 72
• Assignment	73 – 75
• Answer Keys & Explanations	75 – 77
<b>#5. Boundary Layer</b>	<b>78 – 96</b>
• Boundary Layer	78 – 82
• Dimensional Analysis	82 – 86
• Solved Examples	86 – 92
• Assignment 1	93 – 94
• Assignment 2	94
• Answer Keys & Explanations	95 – 96
<b>#6. Flow Through Pipes</b>	<b>97 – 111</b>
• Losses in Pipes	97 – 101
• Viscous Flow	101 – 103
• Solved Examples	103 – 106
• Assignment 1	107 – 108
• Assignment 2	108 – 109
• Answer Keys & Explanations	110 – 111
<b>#7. Hydraulic Machines</b>	<b>112 – 148</b>
• Dynamic Force on a Curve Blade	112 – 114
• Theory of Turbo Machines	114 – 115
• Pelton Wheel	115 – 119
• Reaction Turbines	119 – 121
• Francis Turbine	121 – 122
• Kaplan Turbine	123
• Specific Speed and Performance of Turbines	123 – 125
• Cavitation in Turbines	125
• Centrifugal Pumps	126 – 134
• Solved Examples	134 – 142
• Assignment 1	143 – 144
• Assignment 2	144 – 145
• Answer Keys & Explanations	146 – 148

<b>Module Test</b>	<b>149 – 166</b>
• Test Questions	149 – 157
• Answer Keys & Explanations	158 – 166
 <b>Reference Books</b>	 <b>167</b>

*www.thegateacademy.com*

# Fluid Properties

"If you don't set goals, you can't regret not reaching them."

.....Yogi Berra

## Learning Objectives

After reading this chapter, you will know:

1. Fluids, Properties of Fluids
2. Types of Fluids

## Fluids

It is defined as a substance which deforms continuously even with a small amount of shear force exerted on it, whereas a solid offers resistance to the force because very strong intermolecular attraction exists in it.

Both liquids and gases come under the fluids.

### 1. Liquid

It has definite volume but no shape for all practical purposes considered incompressible.

### 2. Gas

It has no shape and volume highly compressible.

### 3. Vapour

A gas whose temperature and pressure are such that it is very near to the liquid phase.

**E.g.:** Steam

## Properties of Fluids

### Mass Density ( $\rho$ )

It is defined as mass per unit volume. Unit:  $\text{kg/m}^3$ , Dimension:  $\text{M/L}^3$

Absolute quantity i.e., does not change with location.

As pressure increases mass density increases (as large number of molecules are forced into a given volume)

### Specific Weight ( $\gamma$ )

Weight of the substance per unit volume. Also represents force exerted by gravity on a unit volume fluid.

Mass density and specific weight of a fluid are related as  $\gamma = \rho g$ ;

Where,  $g$  = Acceleration due to gravity

Units:  $\text{N/m}^3$ , Dimensions:  $\text{ML}^{-2}\text{T}^{-2}$  or  $\text{FL}^{-3}$

It is not an absolute quantity, varies from place to place, because  $g$  (acceleration due to gravity) is changing from place to place primarily latitude and elevation above M.S.L.

Specific weight of water,  $\gamma = 1000 \times 9.81 = 9810 \text{ N/m}^3$

### Specific Volume ( $v$ )

Specific volume of a fluid is the volume of the fluid per unit weight.

$$v = 1/\rho \text{ (Reciprocal of density)}$$

Units:  $\text{m}^3/\text{kg}$

### Specific gravity ( $G$ )

It is a ratio of specific weight (mass density) of a fluid to the specific weight (mass density) of a standard fluid.

$$G = \frac{\text{Specific weight (or mass density) of a fluid}}{\text{Specific weight (or mass density) of a standard fluid}}$$

For liquids, standard fluid is water at  $4^\circ\text{C}$

For gases, standard fluid is hydrogen or air

Units: No units (as it is a ratio of two quantities having same unit)

Specific gravity of water = 1.0, Mercury = 13.6

Since the density of fluid varies with temperature, specific gravity must be determined and specified at a particular temperature.

### Viscosity

A measure of fluids resistance to shear. A property of a fluid by virtue of which it offers resistance to the movement of one layer of fluid over the adjacent layer. It is due to intermolecular cohesion and transfer of molecular momentum between layers.

- Dynamic Viscosity ( $\mu$ )**

Units: SI:  $\text{Pa}\cdot\text{sec}$  or  $\text{N}\cdot\text{sec}/\text{m}^2$ ; MKS:  $\text{kg}/(\text{m}\cdot\text{sec})$

CGS: poise =  $\text{dyne}\cdot\text{sec}/\text{cm}^2$

Conversion: 1 poise = 0.1  $\text{Pa}\cdot\text{sec}$

Dimensions:  $\text{ML}^{-1}\text{T}^{-1}$  or  $\text{FL}^{-2}\text{T}$

- Kinematic Viscosity ( $\nu$ )**

It is dependent on pressure. For liquids dynamic viscosity decreases with increase in temperature because density of liquid decreases with increase in temperature for it decreases with increase in temperature because molecular momentum increases and cohesion is negligible in gases.

$$\text{Kinematic Viscosity } (\nu) = \frac{\text{Dynamic viscosity}}{\text{Mass density}} = \frac{\mu}{\rho}$$

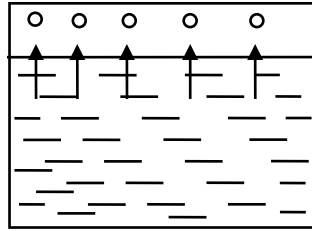
Units: SI:  $\text{m}^2/\text{sec}$ ; CGS:  $\text{cm}^2/\text{sec}$  or stokes

Dimensions:  $\text{L}^2\text{T}^{-1}$

Kinematic viscosity depends on both pressure and temperature.

### Vapour Pressure

In a closed vessel at a constant temperature, the liquid molecules break away from the liquid surface and enter the air space in vapour state. When the air above the liquid surface is saturated with liquid vapour molecules then the pressure exerted on liquid surface is called vapour pressure. Vapour pressure increases with temperature. The low vapour pressure of mercury (along with high density) makes it very suitable for use in barometers and other pressure measuring devices.



### Cavitation

Occurs in a flow system, dissolved gases (vapour bubbles) carried into a region of high pressure and their subsequent collapse gives rise to high pressure, which leads to noise, vibrations and erosion. Cavitation occurs in,

1. Turbine runner
2. Pump impellers
3. Hydraulic structures like spillways and sluice gates
4. Ship propellers

### Compressibility

Change in volume (or density) due to change in pressure. Compressibility is inversely proportional to Bulk Modulus  $K$ .

$$K = \frac{-dP}{\left(\frac{dv}{v}\right)} \text{ or } \frac{-dP}{\left(\frac{d\rho}{\rho}\right)}$$

(Negative sign indicates a decrease in volume with increase in pressure)

Coefficient of compressibility,  $\beta = \frac{1}{K}$

### Surface Tension

It is defined as the tensile force acting on surface of liquid in contact with gas or on the surface between two immiscible liquid such that the contact surface behaves like a membrane.

There are mainly two types of force:

- **Cohesion:** Force of attraction between the molecules of the same liquid.
- **Adhesion:** Force of attraction between the molecules of different liquids (or) between the liquid molecules and solid boundary containing the liquid. A liquid forms an interface with a second liquid or gas. This liquid – air interface behaves like a membrane under tension. The surface energy per unit area of interface is called Surface Tension. It can also be expressed as a line force. Force per unit length.

Units: N/m

Dimensions:  $FL^{-1}$  or  $MT^{-2}$

Surface tension is due to cohesion between liquid molecules. As temperature increases  $\rightarrow$  Surface tension decreases (because cohesion decreases)

Due to cohesion, surface tension pressure changes occur across a curved surface of



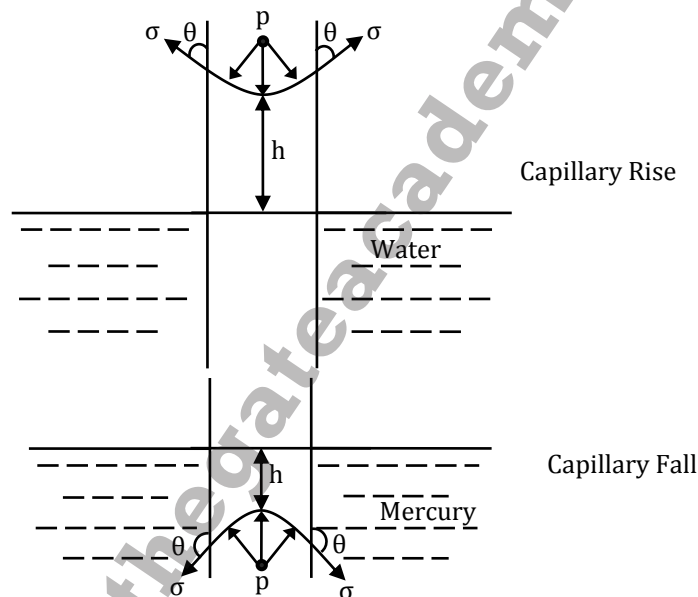
1. **Liquid Jet:** Increase in pressure inside and outside of liquid jet.

$$\Delta P = \frac{2\sigma}{d}; \text{ Where, } d = \text{Dia of jet, } \Delta P = \text{Pressure intensity inside the liquid}$$

2. **Liquid Drop:**  $\Delta P = \frac{4\sigma}{d}$ ; Where,  $d = \text{Dia of drop let}$
3. **Soap Bubble:**  $\Delta P = \frac{8\sigma}{d}$ ; Where,  $d = \text{Dia of bubble}$

### Capillarity

The phenomenon of rise or fall of a liquid surface relative to the adjacent general level of liquid in small diameter tubes. The rise of liquid surface is designated as capillary rise and lowering is called capillary depression. Capillary rise happens when adhesive is stronger than cohesive for example in water capillary depression happens when cohesive is stronger than adhesive for example in mercury.



**E.g.:** Mercury depressive with convers upwards capillary (Rise or Fall)

Units: cm or mm of liquids.

$$h = \frac{4\sigma \cos\theta}{\gamma d}$$

$\sigma$  = Surface tension

$\theta$  = Angle of contact between liquid and boundary

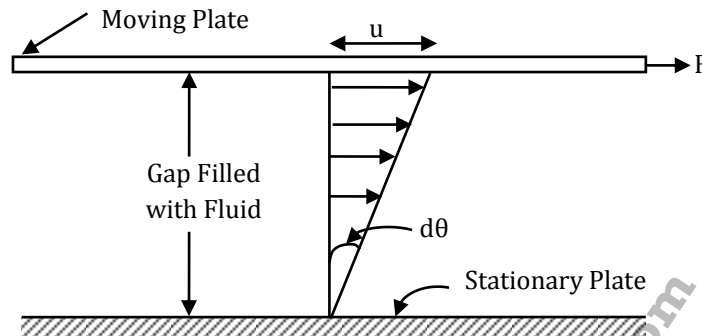
$d$  = Dia. of tube

$\theta = 0^\circ \rightarrow \text{Water and glass}$

$\theta = 130^\circ \rightarrow \text{Mercury and glasses}$

For tube dia.  $> 12 \text{ mm}$  capillary effects are negligible. Hence the dia. of glass tubes used for measuring pressure (manometers, piezometer etc.) should be large enough.

## Newton's Law of Viscosity



Shear stress  $\propto$  Time rate of deformation (shear deformation)

$$\frac{F}{A} \propto \frac{d\theta}{dt}$$

Where,  $F$  is the Force required to move the surface area ' $A$ '

$$\frac{F}{A} \propto \frac{u}{y} \text{ or } \tau = \mu \left( \frac{u}{y} \right)$$

Differential form:  $\tau = \mu \left( \frac{du}{dy} \right)$

Where,  $\tau$  = Shear stress

$(du / dy)$  = Velocity gradient

$\mu$  = Dynamic viscosity

According to Newton's law of viscosity, for a given shear stress acting on fluid ( $\tau$ ), the rate at which fluid deforms ( $u/y$ ) is inversely proportional to viscosity ( $\mu$ ).

## Types of Fluids

### Ideal Fluid or Perfect Fluid

- Non viscous (frictionless) and incompressible.
- Used in the mathematical analysis of flow problems.
- Does not exist in reality.
- Does not offer shear resistance when fluid is in motion.

### Real Fluid

- Possess the properties such as viscosity, surface tension and compressibility.
- Resistance is offered when they are set in motion.

### Newtonian Fluid

- This obeys Newton's Law of Viscosity.
- Newtonian fluid has constant viscosity (Viscosity is independent of shear stress).
- There will be linear relationship between shear stress and resulting rate of deformation.  
**E.g.:** Air, Water, Light Oils and Gasoline.