Fluid Mechanic

Second Stage

Chapter One

1.1 Introduction

Fluid mechanics is that branch of science which deals with the behavior of the fluids at rest as well as in motion. The problems, man encountered in the fields of water supply, irrigation, navigation and water power, resulted in the development of the fluid mechanics.
It deals with the statics, kinematics and dynamics of fluids. Available methods of analysis stem from the application of the following principles, concepts, and laws:
- Newton's law of motion
- The first and second laws of thermodynamics
- The principle of conservation of mass, and
- Newton's law of viscosity.

In the development of the principles of fluid mechanics, some fluid properties play principal roles. In fluid statics, specific weight (or unit weight) is important property, whereas in fluid flow, density and viscosity are predominant properties.

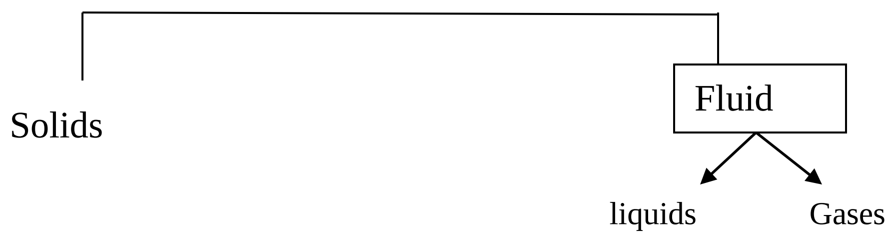
1.2 Definition of a Fluid

A fluid may be defined as a substance which is capable of flowing. It has no definite shape of its own, but conforms to the shape of the containing vessel. Fluids can be classified as liquids or gasses.

A 'liquid' is a fluid, which possesses a definite volume, which varies only slightly with temperature and pressure. Since under ordinary conditions liquids are difficult to compress, they may be for all practical purposes regarded as incompressible.
A 'gas' is a fluid, which is compressible and possesses no definite volume but it always expands until its volume is equal to that of the

container. Even a slight change in the temperature of a gas has a significant effect on its volume and pressure. The fluids are also classified as ideal fluids and real fluids. 'Ideal fluids' are those fluids which have no viscosity and surface tension and they are incompressible. However, in nature the ideal fluids do not exist and therefore, these are only imaginary fluids. 'Real fluids'

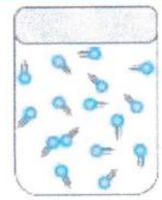
1.3 Materials in Nature



1.4 Liquids and Gases

This section describes liquids and gases, emphasizing behavior of the molecules. This knowledge is useful for understanding the observable characteristics of fluids. Liquids and gases differ because of forces between the molecules. As shown in the first row of Table 1.1. a liquid will take the shape of a container whereas a gas will expand to fill a closed container. The behavior of the liquid is produced by strong attractive force between the molecules. This strong attractive force also explains why the density of a liquid is much higher than the density of gas (see the fourth row). The attributes in Table l.l can be generalized by defining a gas and liquid based on the differences in the attractive forces between molecules. A gas is a phase of material in which molecules are widely spaced. Molecules moved about freely, and forces between molecules are minuscule, except during collisions. -alternatively a liquid is a phase of material in which molecules are closely spaced, molecules move about freely and there are strong attractive forces between molecules.

Table 1.1 COMPARISON OF SOLIDS, LIQUIDS, AND GASES

Attribute	Solid	Liquid	Gas
Typical Visualization			
Macroscopic Description	Solids hold their shape; no need for a container	Liquids take the shape of the container and will stay in open container	Gases expand to fill a closed container
Mobility of Molecules	Molecules have low mobility because they are bound in a structure by strong intermolecular forces	Liquids typically flow easily even though there are strong intermolecular forces between molecules	Molecules move around freely with little interaction except during collisions; this is why gases expand to fill their container
Typical Density	Often high; e.g., density of steel is 7700 kg/m^3	Medium; e.g., density of water is 1000 kg/m^3	Small; e.g., density of air at sea level is 1.2 kg/m^3
Molecular Spacing	Small—molecules are close together	Small—molecules are held close together by intermolecular forces	Large—on average, molecules are far apart
Effect of Shear Stress	Produces deformation	Produces flow	Produces flow
Effect of Normal Stress	Produces deformation that may associate with volume change; can cause failure	Produces deformation associated with volume change	Produces deformation associated with volume change
Viscosity	NA	High; decreases as temperature increases	Low; increases as temperature increases
Compressibility	Difficult to compress; bulk modulus of steel is 160×10^9 Pa	Difficult to compress; bulk modulus of liquid water is 2.2×10^9 Pa	Easy to compress; bulk modulus of a gas at room conditions is about

1.5 Units of Measurement

There are in general four systems of units, two in metric system and two in the English system. Of the two, one is known as the absolute system and the other as the gravitational system. Table below lists the various units of measurement for some of the basic or fundamental quantities.

Quantity	Metric Units		English Units	
	Gravitational	Absolute SI	Gravitational	Absolute BE British
Length	m	m	ft	ft
Mass	metric slug(msl)	gm kg	slug	lb
time				sec
Force	kg(f)	dyne	lb(f)	poundal(pdl)

International System of Units (SI)

Mass	kg
Force	N
Pressure	N/m^2 (Pa)
Mass density	kg/m^3
Weight density (Specific weight)	N/m^3
Work	J
Power	Watt
Dynamic viscosity	$N.s/m^2$
Kinematic viscosity	m^2/s

1.6 Fluid properties

Mass density, Specific weight, Specific volume, specific gravity, compressibility, viscosity, surface tension, capillarity

1.5.1 Mass Density (rho) ρ:

Mass density of a fluid is the mass which it possesses per unit volume.

$$\rho = \frac{M}{V}$$

The mass density of water at 4C in different systems of units is 1 gm/cc (or) 1000 kg/m^3 (or) 62.4 Ib/ft^3.

1.5.2 Specific weight (γ)

It represents the force exerted by gravity per volume of fluid;

$$\gamma = \frac{weight}{Volume}$$

Weight = mass *g

G=acceleration gravity= 9.81 m/sec^2

$$\gamma = \rho \times g$$

1.5.3 Specific Volume (ϑ)

It is a volume occupied by a unit mass of fluid

$$\rho = \frac{mass}{Volume}$$

$$\vartheta = \frac{1}{\rho}$$

1.5.4 Specific gravity (S)

Specific gravity of a liquid is a ratio of its density to that of water at standard temperature

$$S = \frac{\rho}{\rho_W}$$

Standard temp.= 4 C and ρ_W = 1000 kg/m^3

Specific gravity of a gas is a ratio of its density to that of hydrogen gas (or air) at a specific temp, and pressure.

Example: If specific weight of water is 9.81 kN/m^3. The specific gravity of mercury is 13.59. Compute the density of water and the specific weight and density of mercury.

1.5.5 Compressibility

Compressibility is defined as the change in volume of a fluid due to change the pressure and its inversely proportional to the bulk modulus of elasticity (E).

1.5.5.1 Compressible and incompressible fluid

Compressible fluids: fluids with variable density. ex. (gases)
Incompressible fluids: fluids with constant density, ex. (liquids)

$E = \frac{change\ of\ pressure}{volumetric\ change} = \frac{dp}{-\frac{dV}{V}}$ (1)

Since, $\rho = \frac{m}{V}$ $for\ a\ unit\ mass\ \rho = \frac{1}{V}$

$d\rho = -\frac{dV}{V^2} = -dV = V^2 d\rho$ (2)

Substitute 2&3 in eq.1

$$E = \frac{dp}{V^2 d\rho/V} = \frac{dp}{V d\rho} = E = \rho d\rho$$

*Constant (E), no change with temp, and pressure for compressible liquids.
E change with temp, and pressure for incompressible fluids (gases).

Example: Consider water initially at 4 C and 1 atm. It is compressed to 100 atm. At a constant temp. of 4 C , determine the final density of water if E=0.208E5.

1.6 Viscosity

The viscosity of a fluid is a measure of its resistance shear or any deformation. The friction force in fluid flow result from the cohesion and momentum interchange between molecules in the fluid. As the temp. increases the viscosity of all liquids decreases while viscosity of all gases increase.

1.6.1Measurements of viscosity between two parallel plates

Consider a fluid flows between very large parallel plates; the lower plate is fixed while the upper plate is moved with a velocity V by a force F on A.

The plate and the fluid, the fluid velocity between the plates varies linearly between 0 & V, y is the vertical distance from the lower plate and F is applied force.

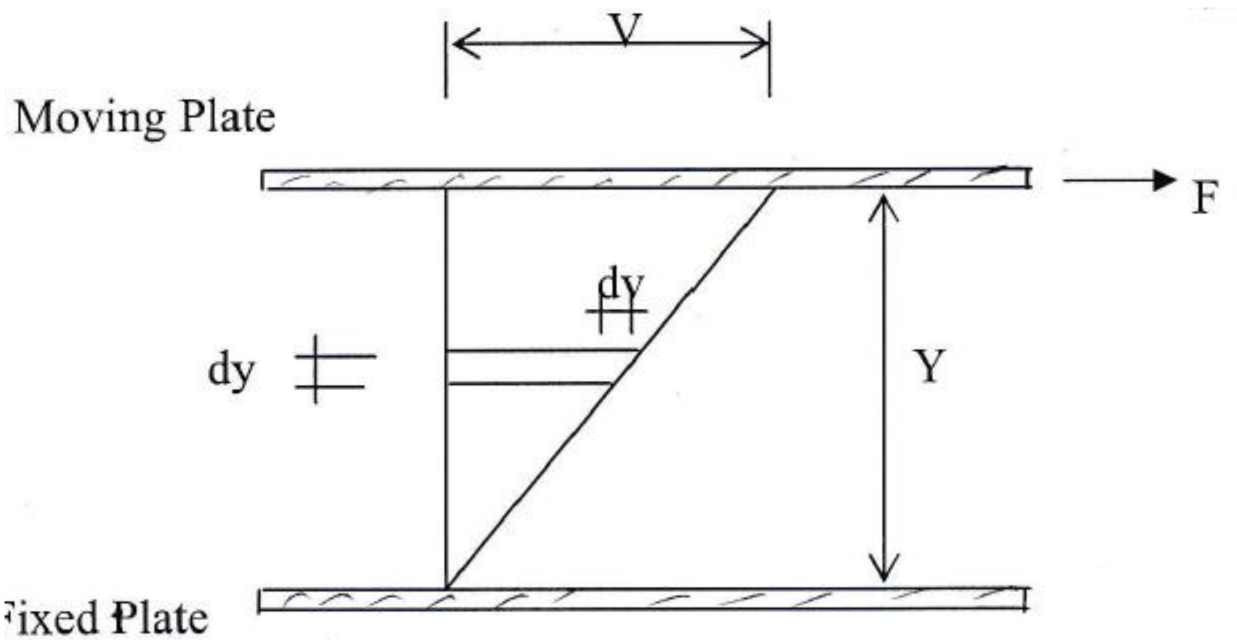


Fig.1.1 Fluid motion between two parallel plates

Experiments show that shear force varies with the area of the plate A, with velocity V and inversely with distance Y.

$$F \infty \frac{A\,V}{Y}$$

Since by similar triangles

$$\frac{V}{Y} = \frac{dv}{dy}$$

$$F \infty\ A.\frac{dv}{dy}$$

$$\left(\frac{F}{A} = \tau\right) \infty \frac{dv}{dy} \qquad \tau = shear\ stress$$

If proportionality constant =μ called dynamic viscosity

$$\tau = \mu \frac{dv}{dy} \qquad \text{Newton law of viscosity}$$

Dynamic viscosity $\mu = \frac{\tau}{\frac{dv}{dy}} = \frac{shear\ stress}{rate\ of\ shear\ strain}$

The dynamic viscosity may be defined as the shear stress required producing unit rate of angular deformation.

μ is dynamic viscosity (absolute viscosity) = $N.sec/m^2$= Pa .sec
where $Pa=N/m^2$
For example μ water @ 20 C = $1.005*10^{-3}$ $N.sec/m^2$
V (nu) Kinematic viscosity m^2/sec =$\vartheta = \frac{\mu}{\rho}$

1.7Classification of Fluids

Fluids are classified into three types

1- Ideal fluid: It is a fluid with no viscosity μ=0.
2- Newtonian fluid : It is a fluid for which the viscosity does not change with time rate of deformation (du/dy)
3- Non Newtonian fluid : It is a fluid for which the viscosity varies with time rate of deformation (du/dy)

Example: The velocity distribution for the flow of a Newtoniann fluid between two wide, parallel plates is given by the eq. $u = \frac{3v}{2}\left[1 - (\frac{y}{h})^2\right]$

where v is the mean velocity .The fluid has a viscosity of 1.48 Pa.s when v =0.2m/s and h =0.2 m . Determine a) the shearing stress acting on the bottom of the wall and, b) the shearing stress acting on a plane parallel to the wall and passing through the centerline.

1.8 Surface Tension

The surface tension sigma σ of a liquid is the work that must be done to bring enough molecules from inside the liquid to the surface to form one new unit area of that surface.

σ= 0.073 N/m for air-water interface

ϭ= 0.48 N/m for air-mercury interface

Liquids have cohesion and adhesion, both of which are forms of molecules attraction. Cohesion enables a liquid to resist tensile stress while adhesion enables it to adhere to another body. The attraction between an imaginary film capable of resisting tension at the interface between a liquid and a gas. The liquid property that creates this capillarity known as a surface tension.

1.9 Capillarity

Rise or fall of liquid in a capillary tube is caused by surface tension and depends on the relative magnitude of the cohesion of the liquid and the adhesion of the liquid to the walls of the containing vessel.

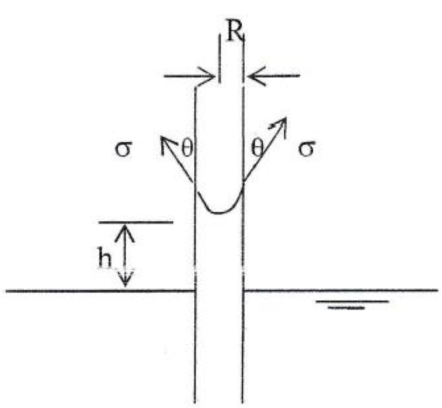
Liquids, such as water, which wet a surface cause capillary rise. In nonwetting liquids (e.g mercury) capillary depression is caused.

$$h = \frac{2\sigma \, Cos\,\theta}{r\,R}$$

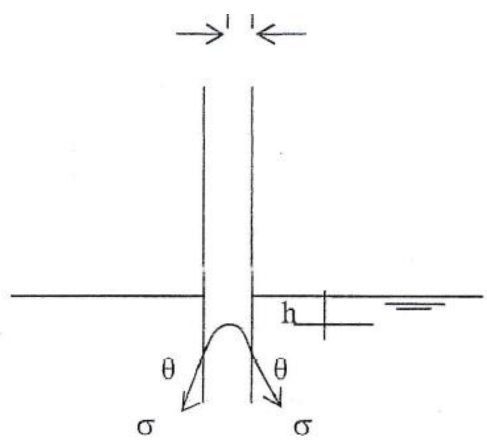
where h : height of capillary rise (or depression)

Ө: wetting angle

R = radius of tube



Capillary Rise

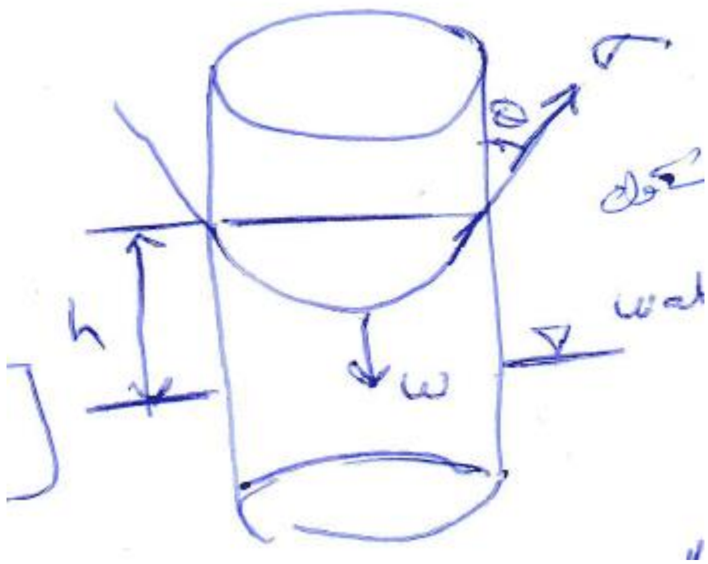


Capillary Depression

Adhesion> cohesion

cohesion > adhesion

Derivation n of capillarity effect in tube:



$$\sum Fy = 0$$
$$\sigma \cos\theta \, \pi \, d - w = 0$$
$$w = mg = \rho \, V \, g = \gamma \frac{\pi}{4} d^2 \, h$$
$$h = \frac{4 \, \sigma \cos\theta}{\gamma \, d} = \frac{2 \, \sigma \cos\theta}{\gamma \, r}$$

** for very clean glass tube ϴ =0 for water

ϴ= 130 degree for mercury (Hg)

Example: A clean tube of internal diameter 3 mm is immersed in a liquid with a coefficient of surface tension 0.48 N/m. The angle of contact of the liquid with the glass can

Example The specific weight of water 9.81 kN/m3 and specific gravity of mercury is 13.55. Compute the density of water and specific weight and density of mercury.

Example: At a certain point in castor oil the shear stress is 0.216 N/m^2 and the velocity gradient is 0.216 S^{-1}, if the mass density of castor oil is 959.42 kg/m^3, find the kinematic viscosity.