ENG 3165 LECTURE 14

FLUID MECHANICS COMPONENT

Fundamentals of Fluid Mechanics

Introduction

- This lecture provides an introduction to Fluid Mechanics.
- Definitions of basic fluid concepts such as specific gravity, viscosity, etc, are given

GENERAL INTRODUCTION

- **Mechanics** is a subject dealing with the conditions under which a body can remain at **rest or in motion**.
- Mechanics can be classified into two: **solid mechanics** and **fluid mechanics**.
- Fluid mechanics is that branch of science which deals with the **behaviour of fluids at rest as well as in motion** and the subsequent **effects of fluid upon its boundaries** which may be either solid surfaces or interfaces with other fluids.
- Both liquids and gases are classified as fluids.

GENERAL INTRODUCTION

- The number of fluids in engineering applications are enormous: breathing, blood flow, swimming, pumps, fans, blowers, turbines, ships, rivers, airplanes, missiles, rockets, engines, jets, etc. Almost everything on this planet either is a fluid or moves within or near a fluid.
- The field of fluid mechanics has been divided into three branches—**fluid statics, fluid kinematics and fluid dynamics**.
- Fluid statics is concerned with the behavior of a fluid at rest.
- Fluid kinematics deals with the motion of fluids without reference to forces that cause the motion.
- Fluid dynamics involves the study of a fluid motion as a consequence of forces that causes the motion

DEFINITION OF A FLUID

- From the point of view of fluid mechanics, all matter consists of only two states, fluid and solid.
- A solid can resist a **shear stress by a static deformation**, a fluid cannot. Any shear stress applied to a fluid, no matter how small, will result in motion of that fluid. The fluid moves and deforms continuously as long as shear stress is applied.
- A fluid is a substance that deforms continuously when subjected to a shear stress, however small the shear stress may be.
- A fluid may be either a liquid or a gas.

GENERAL INTRODUCTION

Real Fluids

- Fluids which do posses various properties like viscosity, surface tension, density, specific weight, specific gravity are termed as real fluids. These fluids always offer resistance to the shear forces acting on them. **All the fluids in actual practice are real fluids.**

Ideal Fluids

- Ideal fluids are purely imaginary fluids. These are fluids which are incompressible and have no viscosity and no surface tension. Imaginary fluids are only considered to simplify the problems. Ideal fluid is also known as in **viscid fluid** or **perfect fluid**.

GENERAL INTRODUCTION

- **Hydraulics:** Hydraulics is the branch of the engineering which deals with the study of fluid (mostly water) in flow as well in rest. It deals with the collection, storage, control, flow, regulation, measurement, and use of water.
- **Hydrodynamics**: Hydrodynamics is the branch of the engineering which deals with the study of fluids in motion and the various forces acting on them
- **Hydrostatics:** Hydrostatics is the branch of engineering which deals with the study of the fluid at rest normally with the pressure exerted by the fluid on an immersed body.

DIFFERENCE BETWEEN A FLUID AND A GAS

- The difference between the two classes of fluids, liquids and gases, is all about the effect of cohesive forces.
- A liquid, being composed of relatively close-packed molecules with strong cohesive forces, tends to retain its volume and will form a free surface in a gravitational field if unconfined from above.
- Since gas molecules are widely spaced with negligible cohesive forces, a gas is free to expand until it encounters confining walls. A gas has no definite volume, and when left to itself without confinement, a gas forms an atmosphere which is essentially hydrostatic

DIFFERENCE BETWEEN A FLUID AND A GAS

THE CONCEPT OF CONTINUUM

- The fluid flow analysis can be attempted from **two different view points.**
- One approach, popularly known as **microscopic,** stems from molecular point of view. It relies on the consideration that fluid essential comprises of molecules the motion of which is characterized by the laws of dynamics. The behaviour of the fluid then can be described by summing up the properties of the molecules following statistical approach.

THE CONCEPT OF CONTINUUM

- The other approach is the **macroscopic** one where the gross behaviour is considered rather than an individual molecule. The macroscopic approach treats the fluid as continuous and the variations of the property values of the individual molecules are not reflected.
- This approach gives the **concept of continuum** where fluids can be treated as a continuous medium disregarding the discontinuity in the microscopic entities. In the continuum approach at each point of the continuous fluid there is a unique value of the field variables such as pressure, velocity, density.
- This continuous matter follows the **conservation laws of mass, momentum and energy.** These laws can be derived using a set of differential equations. In most of the engineering applications, the concept of continuum yields very good results and hence accepted well.

FLUID PROPERTIES: Density or Mass Density

- The mass density or Density of a fluid is defined as the ratio of a mass of fluid to its volume of the fluid.
- Its symbol is ρ (rho) and the unit of mass density is **(kg/m).**
- The density of liquid may be constant but the density of gases changes with the variation of temperature and pressure.
- (The Density of water is 1000 g/m) or (we can say 1 g/cm).

ρ = (Mass of Fluid) / (Volume of Fluid)

$$\rho = \lim_{\Delta V \to V^*} \frac{\Delta m}{\Delta V} = \frac{dm}{dV}$$

FLUID PROPERTIES: Weight Density or Specific Weight

- Weight density or specific density of a fluid is defined as the ratio of the weight of fluid to its volume of the fluid.
- Weight density is called Weight per unit volume of a fluid. This is denoted by symbol $'\gamma'$ *or*' w' and the unit of mass density is (N/m).
- $\boldsymbol{\gamma}$ = (Weight of Fluid) / (Volume of fluid)
- And we know from the previous formula of Density. So this becomes $\boldsymbol{\gamma}$ = ρ * g

$$\text{Specific weight } (\gamma) = \frac{\text{Weight of fluid}}{\text{Volume of fluid}} = \frac{\text{Mass of fluid}}{\text{Volume of fluid}} \times \text{Acceleration due to gravity}$$

$$\gamma = \rho g$$

- The value of weight density or specific weight for water is 9.81*1000 N/m

FLUID PROPERTIES: Specific Volume

- The **specific volume** of a fluid is defined as the ratio of the volume of fluid to the mass of fluid or,
- The volume of a fluid occupied by a unit mass or volume per unit mass of a fluid is called Specific volume.
- The unit of Specific volume is m^3/kg and this is commonly applied to Gases.
- Specific Volume = (Volume of fluid) / (Mass of fluid)
- When we divide by volume of fluid to the Numerator and Denominator the fraction we get is, = (1) / (ρ)
- Specific volume is the reciprocal of Mass Density.

Specific volume is the reciprocal of density i.e. $v = \frac{1}{\rho}$

FLUID PROPERTIES: Specific Gravity

- This is defined as the ratio of the density or weight density of a fluid to density or weight density of a standard fluid.
- The **standard fluid for liquids is water** and for gases, the standard fluid is taken as **air.**
- Sometimes the specific gravity is called **Relative Density.** This is denoted by the symbol 'S' and this is dimensionless because the upper unit and lower units get cancelled.

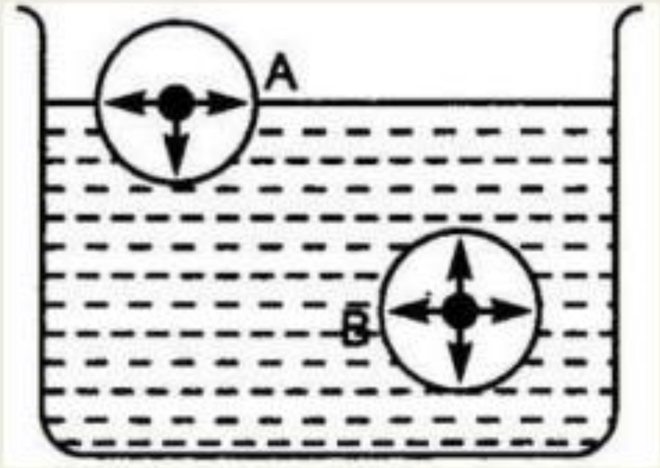
$$S_{liquid} = \frac{\rho_{liquid}}{\rho_{water}}$$

$$S_{gas} = \frac{\rho_{gas}}{\rho_{air}}$$

- Here liquid cannot be the same as water it can be some oil and other.
- Now, Weight density of liquid = S ∗ Weight Density of water = S ∗ 9.81 ∗ 1000 N/m
- Density of liquid = S ∗ Density of water = S ∗ 1000 kg/m³.

FLUID PROPERTIES: Surface Tension

- Surface Tension is the property of liquid which arises due to the fact that the molecules of the liquid at the surface are in a different situation than those in the interior of the liquid.
- A molecule lying inside the liquid is surrounded by other molecules and so is attracted equally in all directions. Hence, the net force of attraction acting on the molecule is zero.
- A molecule lying on the surface is attracted more by the molecules lying in the bulk of the liquid than by the molecules lying above it in the vapor phase. A molecule lying on the surface experiences a net inward attraction.
- As a result of this inward pull on all molecules lying on the surface, the surface behaves as if it were under tension
- **In other words, the surface tension of a liquid is defined as the force acting at right angles to the surface along 1 cm length of the surface.** Thus, the units of surface tension are Newton per meter i.e. Nm^{-1} in the S.I. system



FLUID PROPERTIES: Cohesion, Adhesion, Surface Tension and Capillarity

- **Cohesion** involves inter-molecular attraction between molecules of the same liquid. Cohesion is the property of the fluid by virtue of which liquid molecules are connected with each other so as to form a continuous mass.
- **Adhesion** means attraction between the molecules of a liquid and the molecules of a solid boundary surface or body in contact with the liquid. it is noteworthy that some fluids may not exhibit adhesion. Example: mercury.
- **Surface tension** is caused by the force of cohesion at the free surface.
- **Capillarity** is defined as the phenomenon of rise or fall of a liquid surface in a small tube relative to the adjacent general level of liquid when the tube is held vertically in the liquid. Capillarity rise or fall is due to the combined effect of adhesion and cohesion. This phenomenon of rise or fall of a liquid surface in a small diameter tube relative to the adjacent general level of liquid when the tube is held vertically in liquid is called **capillary or meniscus effect or capillarity**. Such narrow tubes are called capillaries

FLUID PROPERTIES: Compressibility

- Compressibility It is a measure of the relative volume change of a fluid or solid as a response to a pressure (or mean stress) change.
- The degree of compressibility of a substance is characterized by the bulk modulus of elasticity E defined as:

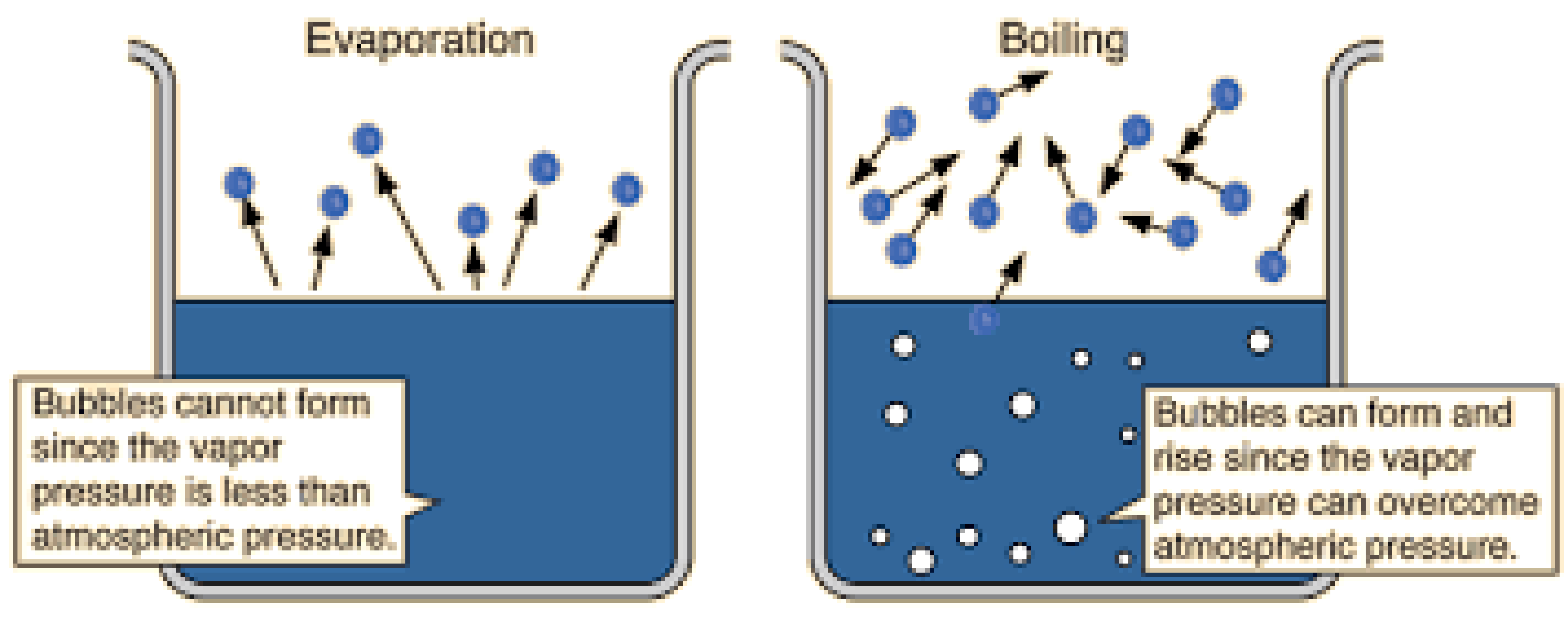
$$E = \lim_{\Delta V \to \Delta V^*} \frac{-\Delta P}{\frac{\Delta V}{V}}$$

- The choice to define compressibility as the negative of the fraction makes compressibility positive in the (usual) case that an increase in pressure induces a reduction in volume

FLUID PROPERTIES: Vapour Pressure

- **Vapor pressure or equilibrium vapor pressure** is defined as the pressure exerted by a vapor in thermodynamic equilibrium with its condensed phases (solid or liquid) at a given temperature in a closed system.
- The equilibrium vapor pressure is an indication of a liquid's **evaporation rate**. It relates to the tendency of particles to escape from the liquid (or a solid). A substance with a high vapor pressure at normal temperatures is often referred to as volatile.
- The pressure exhibited by vapor present above a liquid surface is known as vapor pressure. As the temperature of a liquid increases, the kinetic energy of its molecules also increases. As the kinetic energy of the molecules increases, the number of molecules transitioning into a vapor also increases, thereby increasing the vapor pressure.

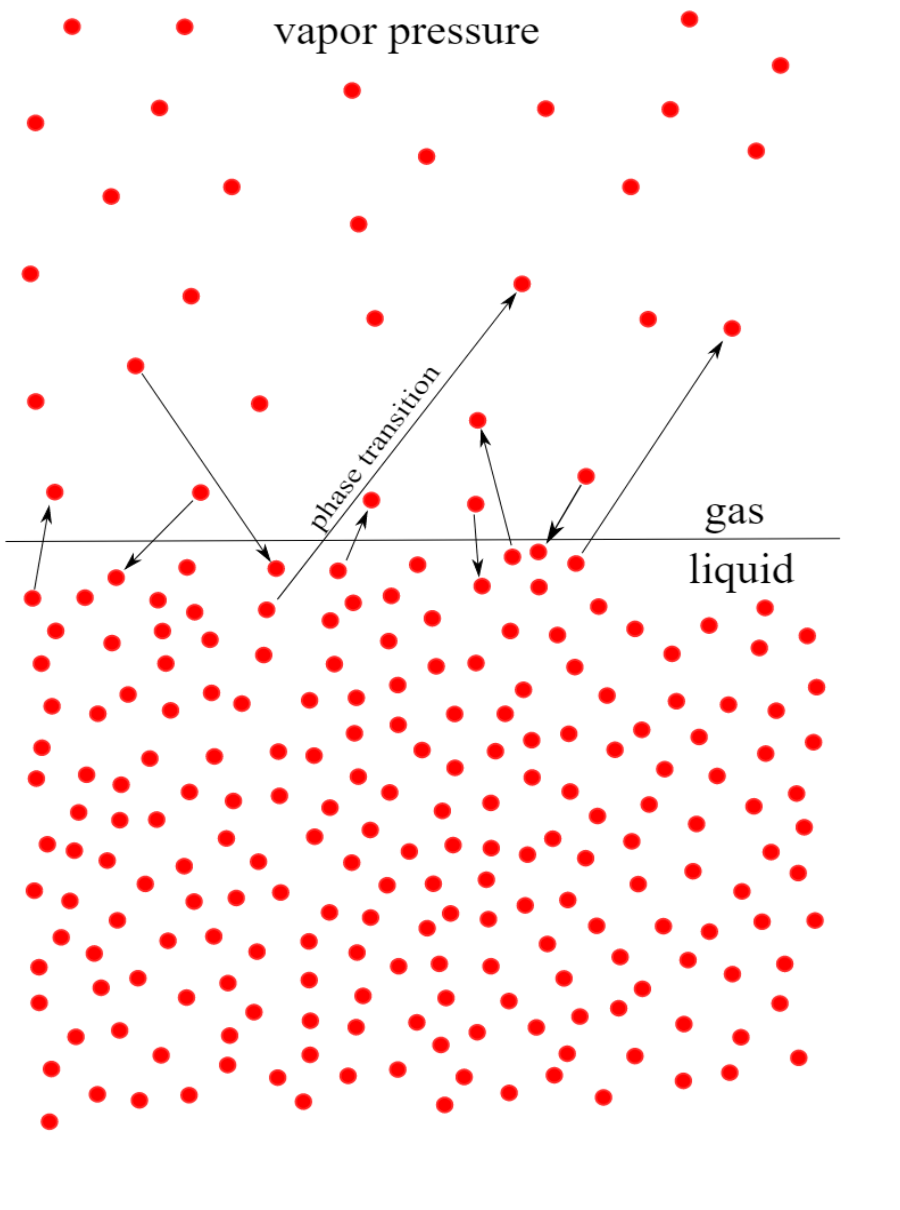
FLUID PROPERTIES: Vapour Pressure



FLUID PROPERTIES: Vapour Pressure

Characteristics of Vapour Pressure

- It is inversely proportional to the forces of attraction existing between the molecules of a liquid.
- It increases with a rise in the temperature. This is because the molecules gain specific weight



VISCOSITY

- It is the property of a fluid which offers **resistance** to the movement of one layer of fluid over another adjacent layer of the fluid. The viscosity is an important property which offers the fluid motion.
- The viscosity of liquid decreases with increase in temperature and for gas it Increases with increase in temperature.
- The viscosity is the measure of the friction of fluids. Viscosity is the physical property that characterizes the flow resistance of simple fluids.

VISCOSITY

- **Newton's law of viscosity** defines the relationship between the shear stress and shear rate of a fluid subjected to a mechanical stress.
- The **ratio of shear stress to shear rate is a constant, for a given temperature and pressure**, and is defined as the viscosity or coefficient of viscosity. Newtonian fluids obey Newton's law of viscosity. The viscosity is independent of the shear rate.
- **Non-Newtonian** fluids do not follow Newton's law and, thus, their viscosity (ratio of shear stress to shear rate) is not constant and is dependent on the shear rate.
- **Dynamic viscosity is the coefficient of viscosity** as defined in Newton's law of viscosity. Kinematic viscosity is the dynamic viscosity divided by the density.

NEWTON'S LAW OF VISCOSITY

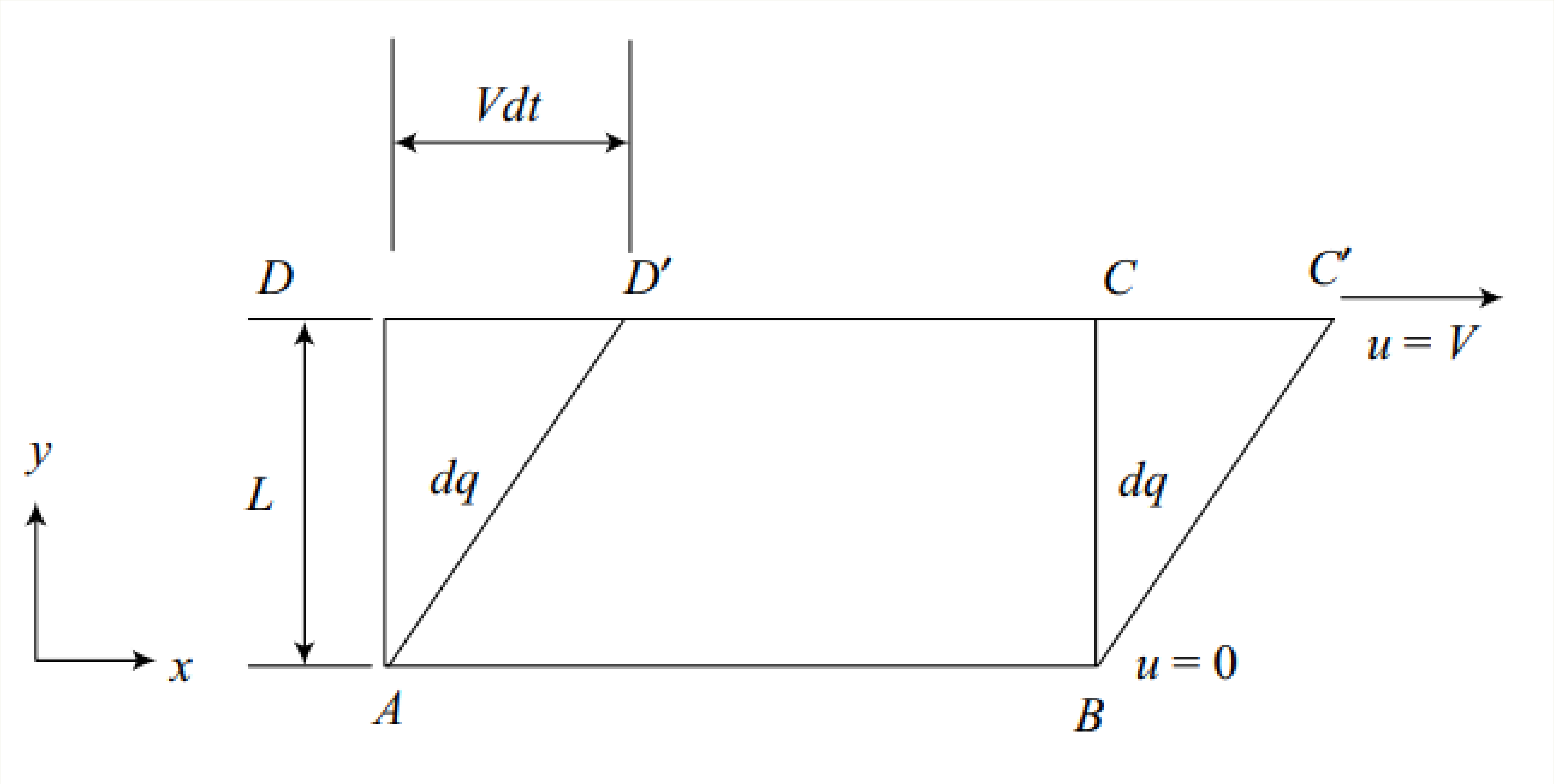
- Let us consider a **fluid contained between two large parallel plates**, separated by a distance **L**. The lower plate is assumed to be stationary, while the upper one is moving parallel to it with a velocity **V** under the influence of the applied shearing force **F**. The fluid particles sticking to the moving plate move with the same velocity V, and the shear stress t acting on this fluid layer is:

$$\tau = \frac{F}{A}$$

where A is the area of contact between the plate and the fluid

- The fluid in contact with the lower plate assumes the velocity same as that of the plate, **which is zero.**
- If the gap separating the two plates is small or the velocity V is high, the velocity distribution will be a straight line

NEWTON'S LAW OF VISCOSITY



NEWTON'S LAW OF VISCOSITY

- The equation of velocity can be written as:

$$u(y) = \frac{y}{L}V$$

- where **y is the vertical distance** measured from the lower plate. The velocity gradient will be:

$$\frac{du}{dy} = \frac{V}{L}$$

- During a **differential time interval dt**, the element of the fluid deforms through a **differential angle dq** while the upper plate moves a **differential distance dx.**

$$dx = Vdt$$

NEWTON'S LAW OF VISCOSITY

- The angular deformation can be expressed as:

$$d\theta = tan\theta = \frac{dx}{L} = \frac{Vdt}{L} = \frac{du}{dy}.dt$$

- The rate of angular deformation (or the shear strain) of a fluid element is equivalent to the velocity gradient $\frac{du}{dy}$

NEWTON'S LAW OF VISCOSITY

- For a well-ordered flow whereby fluid particles move in straight, parallel lines (parallel flow), **Newton's law of viscosity states that the for certain fluids, called Newtonian fluids, the shear stress (τ) on an interface tangent to the direction of flow is proportional to the distance rate of charge of velocity** $\left(\frac{du}{dy}\right)$ wherein the differentiation is taken in a direction normal to the interface.
- Mathematically, Newton's law of viscosity can be expressed as:

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

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

- where, the constant of proportionality μ is known as the **viscosity coefficient** or simply the **viscosity** which is the property of the fluid and depends on its state

VISCOSITY

- In the SI system the dynamic viscosity units are $\boldsymbol{N \cdot s/m^2}$ or, $\boldsymbol{Pa \cdot s}$ or $\boldsymbol{kg/m \cdot s}$
- The unit of dynamic viscosity in CGS (Centimetre - Gram - Second) system is **Poise (P),** named after Jean Louis Marie Poiseuille.

$$\mathbf{1\ Poise = 1\frac{g}{cm \cdot s} = \frac{10^{-3} kg}{10^{-2} m \cdot s} = 0.1\ kg/m \cdot s}$$

$$\mathbf{1\ centiPoise(cP) = \frac{1}{100} poise = 10^{-3}\ kg/m \cdot s}$$

VISCOSITY: Kinematic Viscosity

- In fluid mechanics, the ratio of dynamic viscosity to density appears frequently. The ratio is given the name kinematic viscosity and is designated by Greek letter (nu) $\boldsymbol{\nu}$. It is expressed as:

$$\boldsymbol{\nu} = \frac{\boldsymbol{\mu}}{\boldsymbol{\rho}}.$$

- The kinematic viscosity is considered as a kinematic quantity, since its unit does not contain any unit of mass. Physically, the kinematic viscosity represents the ratio of the ability to diffuse a disturbance in momentum relative to the ability of sustaining the original momentum.
- Kinematic viscosity has an SI unit of $\boldsymbol{m^2 s^{-1}}$, and a CGS unit of $\boldsymbol{cm^2 s^{-1}}$. The CGS unit is also known as Stokes, in honor of the famous mathematician Stokes.

VISCOSITY: Kinematic Viscosity

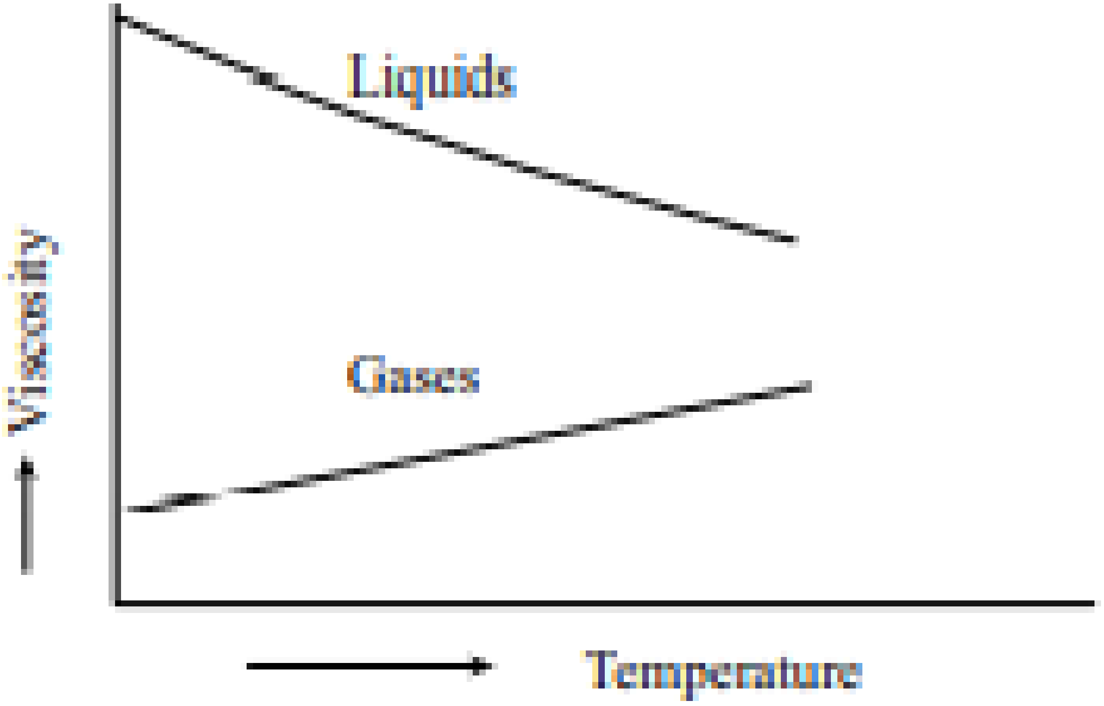
- The CGS unit is also known as Stokes, in honor of the famous mathematician Stokes.

$$\mathbf{1}\ \boldsymbol{stoke} = \mathbf{1}\,\frac{\boldsymbol{cm^2}}{\boldsymbol{s}} = \left(\mathbf{10^{-2}}\right)^{\mathbf{2}}\frac{\boldsymbol{m^2}}{\boldsymbol{s}} = \mathbf{10^{-4}}\ \boldsymbol{m^2/s}$$

$$\mathbf{1}\ \boldsymbol{centistoke} = \frac{\mathbf{1}}{\mathbf{100}}\ \boldsymbol{stoke} = \mathbf{10^{-6}}\ \boldsymbol{m^2/s}$$

- Viscosity is practically independent of pressure and depends upon temperature only. The kinematic viscosity of liquids and of gases at a given pressure is substantially a function of temperature

VISCOSITY: Variation of Viscosity with Temperature



Variation of viscosity of liquids and gases with temperature

EXAMPLE 1

Calculate the specific weight, mass density, specific gravity and specific volume of oil having a volume of 4.5 m^3 and weight of 40 kN.

1. Specific weight:

$$w = \frac{\text{weitht of oil}}{\text{Volume of oil}} = \frac{40 \times 10^3}{4.5} = 8.889 \times 10^3 \text{ N/m}^3 \qquad \text{ANS.}$$

2. Mass density of oil

$$p = \frac{\text{specific weight of oil}}{\text{Acceleration due to gravity}} = \frac{w}{g}$$

$$= \frac{8.889 \times 10^3}{9.81} = 906.1 \text{ kg/m}^3 \qquad \text{ANS.}$$

3. Specific gravity of oil

$$S = \frac{\textit{Specific weight of oil}}{\textit{Specific weight of water}} = \frac{8.889 \times 10^3}{9.81 \times 10^3} = 0.906 \qquad \text{ANS.}$$

4. Specific volume of oil

$$v = \frac{1}{p} = \frac{1}{906.1} = 1.1 \times 10^{-3} \text{m}^3\text{/kg} \qquad \text{ANS.}$$

EXAMPLE 2

The specific gravity and the dynamic viscosity of a fluid are 13.6 and 0.002 $N.s/m^2$ respectively. Calculate its (i) density, and (ii) kinematic viscosity.

Solution

$$S_{liquid} = \frac{\rho_{liquid}}{\rho_{water}}$$

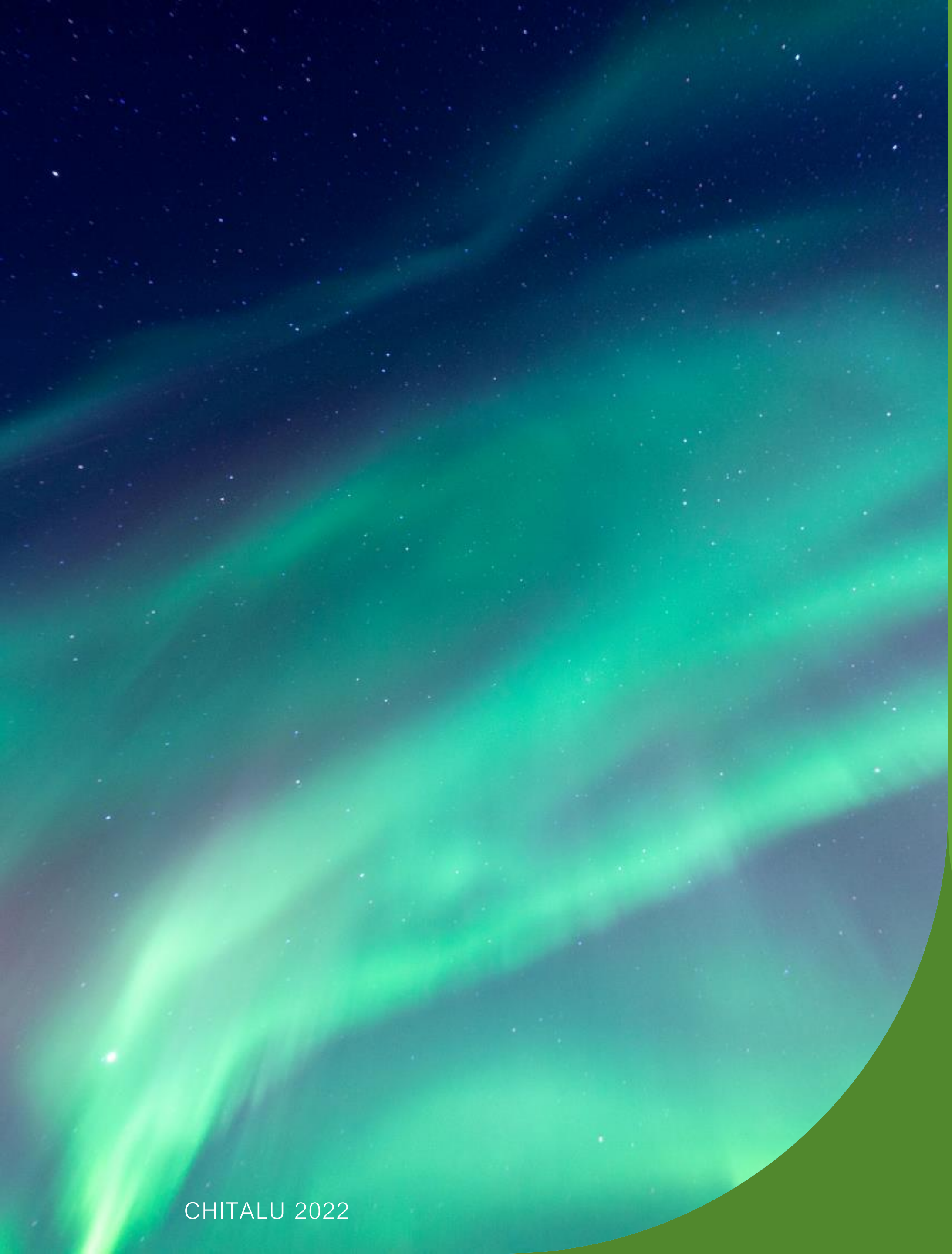
$$\rho liquid = \rho_{water} \times S_{liquid}$$

$$\rho_{liquid} = 1000 \times 13.6 = 13600 \text{ kg/m}^3$$

$$\text{Kinematic viscosity, } v = \frac{\mu}{\rho} = \frac{0.002}{13600} = 1.47 \times 10^{-7} \text{ m}^2/\text{s}$$

“There's no evidence whatsoever that Darwin had anything useful to say or anything to say period about how life began or how the universe began or how gravity began or how physics began or fluid motion or how thermodynamics began. He had nothing to say about that whatsoever.

Ben Stein



Thank You

Eng. Flora Chitalu
The University of Zambia
School of Engineering
Department of Mechanical Engineering
flora.chitalu@unza.zm