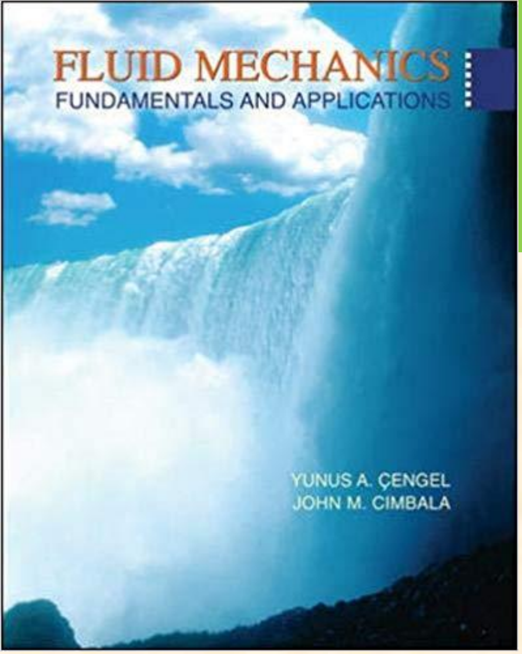



YUNUS A. ÇENGEL and JOHN M. CIMBALA, "Fluid Mechanics: Fundamentals and Applications",1st ed., McGraw-Hill,2006.

**Course name**

***Principles of Fluid Mechanics***

# Lecture-01- Chapter-01

## Introduction to Fluid Mechanics

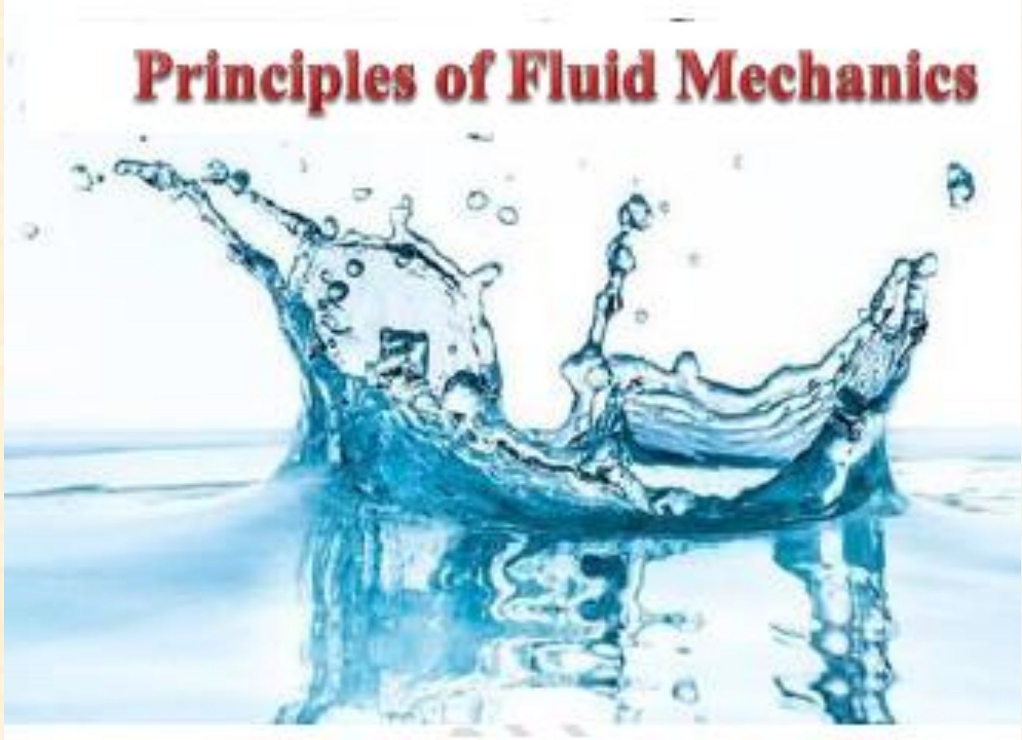
Lecture slides by

**Assistant Professor Dr. Thamer Khalif Salem**

University of Tikrit

# Outline

- ***Introduction***
- ***Application Areas of Fluid Mechanics***
- ***Fluid Properties***
- ***CLASSIFICATION OF FLUID FLOWS***
- ***Examples***
- ***Exams and Grading Policy:***
- ***References***



# Introduction

**Fluid Mechanics** is defined as the science that deals with the behavior of fluids at rest (*fluid statics*) or in motion (*fluid dynamics*), and the interaction of fluids with solids or other fluids at the boundaries.

**Fluid:** It is a substance that deforms continuously when subjected to a shear stress. It is either gas or liquid.

**Consider** a rectangular rubber block tightly placed between two plates. As the upper plate is pulled with a force ***F*** while the lower plate is held fixed, the rubber block deforms, as shown in Fig. 1–2. The angle of deformation **α** (called the *shear strain* or *angular displacement*) increases in proportion to the applied force ***F***.

**You** will recall from statics that **stress** is defined as force per unit area and is determined by dividing the force by the area upon which it acts. The normal component of the force acting on a surface per unit area is called the **normal stress**, and the tangential component of a force acting on a surface per unit area is called **shear stress** (Fig. 1–3). In a fluid at rest, the **normal stress** is called **pressure**.

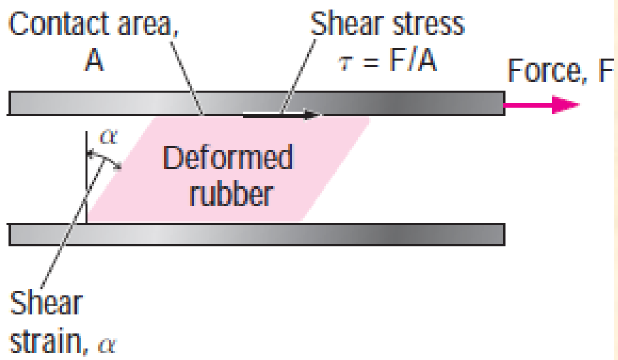



FIGURE 1–2

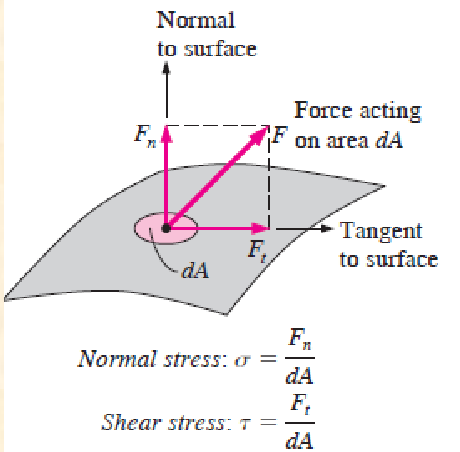



FIGURE 1–3

# Application Areas of Fluid Mechanics

Fluid mechanics is widely used both in everyday activities and in the design of modern engineering systems from vacuum cleaners to supersonic aircraft.

Natural flows and weather

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Boats

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Cars

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Piping and plumbing systems

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Industrial applications

*Courtesy UMDE Engineering, Contracting, and Trading. Used by permission.*

# Fluid Properties

That is, a fluid in direct contact with a solid "**sticks**" to the surface due to viscous effects, and there is no slip. This is known as the **no-slip condition** (assumes a **zero velocity relative to the surface**) all velocity profiles must have zero values with respect to the surface at the points of contact between a fluid and a solid surface (Fig. 1–9)..

The flow region adjacent to the wall in which the **viscous effects** (and thus the velocity gradients) are significant is called the **boundary layer.** The fluid property responsible for the no-slip condition and the development of the boundary layer is ***viscosity***

**1. Viscosity (μ)**

It is the property of fluid by virtue of which it offers resistance to shear.

Molasses and tar are example for highly viscous liquids. Water and air have small resistance.

-The viscosity of **gas increase** with temperature.

-The viscosity of **liquid decrease** with temperature.

Units $\mu = N.s/m^2$ or kg/m.s

A common units is poise (P)
1 Poise (g/cm.s)=0.1 N.s/m2 (Pa.s)
10 P=1 Kg/m.s

| Name | Definition | Symbol |
|---|---|---|
| Shear stress | **F/A** | **σ** |
| Shear strain | $dX_1/dx_2$ | γ |
| Shear rate | $dv_1/dx_2$ | ˙γ |
| Viscosity | σ/˙γ | η(˙γ) |

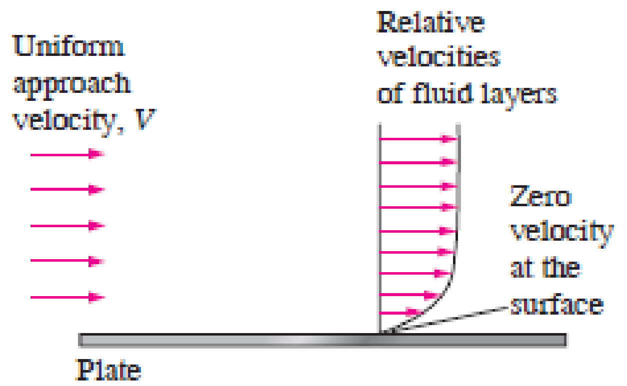


FIGURE 1–9

# Fluid Properties

- **Shear Stress:** $\tau = \frac{F}{A} = \frac{shear\ force}{surface\ area}$

**Shear Force:** It is the force components tangents to surface of liquid.

- **Body force or Liquid weight (F or W):** $F = W = ma$

- **Newton's Law of Viscosity:**

Experimentally shown that: $F \propto \frac{AU}{t}$

***Where :***

*A: the area of moving plate ($m^2$)* المساحة السطحية للصفيحة المتحركة

*U: Steady velocity of moving plate (m/s)*

*T: The distance between the plate (m)* المسافة بي الصفيحتين

$$F = \frac{\mu A U}{t}$$

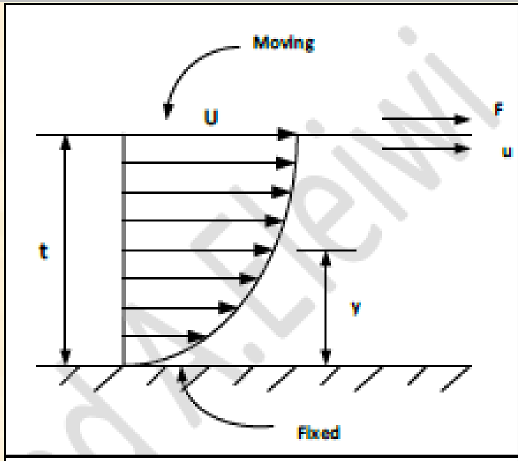
*Since* $\tau = \frac{F}{A}$ *Then* $\tau = \mu \frac{U}{t}$

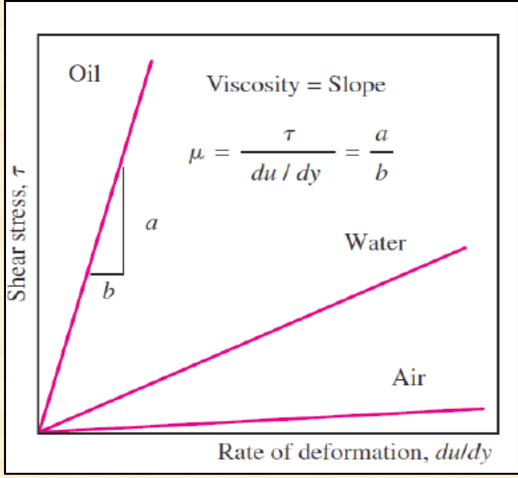
*U/t: The angular deformation of fluid =du/dy*

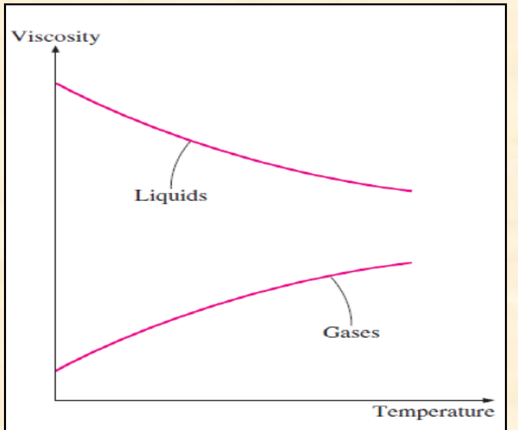
*Then* $\tau = \mu \frac{du}{dy}$

**Newton's Law of Viscosity (Newtonian Fluid)**

**هو المائع الذي يتبع قانون نيوتن للزوجة**



# Fluid Properties

- **Kinematic Viscosity ($\nu$):** It is the ratio of viscosity to mass density $\nu = \frac{\mu}{\rho}$ (m²/s)
- **Density (ρ):** It is the mass per unit volume $\rho = \frac{m}{\forall}$ (Kg/m³) $\rho_{water} = 1000\ kg/m^3$
- **Specific Weight (Unit Gravity Force) ($\gamma$ ):** The force per unit volume and It's change with location

  $\gamma_{water} = \rho\, g = 1000 * 9.81 = 9810$ (N/m³)
- **Specific Gravity (Relative Density) ($\delta$):** It is the ratio of the specific weight for substance as (liquid or solid) to the water

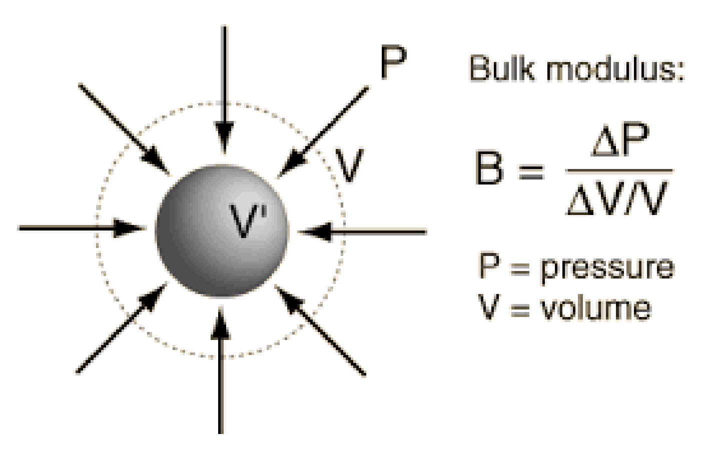
$$\delta = \frac{\gamma_s}{\gamma_w} = \frac{Specific\ weight\ of\ substance}{Specific\ weight\ of\ water} \quad (-)$$

- **Specific Volume ($\forall_s$):** It is the reciprocal of density $\forall_s = 1/\rho$ (m³/Kg)
- **Bulk Modulus of Elasticity (K):** the proportion of volumetric stress linked to the volumetric strain of definite material.

$$K = -\frac{dp}{d\forall/\forall} = -\frac{\Delta P}{\Delta\forall/\forall} = -\frac{P_2 - P_1}{\frac{\forall_2 - \forall_1}{\forall_1}} \quad (N/m^2)$$

K:The compressive stress per unit volumetric strain

$\forall$ : Volume (m³)

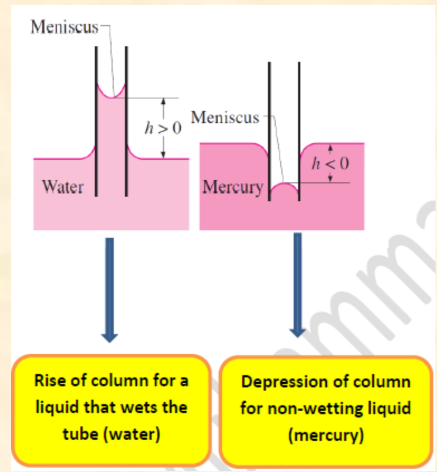


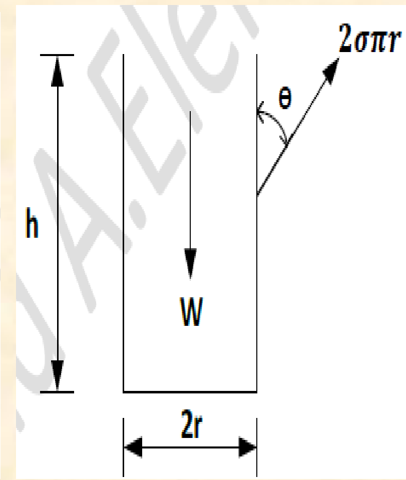
# Fluid properties

•**Surface Tension (σ):** Liquid behaves like small spherical balloons filled with the liquid, and the surface of the liquid acts like stretched elastic membrane under tension. The pulling force that causes this tension is due to attraction forces between the molecules of liquid .This **force per unit length is called surface tension (N/m).**

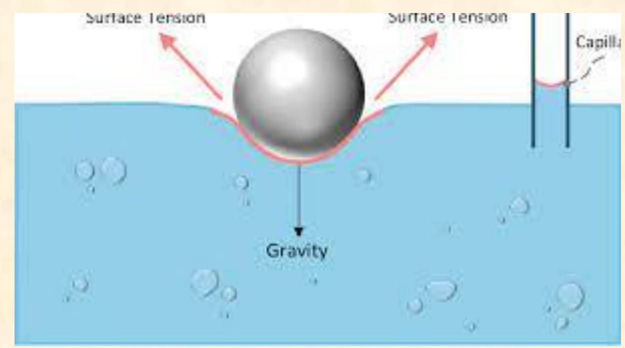
$$h = \frac{2\sigma \cos\theta}{\gamma r} \text{ (m)} \quad \text{and} \quad P = \frac{2\sigma}{r}$$

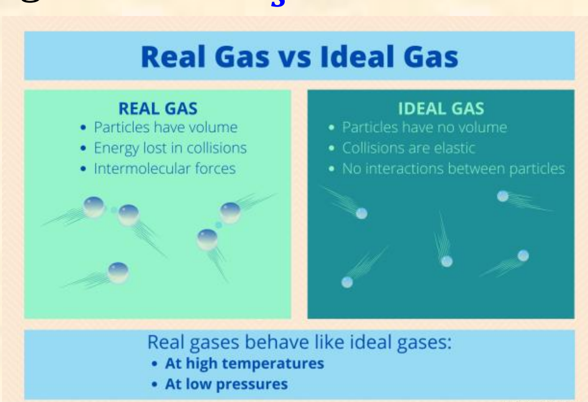
**Where**: h: liquid height , P: droplet pressure



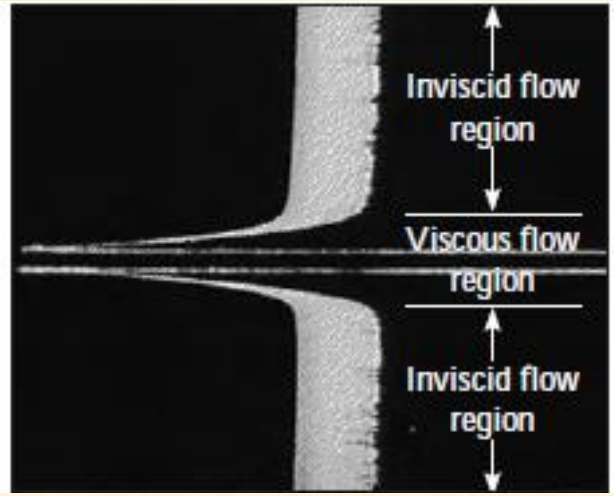

- **Pressure (P):** The normal force pushing against a plane area divided by the area: units N/m2 or pascal (Pa).
- **Vapor Pressure ($P_v$):** The vapor molecules exert a partial pressure in the space known as vapor pressure.
- **Perfect Gas:** It is a substance that satisfies the perfect gas law $P\forall_s = RT$ or $P = \rho RT$ or $PV = mRT$



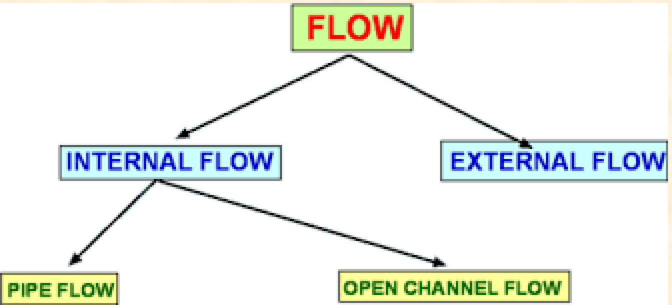



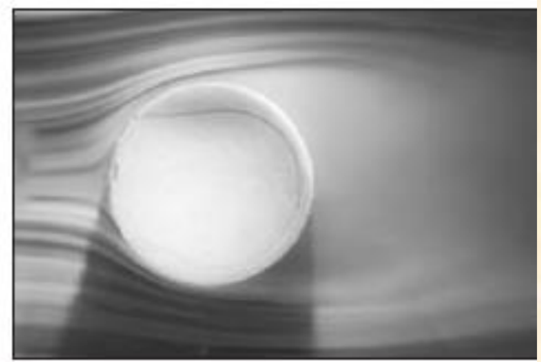
# CLASSIFICATION OF FLUID FLOWS

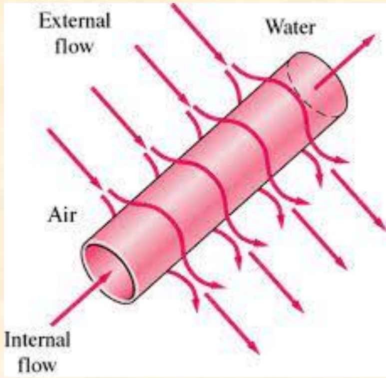
- **Viscous versus Inviscid Regions of Flow:** There is no fluid with zero viscosity, and thus all fluid flows involve viscous effects to some degree. Flows in which the frictional effects are significant are called **viscous flows.**
- where viscous forces are negligibly small compared to inertial or pressure forces. Neglecting the viscous terms in such **inviscid flow regions**




- **Internal versus External Flow:** The flow of an unbounded fluid over a surface such as
- a plate, a wire, or a pipe is **external flow.** The flow in a pipe or duct is **internal flow**

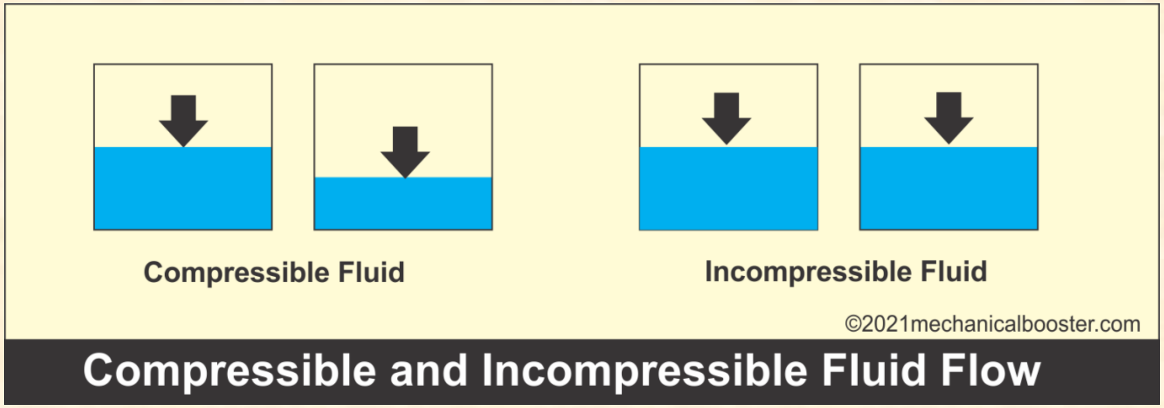




# CLASSIFICATION OF FLUID FLOWS

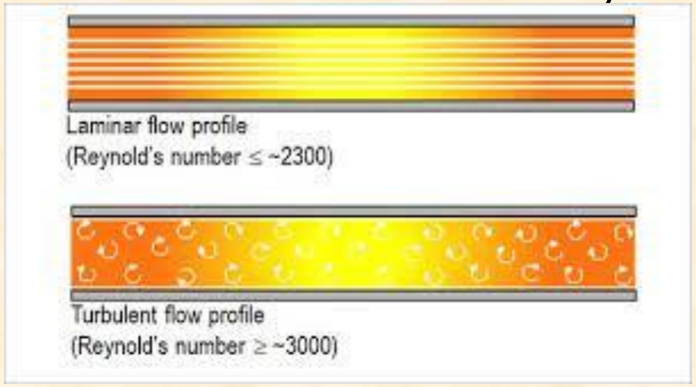
- **Compressible versus Incompressible Flow:** Incompressibility is an approximation, and a flow is said to be **incompressible** if the density remains nearly constant throughout.
- **A compressible fluid can experience a density change during flow (not constant).**




- **Laminar versus Turbulent Flow:**

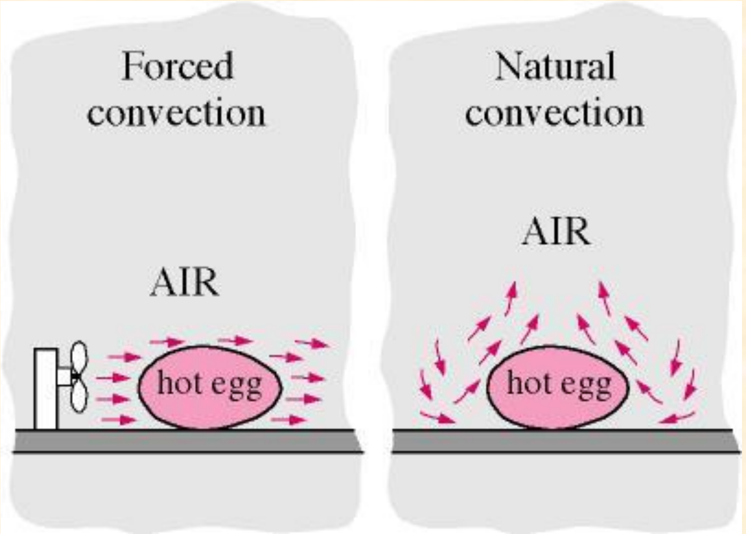
• The highly ordered fluid motion characterized by smooth layers of fluid is called **laminar.** The highly disordered fluid

- motion that typically occurs at high velocities and is characterized by velocity fluctuations is called **turbulent**

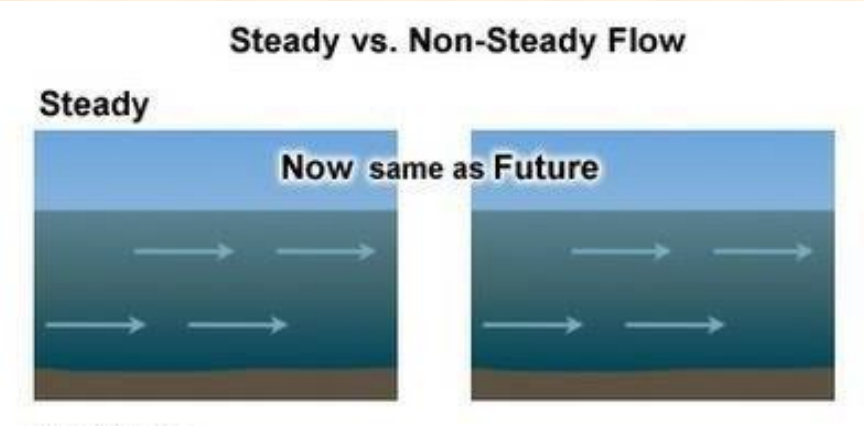


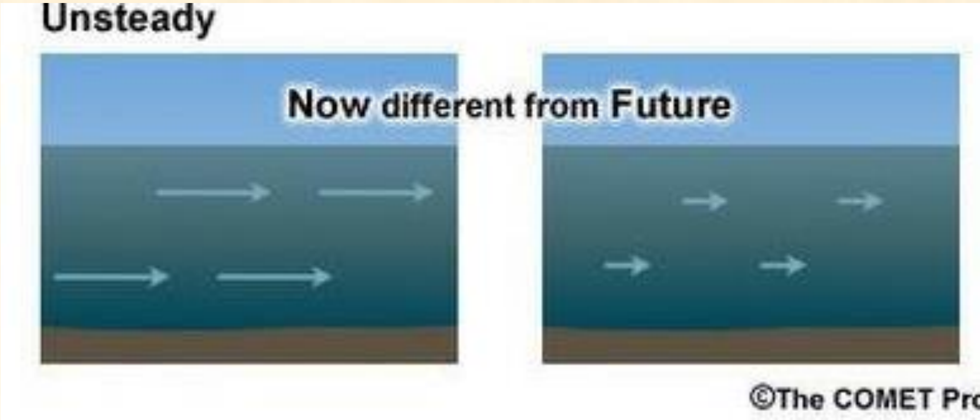
# CLASSIFICATION OF FLUID FLOWS

- **Natural (or Unforced) versus Forced Flow:** In **forced flow,** a fluid is forced to flow over a surface or in a pipe by external means such as a pump or a fan.
- In **natural flows,** any fluid motion is due to natural means such as the buoyancy effect, which manifests itself as the rise of the warmer (and thus lighter) fluid and the fall of cooler (and thus denser).




- **Steady versus Unsteady Flow:** The term **steady** implies *no change at a point with time* The opposite of steady is **unsteady.**



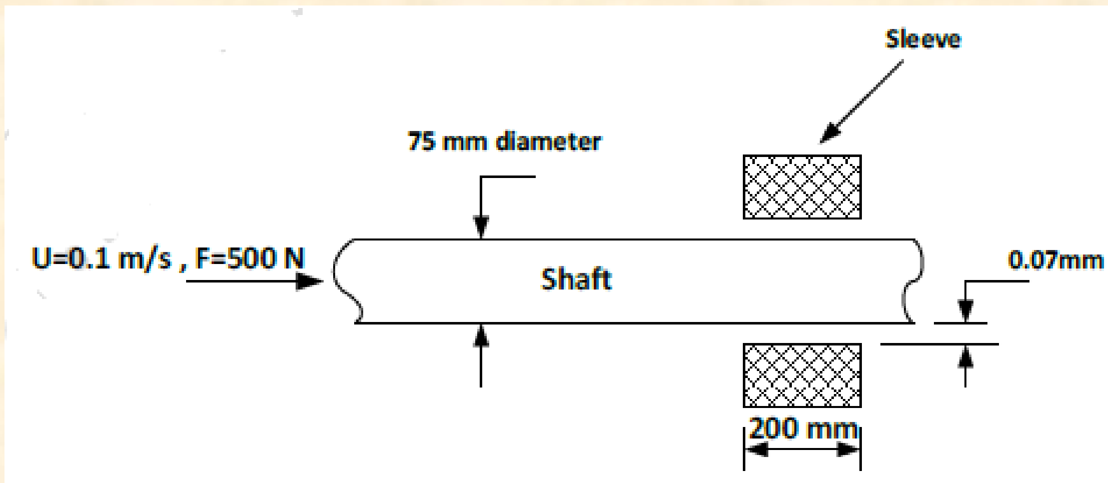



# Examples:

***Example** $_1$ **:***

A Newtonian fluid in the clearance between a shaft and a concentric sleeve. When a force of **500 N** is applied to the sleeve parallel to the shaft, the sleeve attains a speed of **1 m/s** .If a **1500 N** force is applied. What **speed will the sleeve attain**? The temperature of the sleeve remains constant.

**Sol.$_1$:**




*F1=500 N ,U=1 m/s*

*Since:* $F = \mu \frac{AU}{t}$ *this lead to* $500 = \mu \frac{A*1}{t}$ $\longrightarrow$ $\mu = \frac{500\,t}{A}$

*Since Temperature is constant and this lead to μ=Constant*

$F_2 = \mu \frac{AU}{t}$ $\longrightarrow$ $1500 = \frac{500*t}{A} * \frac{AU}{t}$ $\longrightarrow$ *u=3 m/s*

# Examples:

***Example $_2$ :***

A plate 0.5 mm distance from a fixed plate, moves at 0.25 m/s and requires a force per unit area of 2 Pa to maintain this speed. Determine the viscosity of the substance between the plates.

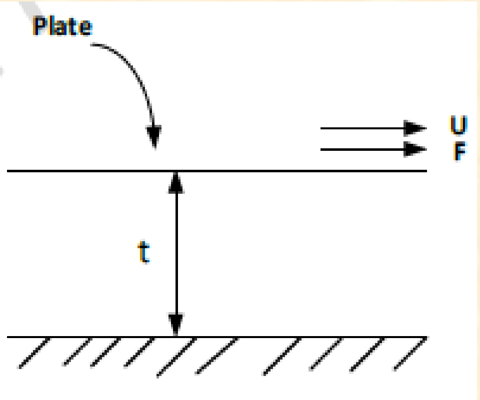
**Sol.$_2$:**

$F/A = 2\ Pa\ (N/m^2), t = 0.5\ mm,$

$U = 0.25\ m/s$

$$\text{Since } F = \mu \frac{AU}{t} \text{ or } \frac{F}{A} = \frac{\mu U}{t} = 2\ Pa$$

$$2 = \mu \frac{0.25}{0.5*10^{-3}} \longrightarrow \mu = 0.004\ Pa.s$$




***Example $_3$ :***

A liquid compressed in a cylinder has a volume of 1 liter (1000 cm$^3$) at 1 MN/m$^2$ and volume of 995 cm$^3$ at 2MN/m$^3$.What is its bulk modulus of elasticity?

**Sol.$_3$:**

$$K = -\frac{\Delta P}{\Delta \forall / \forall} = \frac{(2-1)}{(995-1000)/1000} = 200\ MPa$$

***Example $_4$ :***

For K=2.2 GPa for bulk modulus of elasticity of water .What is pressure is required to reduce its volume by 0.5 percent?

**Sol.$_4$:**

$$K = -\frac{\Delta P}{\Delta \forall / \forall} = -\frac{\Delta P}{0.5 * 10^{-2}} = 2.2 * 10^9$$

Then

$$\Delta P = -11\ Mpa$$

# Examples:

***Example $_5$ :***

Determine the capillary rise for distilled water at 40 oC in a circular 6mm diameter glass tube

**Sol.$_5$:**

$$h = \frac{2\sigma}{\gamma r} = \frac{2 * 0.071}{9.737 * 3 * 10^{-3}} = 4.8\, mm$$

***Example $_6$ :***

The viscosity of fluid is to be determined by a viscometer constructed of two **40 cm** long concentric cylinder. The outer diameter of the inner cylinder is **12 cm**, and the gap between the two cylinders is **0.15 cm**. The inner cylinder is rotated at **300 rpm**, and the torque is measured to be (**1.8 N.m**) .Find the viscosity of the fluid?

**Sol.$_6$:**

$$T = F * R = \tau * A * R$$

$$T = \mu \frac{du}{dy} * A * R$$

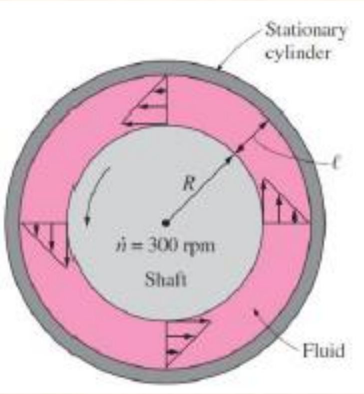
$$U = \omega * R$$

$$T = \mu * \frac{\omega R}{l} (2\pi R L) R$$

$$T = \mu \frac{2\pi \omega L R^3}{l}$$

$$\mu = \frac{T l}{2\pi \omega L R^3} = \frac{1.8 * 0.0015}{2\pi * 0.4 * 0.06^3 * \left(\frac{2\pi * 300}{60}\right)}$$

$$\mu = 0.158\, Pa.s$$



# Exams and Grading Policy:

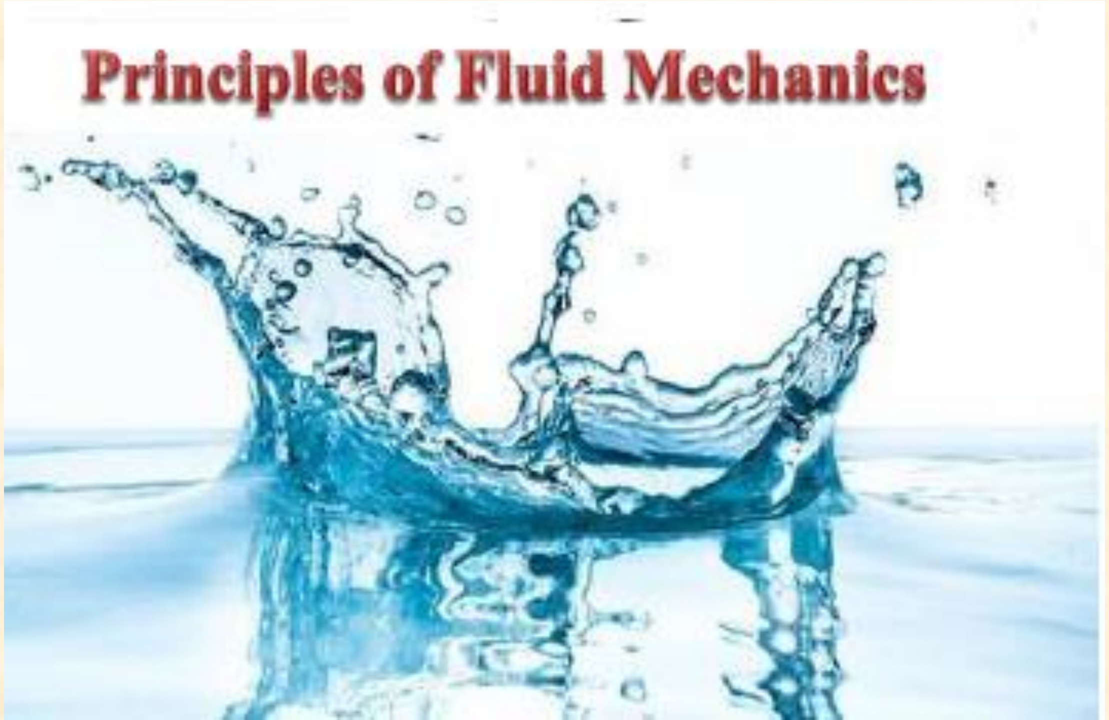
❖ The distribution of Fluid mechanics degree for the students in course-1 as following the table:

| Exam 20% | | Report (Class Activity) 10% | | Extra Degree 5% | | | Final Exam 50% | Laboratory 15% | | | Final |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) | (2) | Report Structures | Report Discussion | Contribution | Homework | Quizzes | - | Report Structures | Report Discussion | Experimental Contribution | |
| **10 %** | **10 %** | 7 % | 3 % | **2 %** | 2 % | 3 % | 35 % | 7 % | 3 % | 5 % | **50 %** |

# References:

References:


- Fluid Mechanics Fundamentals and applications By Yunus A.Cengel and John M.Cimbala.
- Fluid Mechanics,By Streeter,Victor L.
- Fluid Mechanics with Engineering Applications By Robert L.Daugherty.

- Note: Solve all five Homeworks and sending me the answering next week on Sunday 26 October 2022.
- I hope everything is clear for all students

Good luck