AHSANULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY (AUST)

ME-3105: FLUID MECHANICS

(LEC-1: Fluid Properties)

BY

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Associate Professor

Department of MPE, AUST

ABOUT ME

- BSME from BUET, MASTERS in ME from UTA, TX (Major: Structural analysis & Design); PhD from BUET in ME.
- I worked more than 12 (ten) years in Aerospace Company in USA.
- Stress Analysis and Design, Finite Element (FE) Analysis. Design Support (worked mainly in Boeing 747 & 737 Plane. NASA-SOFIA and Black Hawk Helicopter MOD program).
- Experienced in Finite Element (FE) tools: Nastran/Patran, Pro-Mechanica & ANSYS; Design tools: CATIA, Pro-E and AutoCAD and other tools: MathCAD, MatLab.
- Joined in AUST in 2016.

ABOUT ME & APPLICATION OF FLUID MECHANICS

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CLASS SCHEDULE

ME-3105: Fluid Mechanics (ME 3/1)

Monday (Section B, 8A04)): 1:50 pm to 3:30 pm.

Tuesday (Section B, 8A04): 11:20 am to 12:10 pm

Tuesday (Section A, 8A06): 1:00 pm to 2:40 pm

Thursday (Section A, 8A04): 11:20 am to 12:10 pm

<u>Course Materials</u>

Text Books:

Fluid Mechanics- Fundamentals and Application by ***Yunus Cengel*** *and John Cimbala; 3rd edition; Published by McGraw Hill.*

Reference Books:

1) ***Fluid Mechanics*** **by Frank M. White, McGraw-Hill Higher Education.**
2) ***Introduction to Fluid Mechanics*** **by Robert Fox and McDonald; 7th edition; Published by John Wiley & Sons.**
3) ***A Textbook of Hydraulics, Fluid Mechanics and Hydraulic Mechanics by R S Khurmi;*** **15th edition; Published by S Chand & Co Ltd.**
4) ***Fluid Mechanics and Fluid Power Engineering by Dr. D. S Kumar*****; 7th edition; Published by S.K. Kataria & Sons.**
5) ***Dr. Md. Quamrul Islam & Dr. Amalesh Chandra Mandal, Fluid Mechanics Through Worked Out Problems*****.**

CLASS NOTES

- Uploaded in the google classroom.
- Classroom Link:

https://classroom.google.com/c/NzM5MDM2OTA5OTgx?cjc=i5plmp6

https://classroom.google.com/c/NzM5MDM2OTA5OTgx

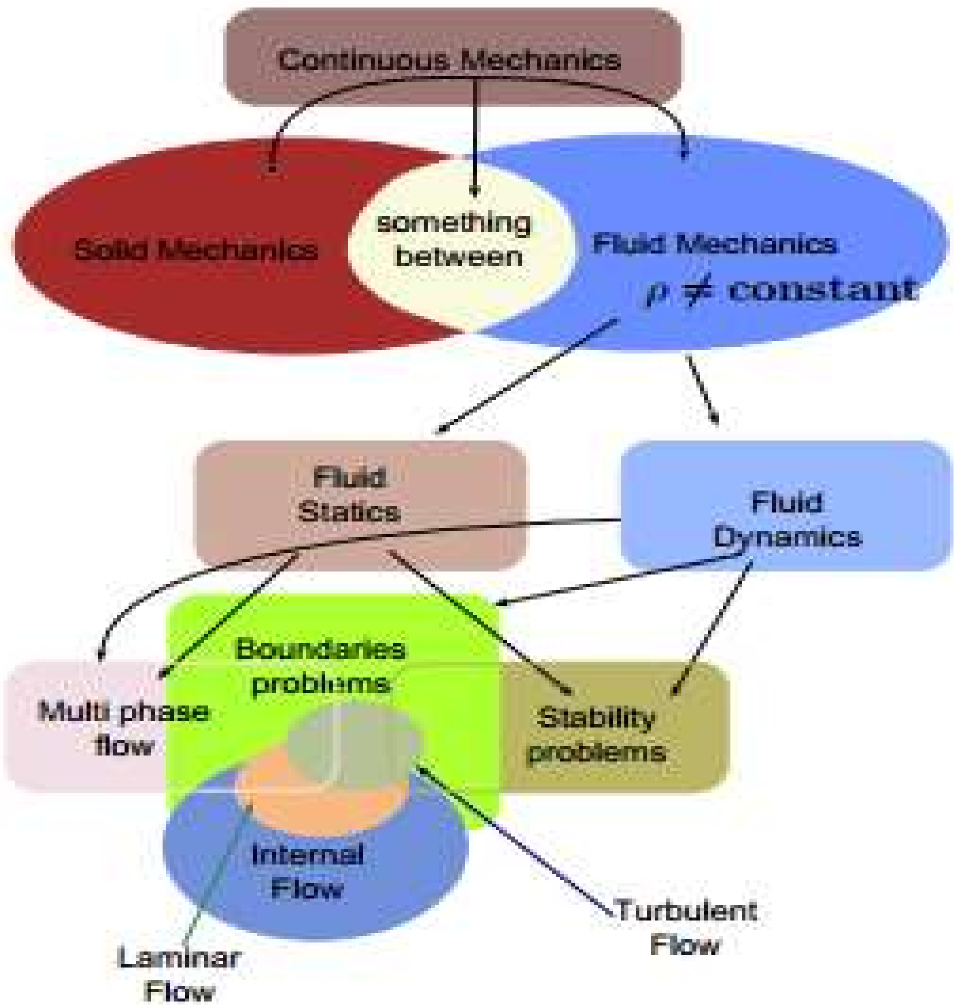
- Code: i5plmp6

FLUID MECHANICS

- The mechanics of fluids is the field of study in which the fundamental principles (Laws) of general mechanics are applied to Fluids (liquids and gases). These principles are those of the conservation of matter and energy, laws of thermodynamics, Newton's second law and laws of equilibrium of static body and compressibility of fluids.

- The study of Fluid Mechanics is further sub-divided into two. Fluid at rest the study is known as Fluid Statics, whereas if the fluid is in motion, the study is called Fluid Dynamics.

FLUID MECHANICS



DEVELOPMENT OF FLUID MECHANICS

- The problems are encountered in ancient period in the fields of water supply, irrigation, navigation, water power, designing of arrows & boats resulted in development of the Fluid Mechanics.

- Archimedes's Principle (Law of Buoyancy) which is considered to be as true today, the knowledge of the ancients (250 B.C) appears in the modern Fluid Mechanics.

- After fall of Roman Empire (476 AD), there was no record of progress in Fluid Mechanics until Leonardo Da Vinci first designed chambered canal lock in 1500 AD.

DEVELOPMENT OF FLUID MECHANICS

- Notable contribution to theoretical Hydrodynamics have been made by Leonhard Euler, **Isaac Newton**, Daniel Bernoulli, Ernst **Mach**, Navier, Stokes, Giovanni **Venturi**, Hagen Poiseuille, Julius **Weisbach**, Henry **Darcy,** Francis and many others.

- The founder of modern Fluid Mechanics is the German professor Ludwig Prandtl (Boundary Layer theory); considered as Father of Fluid Mechanics.

- Other notable contributor to modern fluid Mechanics are Heinrich **Blasius**, Edgar **Buckingham**, **Von-Karman**, Osborn **Reynolds**, **Rouse** and many others.

DEVELOPMENT OF FLUID MECHANICS

Leonardo da Vinci

Ernst Mach

Osborne Reynolds

Daniel Bernoulli

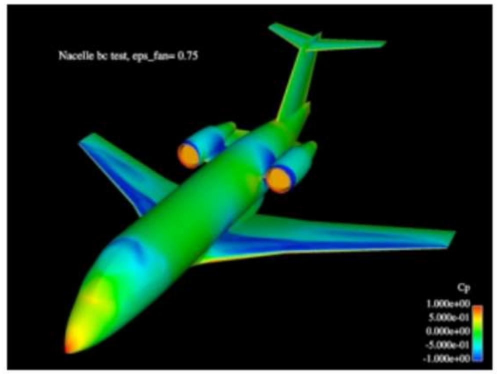
Isaac Newton

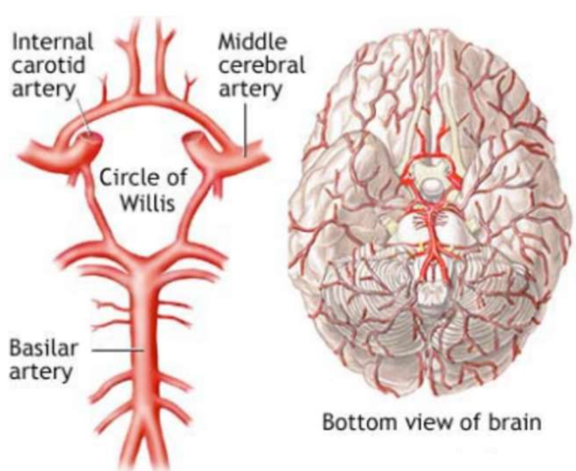
Ludwig Prandtl

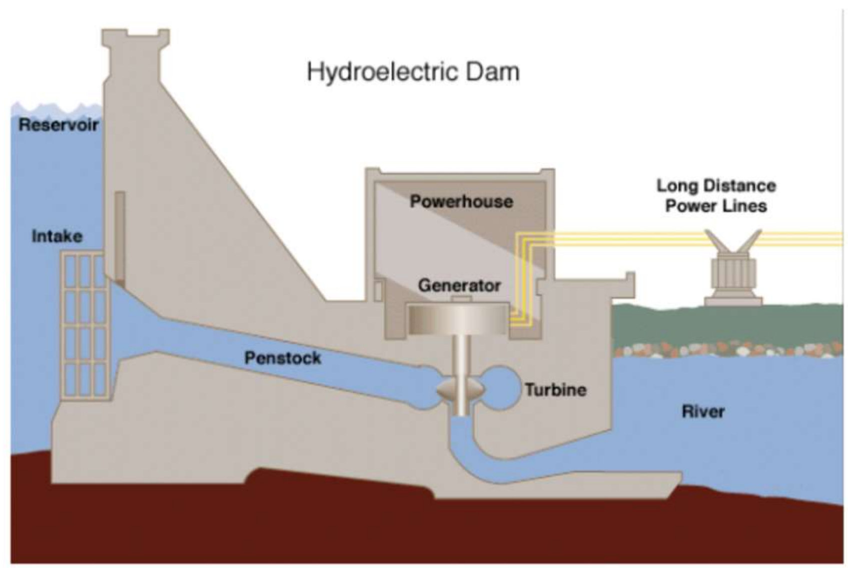
SCOPE OF FLUID MECHANICS

- Fluid Mechanics is the study of fluids at Rest or in Motion.
- It has traditionally been applied in such areas as the design of canal, levee and dam systems.
- Design of **a**irplane, **s**hips, pumps, compressors, and piping and **ducting** used in the water and air.
- **Air Conditioning systems** of homes and businesses, as well as the piping systems needed in chemical plants.
- The **aerodynamics of automobiles;** subsonic & supersonic **airplanes, missiles, and helicopter.**
- Development of many different **flow measurement** devices such as gas pump meters etc.
- Wind Turbine, Energy generation from **ocean Waves, Aerodynamics of large buildings, artificial hearts and valves, micro fluid mechanism (LG rolling LCD TV)** etc.

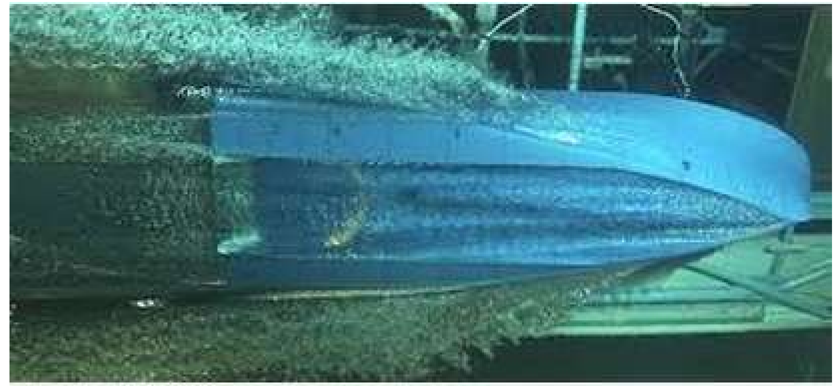
EXAMPLE OF APPLICATION OF FLUID MECHANICS

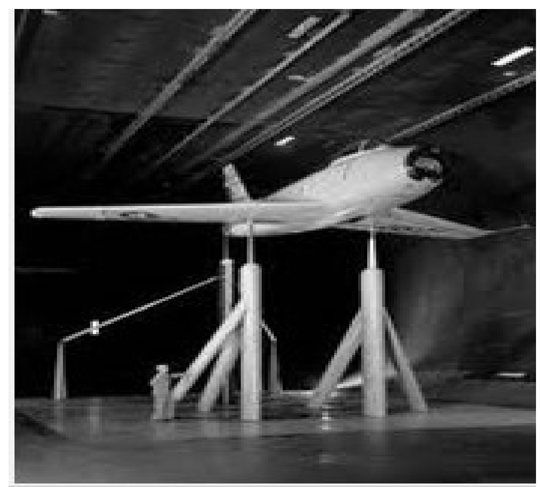






EXAMPLE OF APPLICATION OF FLUID MECHANICS





DEFINITION OF FLUID

- **Fluid:** It is a substance in either liquid or gas phases, which is capable of flowing, has no definite shape, conforms to the shape of the containing vessel. **Fluid** can not support shear force and deform continuously to minimize applied shear forces.
- ***Liquid:*** A liquid possesses a definite volume, which varies only slightly with temperature and pressure. Under ordinary conditions liquids are difficult to compress and is considered as incompressible for practical purpose.
- ***Gas:*** 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.
- Fluids are also classified as an ideal fluids and practical or real fluids (talk later about it).

DEFINITION OF FLUID

- The following properties of fluids are important to the study of Fluid Mechanics:
  - (1). Density (ρ)
  - (2). Specific Volume (v)
  - (3). Specific Weight (γ)
  - (4). Specific Gravity (S.G)
  - (5). Viscosity (μ)
  - (6). Kinematic Viscosity (ν)
  - (7). Compressibility
  - (8). Surface Tension
  - (9). Capillarity
  - (10). Vapour Pressure and
  - (11). Fluid Pressure.

(Note: μ = Mu; ρ = Rho; γ = Gamma; ν = Nu, β = Beta, σ = Sigma)

PROPERTIES OF FLUID

- **Density (ρ):** Mass per unit volume of fluid is called Density of fluid. It is also known as Mass Density (ρ). Unit of ρ is Kg/m^3.
- **Specific Volume (v):** Volume occupied by a unit mass of fluid is called Specific Volume of fluid (v). Unit of v is m^3/kg ($v = 1/\rho$).
- **Specific Weight (γ):** Weight per unit volume of fluid is called specific weight. Specific Weight is not absolute property of the fluid since it is depend on gravitational field. Unit of γ is N/m^3 ($\gamma = \rho g$).
- **Specific Gravity (SG):** Specific Gravity is a dimensionless ratio of a fluid's density to a standard reference density. For solid and liquid, the standard reference density is the density of pure water.

$$SG = \gamma/\gamma_{water} = \rho/\rho_{water}$$

PROPERTIES OF FLUID

- **Viscosity (μ):**
  - Viscosity of fluid is measure of its resistance to shear or angular deformation.
  - Due to viscosity, fluid offers resistance to the movement of one layer over an adjacent layer.
  - Unit of μ is $N.s/m^2$. It is also called absolute viscosity or dynamic viscosity.
- **Kinematic Viscosity (ν):**
  - It is ratio of absolute viscosity to the density (ρ).

    $\nu = \mu/\rho$; unit of ν is m^2/s.

(Note: μ = Mu; ρ = Rho; γ = Gamma; ν = Nu β = Beta, σ = Sigma)

PROPERTIES OF FLUID

- **Compressibility of Fluid:** The compressibility of fluid is measured by the *Bulk Modulus of Elasticity (K);* which is a measure of resistance of a fluid to uniform compression. It is defined as ratio of infinitesimal increase of pressure to the resulting relative decrease in volume.

$$K = - dP/(dV/V)$$

where dP = change in pressure; dV = resulting change in volume; V = Volume of fluid

$V = 1/\rho$; $\rho * V = 1$; $\rho * dV + V * d\rho = 0$; $dV/V = -d\rho/\rho$;
$K = -dP/(dV/V) = dP/(d\rho/\rho)$.

Bulk Modulus of Elasticity (K) is function of pressure and temperature. The unit of K is same as pressure (N/m^2). Inverse of the Bulk Modulus of Elasticity is called *Coefficient of compressibility* β, i.e. $\beta = 1/K$.

PROPERTIES OF FLUID

- **Surface Tension (σ):** Liquid have both cohesion and adhesion property. Both of which are form molecular attraction.
  - Cohesion enables a liquid to resist tensile stress, while adhesion enables it to adhere to another body. Due to intermolecular cohesive forces, the membrane or skin that seems to form on the free surface of the liquid is known as *Surface Tension, σ*.
  - For example, a small needle placed gently upon the water surface will not sink but will be supported by the tension at the water surface.
  - It is expressed as tensile force per unit distance on the surface, $\sigma = F/L$ and unit N/m.

PROPERTIES OF FLUID

Example of Surface Tension:

PROPERTIES OF FLUID

➢ **Capillarity of Liquid:** Liquid have both cohesion and adhesion property. *When cohesion is of less effect than the adhesion, the liquid will wet a solid surface it touches and rise at the point of contact. If cohesion is predominates, the liquid surface will depressed at the point of contact*.

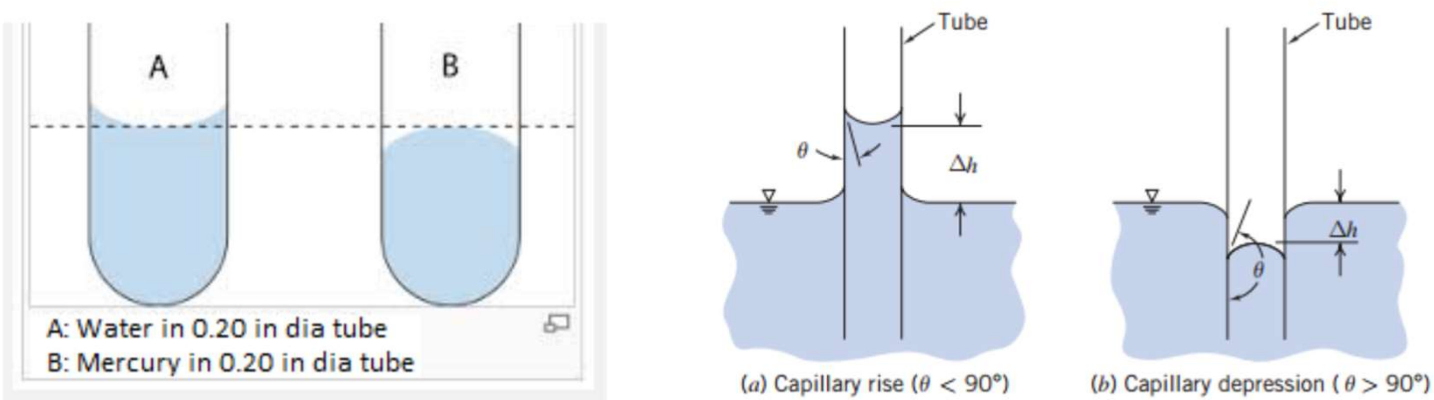
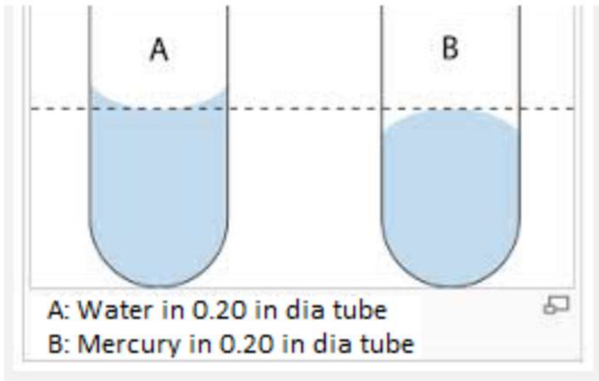


Fig: Capillary action of liquid in small diameter tube

PROPERTIES OF FLUID

➢ Capillarity of Liquid:



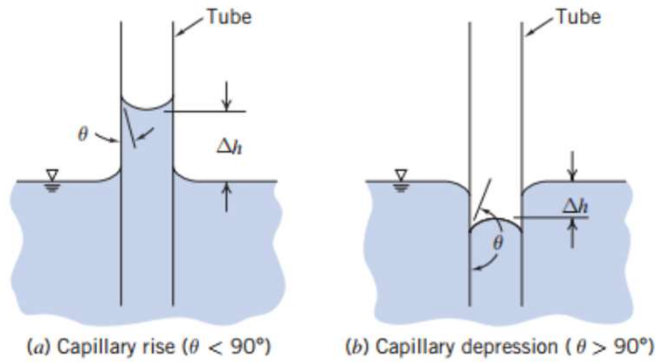
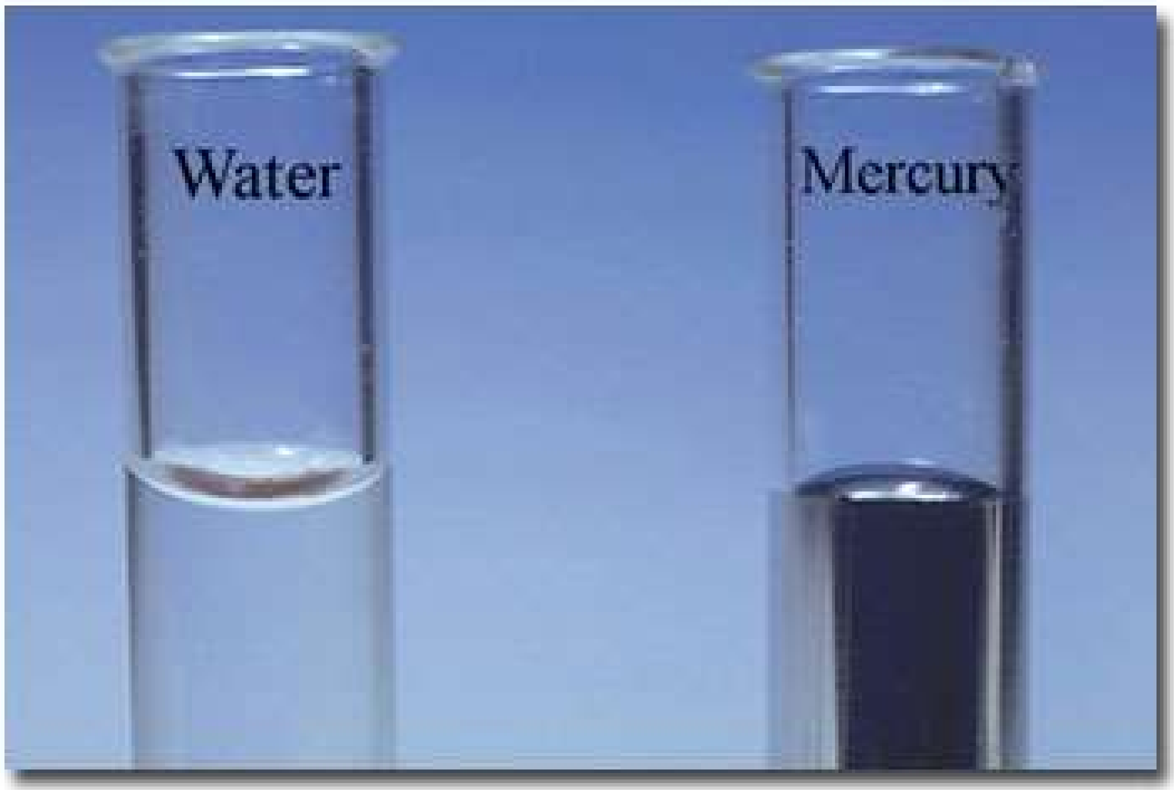


Fig: Capillary action of liquid in small diameter tube

- Such a phenomenon of rise and fall of liquid surface relative to the adjacent general level of liquid is known as capillarity; and the curve surface developed due to capillarity is called Meniscus.
- *The capillary rise or depression of liquid can be determined by considering the conditions of equilibrium in a circular tube of small diameter inserted in a liquid.*

PROPERTIES OF FLUID

➢ Capillarity of Liquid:



PROPERTIES OF FLUID

Vapour Pressure:

- Pressure exerted by the vapour formed at the free surface of a liquid is called vapour pressure.
- Vapour pressure of liquid increases with temperature.
- If external pressure imposed on the liquid is reduced to equal or less than vapour pressure of the liquid, then boiling of liquid will start at ordinary or normal temperature.
- Mercury has very low vapour pressure.

PROPERTIES OF FLUID

- **Cavitations:**
  - The vaporization of liquid will start in the flow system if the pressure at any point in the liquid flow approaches the vapour pressure of the liquid, resulting in the pockets of dissolved gases and vapors.
  - The bubbles of vapour are carried out by the flowing liquid into a region of high pressure where they collapse and giving rise to high impact pressure.
  - The pressure developed by the collapsing bubbles is so high that the material from the adjoining boundaries (turbine blade, pipes etc) gets eroded and cavities are formed on them. This phenomenon is known as Cavitation.

PROPERTIES OF FLUID

- **Fluid Pressure:**
  - The normal force exerted by a liquid or fluid on unit area of its boundary or control surface is called Fluid Pressure.
  - Fluid Pressure, $P = F/A$ or dF/dA, where dF is the *infinitesimal* force acting on infinitesimal area of boundary surface dA.
  - The unit pressure is N/m^2 or Pa (Pascal) or KPa.

PROBLEM ON BULK MODULUS OF ELASTICITY

Problem-1: At a depth of 2 kilometers in the ocean the gage pressure is 840 Kg(f)/cm^2; density and bulk modulus of elasticity of water at the surface are 1025 kg/m^3 and 24000 kg(f)/cm^2 respectively. (a). What will be the density of water at the depth of 2 kilometer ? (b). What will be specific volume and change of volume at that depth?

Problem (a):

Given, $P_2 = 840 \frac{Kg \cdot f}{cm^2}$ (Gage Pessure) $\rho_s = 1025 \frac{kg}{m^3}$

$K = 24000 \frac{Kg \cdot f}{cm^2}$ (a). $\rho_2 = ?$ (b). $v_2 = ?$ & $\Delta V = ?$

Solution:

$$K = -\frac{dP}{\frac{dV}{V}} = \frac{dP}{\frac{d\rho}{\rho}} \qquad 24000 \frac{Kg \cdot f}{cm^2} = \frac{840 \frac{Kg \cdot f}{cm^2}}{\frac{d\rho}{\rho_1}}$$

$$\frac{d\rho}{\rho_1} = 0.035 \qquad \rho_2 - \rho_1 = d\rho = 0.035\,\rho_1$$

PROBLEM ON BULK MODULUS OF ELASTICITY

SOLUTION (Con'td):

$$\frac{d\rho}{\rho_1} = 0.035 \qquad \rho_2 - \rho_1 = d\rho = 0.035\,\rho_1$$

$$\rho_2 = (1 + 0.035)\rho_s = 1.035 \times 1025\,\frac{Kg}{m^3} \qquad (\rho_1 = \rho_s)$$

$$\boxed{\rho_2 = 1060.88\,\frac{Kg}{m^3}}$$ Specific volume, $$\boxed{v_2 = \frac{1}{\rho_2} = 9.43 \times 10^{-4}\,\frac{m^3}{Kg}}$$

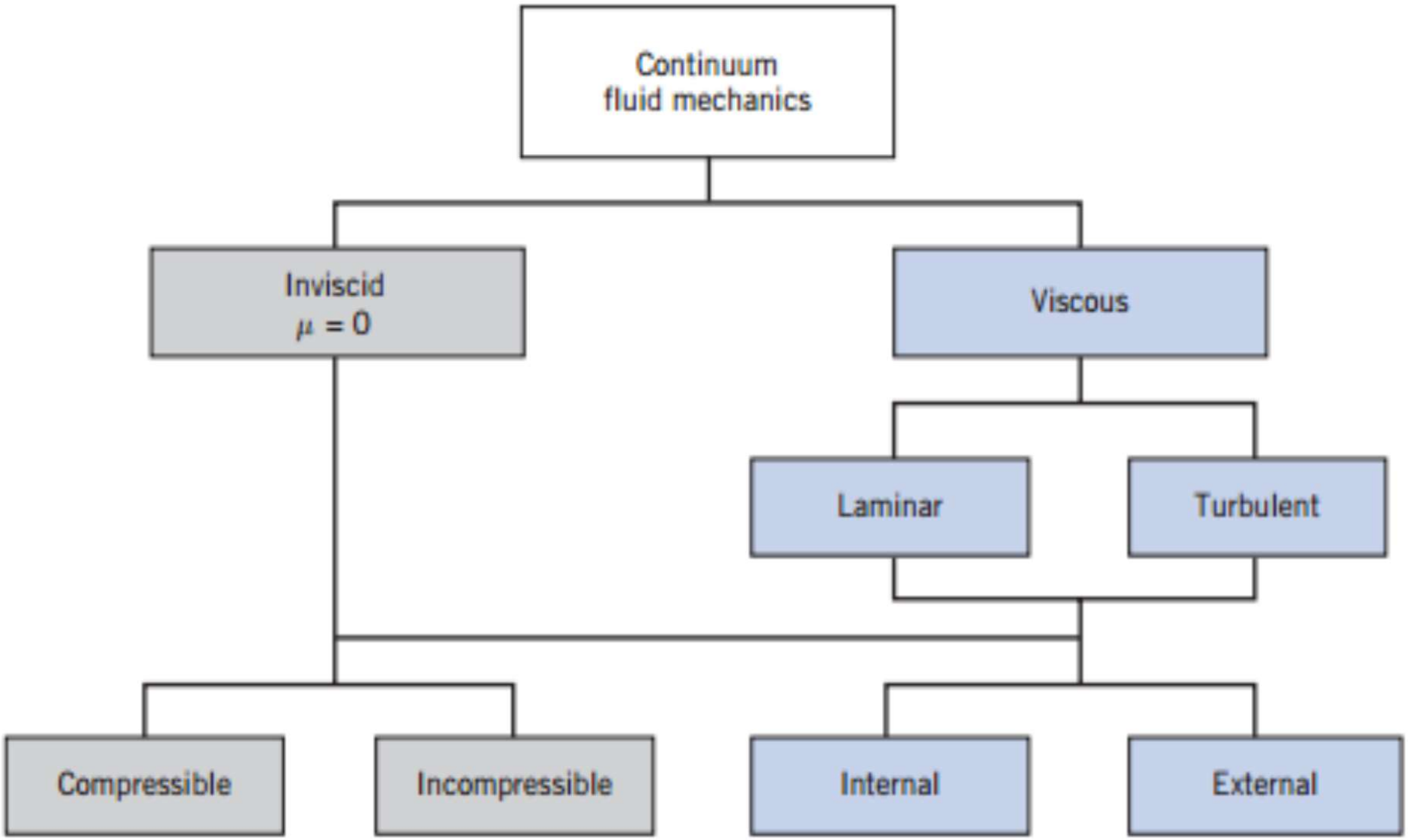
$$d\rho = 0.035\,\rho_1 = 35.875\,\frac{Kg}{m^3}$$

Change in volume, $$\boxed{dV = \frac{1}{d\rho} = 0.0278\,\frac{Kg}{m^3}}$$ (decreased)

CONTINUUM CONCEPT OF FLUID

- *Mathematical idealization of fluid as a continuous distribution of matter (with no empty space or void) as most engineering problem fluid have large of molecules and distance between molecules are very small.*
- As a consequence of the continuum assumption, *each fluid property is assumed to have a definite value at every point in space.* Thus fluid properties such as density, temperature, velocity, and so on are *considered to be continuous functions of position and time.*
- The density at a point may also vary with time (*as a result of work done on or by the fluid and/or heat transfer to the fluid*). Thus the *complete representation of density (the field representation) is given by* $\rho = f(x, y, z, t)$.

CONTINUUM CONCEPT OF FLUID



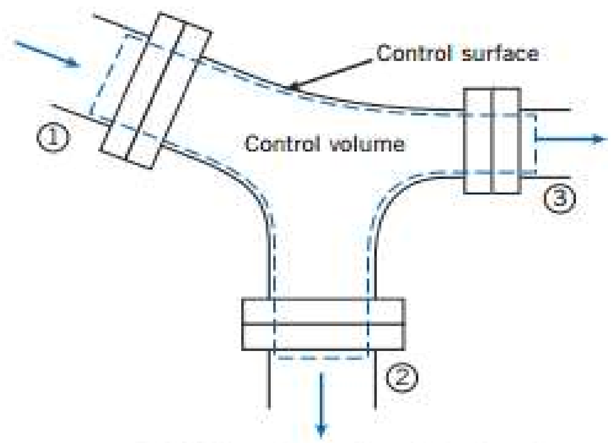
Possible classification of continuum fluid mechanics.

SYSTEM, CONTROL VOLUME, CONTROL SURFACE AND FLUID PERTICLE

System: A system is defined as a fixed, identifiable quantity of fluid; the system boundaries separate the system from the surroundings. The boundaries of the system may be fixed or movable; however, no mass crosses the system boundaries.

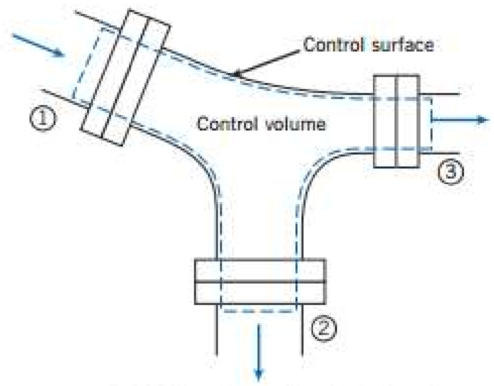
Control Volume: A control volume is an arbitrary volume in space through which fluid flows.

Control Surface: The geometric boundary of the control volume is called the control surface. The control surface may be real or imaginary; it may be at rest or in motion.



Fluid flow through a pipe junction.

SYSTEM, CONTROL VOLUME, CONTROL SURFACE AND FLUID PERTICLE



Fluid flow through a pipe junction.

Fluid Particles: An infinitesimal lump of fluid is called a fluid element or a particle. *A fluid particle assumed to have very small but non-zero dimension,* as its volume δv, mass 'δm' and density ρ such that ρ = δm/δv.

The shape of fluid particle may be *triangular, prism, cylindrical and spherical* (depend on coordinate system).