ENVE 2061: BASIC FLUID MECHANICS

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Introduction to Fluid Mechanics

- The movement of clouds in atmosphere
- The flight of birds through the air
- The flow of water in streams
- Breaking of waves at the seashore

Fluid mechanics phenomena are involved in all of these.

Introduction to Fluid Mechanics

Some of the many other aspects of our lives that involve the fluid mechanics;

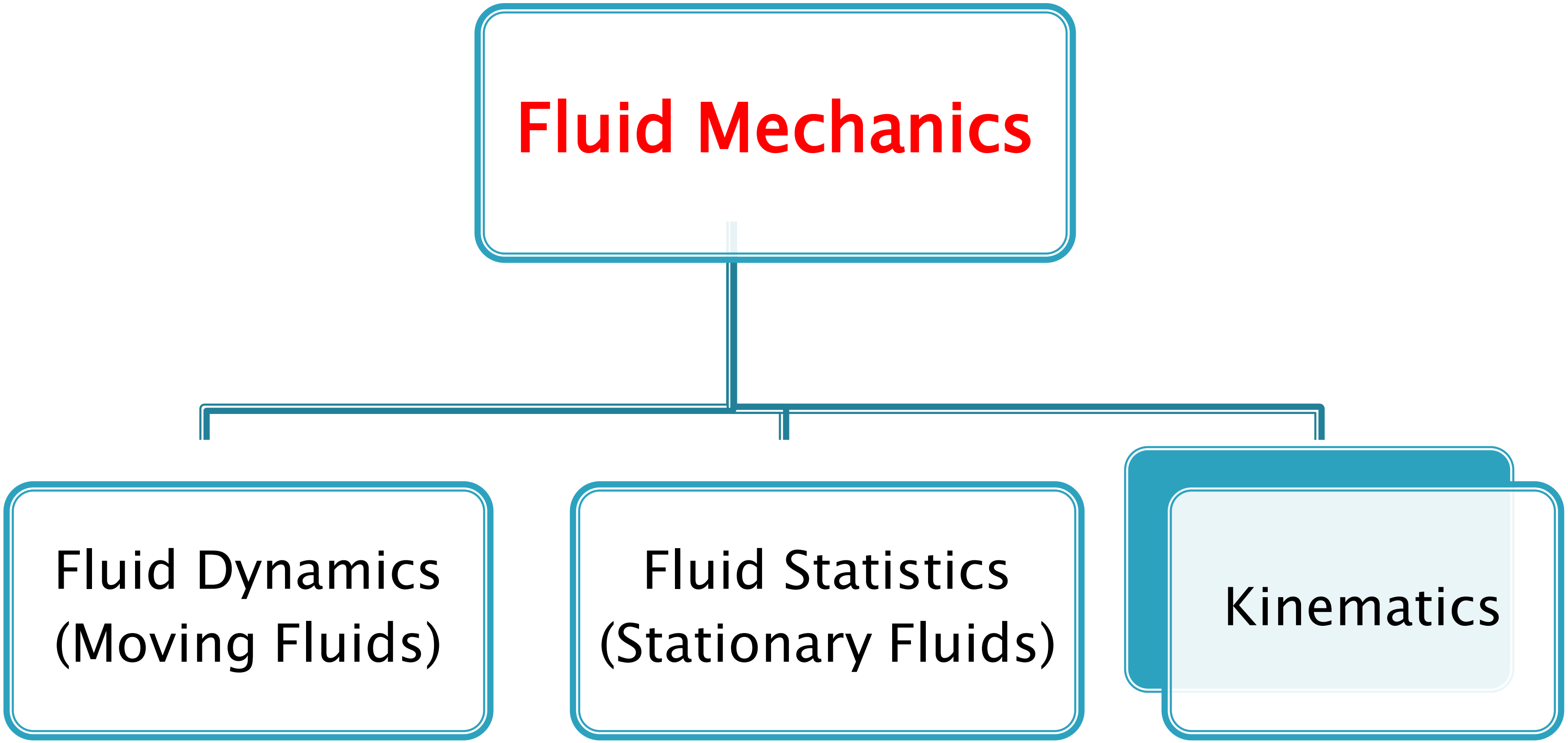
- Flow in pipelines and channels
- Movements of blood in the body
- Wind loading on buildings
- Motion of projectiles
- Combustion
- Irrigation
- Sedimentation
- Meteorology
- Oceanography
- Motion of moisture through soils and oil through geologic formations and other applications

Introduction to Fluid Mechanics

- Fluid Mechanics: It is the study of fluids and forces on them

- Fluids: liquids, gases and plasmas

you will be involved in the analysis and design of systems that require a good understanding of fluid mechanics.


Fluid Mechanics
Fluid Dynamics (Moving Fluids)
Fluid Statistics (Stationary Fluids)
Kinematics

PROPERTIES OF FLUID

What is fluid?

- *a fluid* is defined as a substance that deforms continuously when acted on by a shearing stress of any magnitude.

- ***a*** ***shearing stress*** *(force* per unit area) is created whenever a tangential force acts on a surface.

CHARACTERISTICS OF FLUID

What is fluid?

- When common *solids* such as steel or other metals are acted on by a *shearing stress*, they will initially *deform* (usually a very small deformation), but they will not continuously deform (flow).

- However, common *fluids* such as water, oil, and air satisfy the definition of a fluid—that is, they will *flow* when acted on by a shearing stress.

DISTINCTION BETWEEN A SOLID AND FLUID

Solid	Liquid
• Molecules of solid are usually closer together than those of a fluid. • The attractive forces between the molecules of a solid are so large that a solids tends to retain its shape.	• Attractive forces between the molecules are smaller. • The intermolecular cohesive forces in a fluid are no great enough to hold the various elements of the fluid together.

DISTINCTION BETWEEN A GAS AND A LIQUID

Gas	Liquid
• Molecules of a gas are much farther apart than those of a liquid. • Gas is very compressible and when all external pressure is removed it tends to expand indefinitely. • In equilibrium only when it is completely enclosed. •	• A liquid is relatively incompressible • İf all pressure, except that its own vapor pressure, is removed, the cohesion between molecules holds them together • Liquid does not expand indefinitely

Dimensions and Units

- it is necessary to develop a system for describing fluid characteristics both ***qualitatively*** *and* ***quantitatively***
- **Qualitative ➔** identify the nature, or type, of the characteristics (such as length, time, stress, and velocity)
- ***Quantitative*** **➔** numerical measure of the characteristics.

Dimensions and Units

- The quantitative description requires both a **numbe**r and a **standard** by which various quantities (dimensions) can be compared.
  - for length might be a meter or foot
  - for time an hour or second
  - for mass a slug or kilogram.

- Such standards are called units, and several systems of units are in common use

- The qualitative description is conveniently given in terms of certain primary quantities,
  - such as length (L), time (T), mass (M) and temperature (θ)

Dimensions and Units

These primary quantities (dimensions) can then be used to provide a qualitative description of any other secondary quantity (dimension): for example,

$$area \doteq L^2 \qquad velocity \doteq LT^{-1} \qquad density \doteq ML^{-3}$$

$$(\doteq)$$

the symbol is used to indicate the dimensions of the secondary quantity in terms of the primary quantities.

to describe qualitatively a velocity,

$$V \doteq LT^{-1}$$

"the dimensions of a velocity equal length divided by time."

Dimensional Homogeneity

- All theoretically derived equations are dimensionally homogenous ;

- The dimensions of the left side must be the same as those on the right side and all the additive separate terms must have the same dimensions

$$V = Vo + at$$

$$LT^{-1} = LT^{-1} + LT^{-1}$$

$$d = 16.1t^2$$

Systems of Units

- The International Systems of Units (SI)
  - Length = meter (m)
  - Time = second (s)
  - Mass = kilogram (kg) or $N.s^2/m$
  - Force = newton (N) or $kg.m/s^2$

- The U.S. Customary System (English Gravitational Unit System or British Units)
  - Length = foot (ft)
  - Time =second (s)
  - Force = pound (lb)
  - Mass =slug or $lb\text{-}s^2/ft$

1 lbm = 0.45 kg
1 ft =0.3048 m

Primary dimension	SI unit	BG unit	Conversion factor
Mass $\{M\}$	Kilogram (kg)	Slug	1 slug = 14.5939 kg
Length $\{L\}$	Meter (m)	Foot (ft)	1 ft = 0.3048 m
Time $\{T\}$	Second (s)	Second (s)	1 s = 1 s
Temperature $\{\Theta\}$	Kelvin (K)	Rankine (°R)	1 K = 1.8°R

Secondary dimension	SI unit	BG unit	Conversion factor
Area $\{L^2\}$	m^2	ft^2	1 m^2 = 10.764 ft^2
Volume $\{L^3\}$	m^3	ft^3	1 m^3 = 35.315 ft^3
Velocity $\{LT^{-1}\}$	m/s	ft/s	1 ft/s = 0.3048 m/s
Acceleration $\{LT^{-2}\}$	m/s^2	ft/s^2	1 ft/s^2 = 0.3048 m/s^2
Pressure or stress $\{ML^{-1}T^{-2}\}$	Pa = N/m^2	lbf/ft^2	1 lbf/ft^2 = 47.88 Pa
Angular velocity $\{T^{-1}\}$	s^{-1}	s^{-1}	1 s^{-1} = 1 s^{-1}
Energy, heat, work $\{ML^2T^{-2}\}$	J = N · m	ft · lbf	1 ft · lbf = 1.3558 J
Power $\{ML^2T^{-3}\}$	W = J/s	ft · lbf/s	1 ft · lbf/s = 1.3558 W
Density $\{ML^{-3}\}$	kg/m^3	$slugs/ft^3$	1 $slug/ft^3$ = 515.4 kg/m^3
Viscosity $\{ML^{-1}T^{-1}\}$	kg/(m · s)	slugs/(ft · s)	1 slug/(ft · s) = 47.88 kg/(m · s)
Specific heat $\{L^2T^{-2}\Theta^{-1}\}$	$m^2/(s^2 \cdot K)$	$ft^2/(s^2 \cdot °R)$	1 $m^2/(s^2 \cdot K)$ = 5.980 $ft^2/(s^2 \cdot °R)$

Source:White, Fluid Mechanics, 4th Edition

Force (F)

- Force is usually considered as the primary dimension in English System

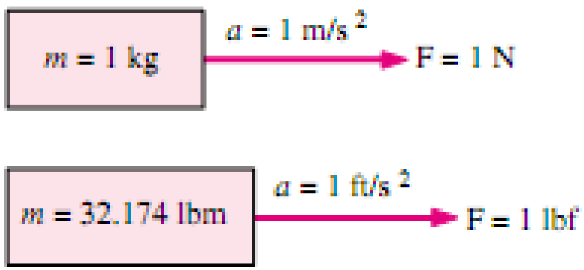
$$\text{Force} = (\text{mass})\ (\text{acceleration})$$

In SI system➔ Force unit is N

1 N = force required to accelerate a mass of 1 kg at a rates of 1 m/s^2.

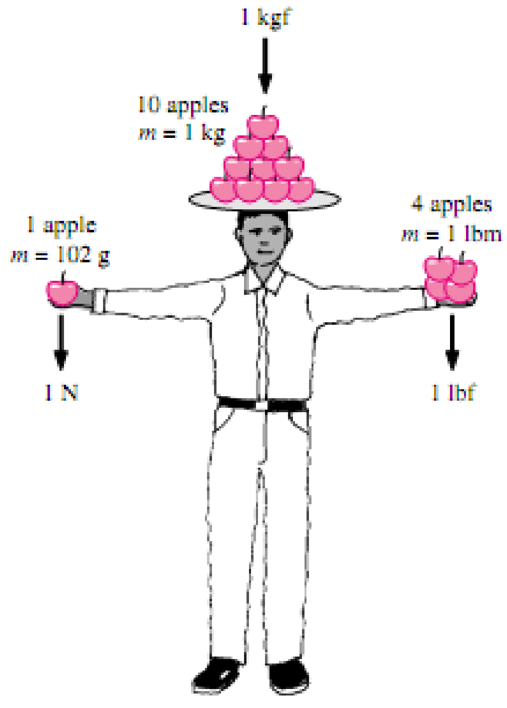
In English System ➔ Force unit is pound-force (lbf)

1 lb_f = force required to accelerate a mass of 32. 174 lb_m (1 slug) at a rate of 1 ft/s^2.



Source:Çengel & Turner, Fundamentals of Thermal-Fluid Sciences

Relative Magnitudes of the Force Units



- 1 N = weight of 102 g
- 1 lbf = weight of 454 g
- 1 kgf= weight of 1 kg = 9.807 N

Source:Çengel & Turner, Fundamentals of Thermal-Fluid Sciences

Weight versus Mass

- Mass : Measure of the amount of material in an object.
- does not change with the body's position, movement or alteration of its shape unless material is added or removed.

- Weight: Gravitational force acting on a body mass

$$W = m.g$$

W → N, m → kg

g → 9.807 m/s2 in SI system
32.174 ft/s2 in US Customary at sea level and 45 latitude

Work

- Work is a form of energy and simply defined as force times distance

$$W = \text{Force (N)} \times \text{Distance (m)}$$
$$1 \text{ Joule} = 1 \text{ N.m}$$

- In SI system ➔ kilojoules (1 kJ=1000 J)
- In English System ➔ Btu (British Thermal Unit)

  - Btu: The energy required to raise the temperature of 1 lbm of water at 68 ^oF by 1^oF.

- 1 calorie : the energy required to raise the temperature of 1 g of water at 15^oC by 1 ^oC

$$1 \text{ cal} = 4.1868 \text{ J}$$
$$1 \text{ Btu} = 1.055 \text{ kJ}$$

PRESSURE

- Pressure is defined as the amount of force exerted on a unit area of a substance

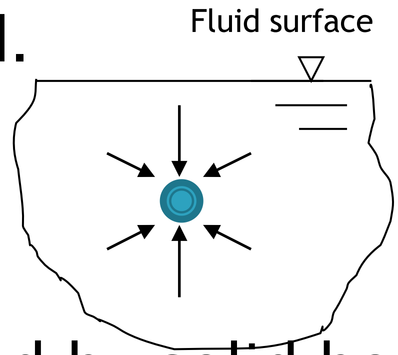
$$\text{Pressure} = \frac{Force}{Area\ of\ which\ the\ force\ is\ applied}$$

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

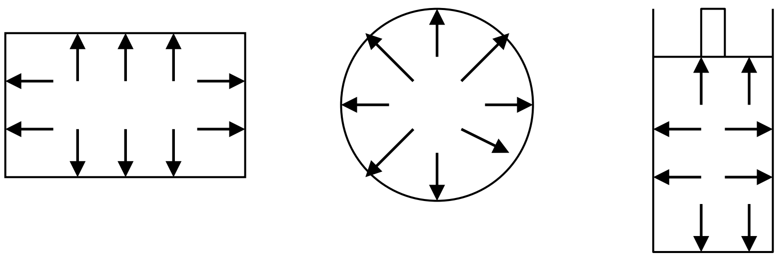
Unit: N / m^2 or Pascal (Pa).

(Also frequently used is bar, where 1 bar = 10^5 Pa).

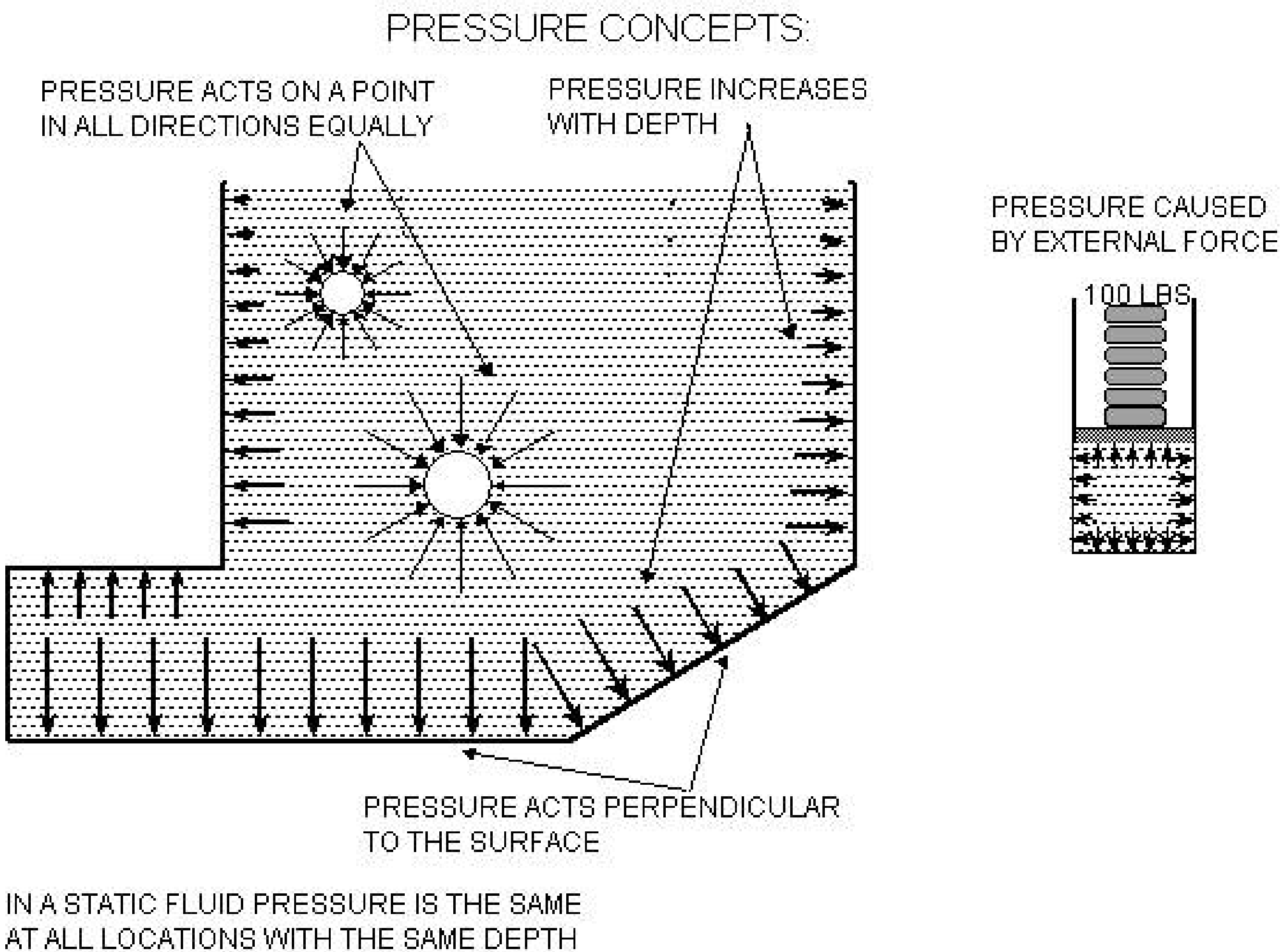
- *Two important principles about pressure;*
  - Pressure acts uniformly in all directions on a small volume of a fluid.



  - In a fluid confined by solid boundaries, pressure acts perpendicular to the boundary.



  - These principles called Pascal's principles


PRESSURE CONCEPTS:
PRESSURE ACTS ON A POINT
IN ALL DIRECTIONS EQUALLY
PRESSURE INCREASES
WITH DEPTH
PRESSURE CAUSED
BY EXTERNAL FORCE
100 LBS
PRESSURE ACTS PERPENDICULAR
TO THE SURFACE
IN A STATIC FLUID PRESSURE IS THE SAME
AT ALL LOCATIONS WITH THE SAME DEPTH

COMPRESSIBILITY

- Compressibility: change of volume (V) of a substance that is subjected to a change in pressure on it.
- Quantity used to measure bulk ***modulus of elasticity*** or, simply, ***bulk modulus***, E.

$$E = \frac{-\Delta P}{(\Delta V)/V}$$

- The units are same as those for the pressure.

COMPRESSIBILITY

- Liquids are very slightly compressible
- It would take a very large change in pressure to produce a small change in volume.

Bulk modulus for selected liquids at atmospheric pressure and 20^{0}C.

Liquid	Bulk Modulus (psi)	Bulk Modulus (MPa)
Ethyl alcohol	130 000	896
Benzene	154 000	1 062
Machine oil	189 000	1 303
Water	316 000	2 179
Glycerine	654 000	4 509
Mercury	3 590 000	24 750

Liquids will be considered as **incompressible**

Density, specific weight and specific gravity

- **Density:** Amount of mass per unit volume of substance

$$\rho = \frac{m}{V} = \frac{mass}{volume}$$

- Symbol: ρ

- Units: $\frac{kg}{m^3}$ in SI system

  : $\frac{slugs}{ft^3}$ in U.S. customary units.

Density, specific weight and specific gravity

- Specific weight: The amount of weight per unit volume of a substance.

- Symbol: γ

$$\gamma = \frac{w}{V} = \frac{weight}{volume} = \frac{W}{\forall} = \frac{m.g}{\forall} = \rho.g$$

- Units: $\frac{N}{m^3}$ in SI system

  : $\frac{Ib_f}{ft^3}$ in U.S. customary units.

- $\gamma_{water} = 9.80\ \frac{N}{m^3}$ $(15.5^0$ C), 62.4 $\frac{Ib_f}{ft^3}$ $(60^0$ F),

Density, specific weight and specific gravity

- **Specific gravity:** Ratio of the density of a substance to the density of water at 4^0C.

- Ratio of the specific weight of a substance to the specific weight of the water at 4^0C.

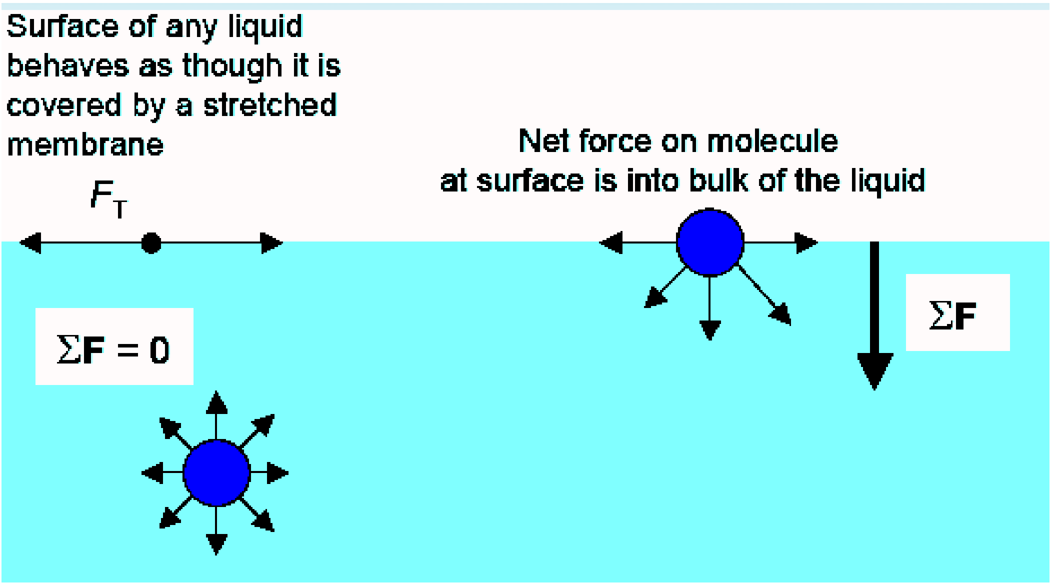
$$sg = \frac{\gamma s}{\gamma w @ 4^o C} = \frac{\rho s}{\rho w @ 4^o C}$$

$\rho H_2O \ at \ 4^oC = 998 \text{ kg/m}^3 \cong 1000 \text{ kg/m}^3$ is taken for practical purposes

$\rho H_2O \ at \ 4^oC = 1.94 \text{ slugs/ft}^3$

SURFACE TENSION

- Liquids have cohesion and adhesion, both of which are forms of molecular attraction.
- Cohesion enables a liquid to resist tensile stress
- Adhesion enables it to adhere to another body.



Capillarity

- It is the property of exerting forces on fluids by fine tubes or porous media
- It is due to both cohesion and adhesion
- Cohesion $<$ Adhesion ➔ The liquid will wet a solid surface with which it is in contact and rise at the point of contact
- Cohesion$>$Adhesion ➔ The liquid surface will be depressed at the point of contact.