FLUID MECHANICS

Tishk International University

Faculty of Engineering

Mechatronics Engineering Department

Lecture 1

Definition Terms & Properties of Fluids

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REFERENCES

Frank M. White, “Fluid Mechanics”, Fourth Edition, 1997.❑
● Edward J. Shaughnessy, Jr., Ira M. Katz, James P. Schaffer, “Introduction to Fluid Mechanics”, 2005.
● Bernard Massey, “Mechanics of Fluids”, Eighth edition, 2006.
● Bruce R. Munson, & Donald F. Young, “Fundamentals of Fluid Mechanics”, Sixth Edition, 2009.

STUDENTS OBLIGATION

- attending classes on time and regularly.
- being prepared for classes with all necessary supplies.
- Students need to respect the ideas and opinions of their classmates in and outside of the classroom
- If you are more than 10 minutes late, you will be declared absent.
- The homework and assignments should be submitted on time.
- The students have to participate in all quizzes and exams

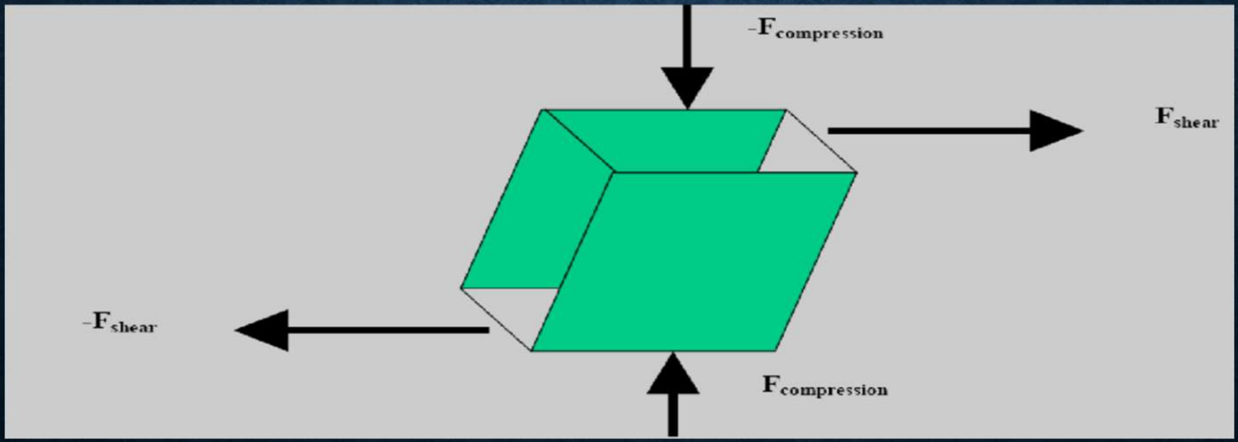
INTRODUCTION

What is a fluid? •

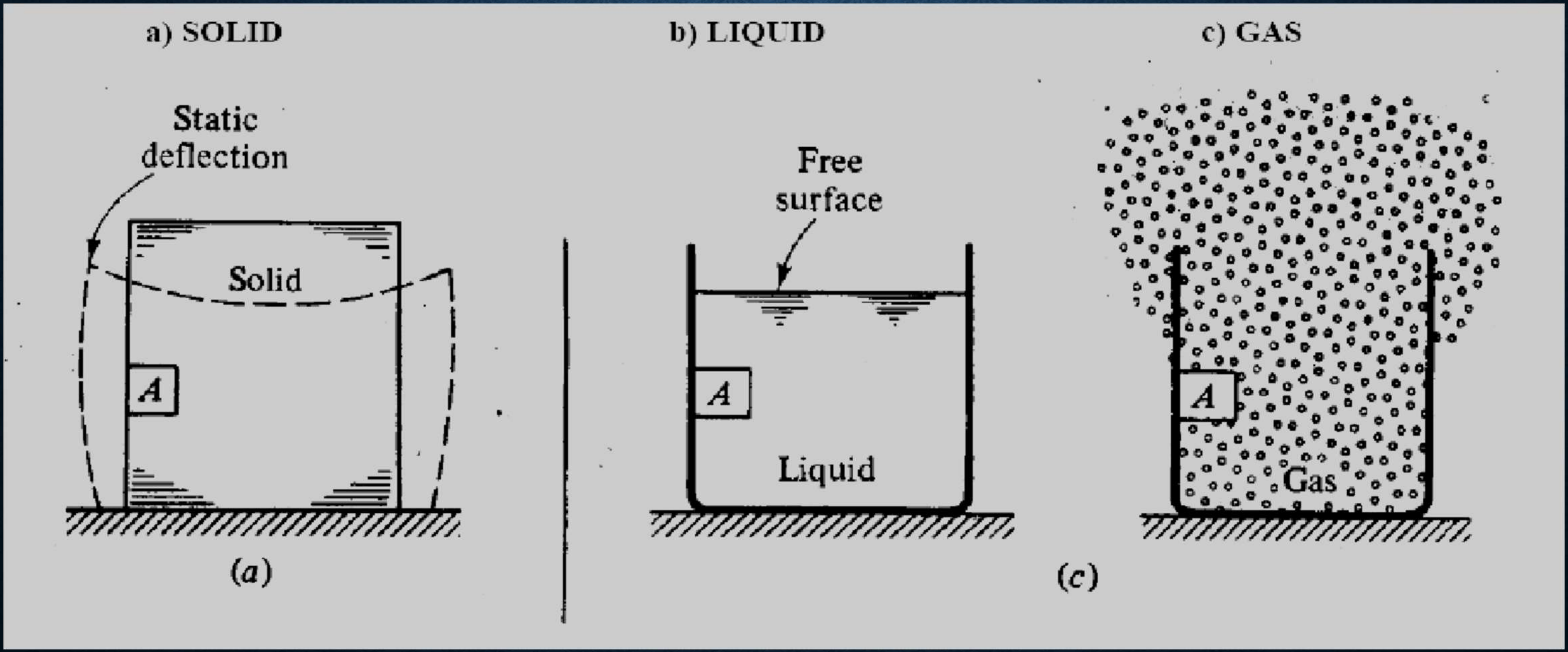
A fluid is a material which is incapable of supporting shear force •

•**What is a shear force?** •

A Shear is a force that is applied tangentially to a material element. •



Solid can support static deflections; fluids need a container.



DEFINITIONS

Mass: is the property of a body of fluid that is a measure of its inertia or resistance to a change in motion. It is also a measure of the quantity of fluid.

Weight: is the **force exerted on an object due to gravity**. It depends on both the mass of the object and the acceleration due to gravity.

$$W = m \cdot g$$

$$N = kg * m/s^2$$

Mass = Volume * Density → $m = V \times \rho$

$$Kg = m^3 \times kg/m^3$$

UNITS

• Main units are: Length (L), Mass (M), and Time (T). Most of the other quantities like force, pressure, power, and more can be derived from the main three quantities: LMT.

THE U.S. CUSTOMARY SYSTEM

- sometimes called the English or British Gravitational (BG) Unit System, or the Pound-foot-second system.

Dimension	Unit
Length (L)	foot (ft)
Mass (M)	*slug $= \frac{lb.\sec^2}{ft}$
Time (T)	second (s)
Force (F)	F = mass × acceleration = pound (lb)
Temperature (θ)	Rankin °R Fahrenheit °F

Force = Mass * Acceleration

$$F = m.a \quad \rightarrow \quad m = \frac{F}{a}$$

Where:

a acceleration expressed in units of (ft/s^2)

$$m = \frac{F}{a} = \frac{lb}{ft/s^2} = \frac{lb.s^2}{ft} = slug$$

Note: Acceleration due to gravity (g) in BG units = **32.20 ft/s^2**

THE INTERNATIONAL SYSTEM OF UNITS (SI)

Dimension	Unit
Length (L)	meter (m)
Mass (M)	kilogram (kg)
Time (T)	second (s)
Force (F)	Newton (N) = kg.m/s^2) = MLT^{-2}
Temperature (θ)	Kelvin °K Celsius °C

Acceleration due to gravity, g in SI units = **9.81 m/s^2**.

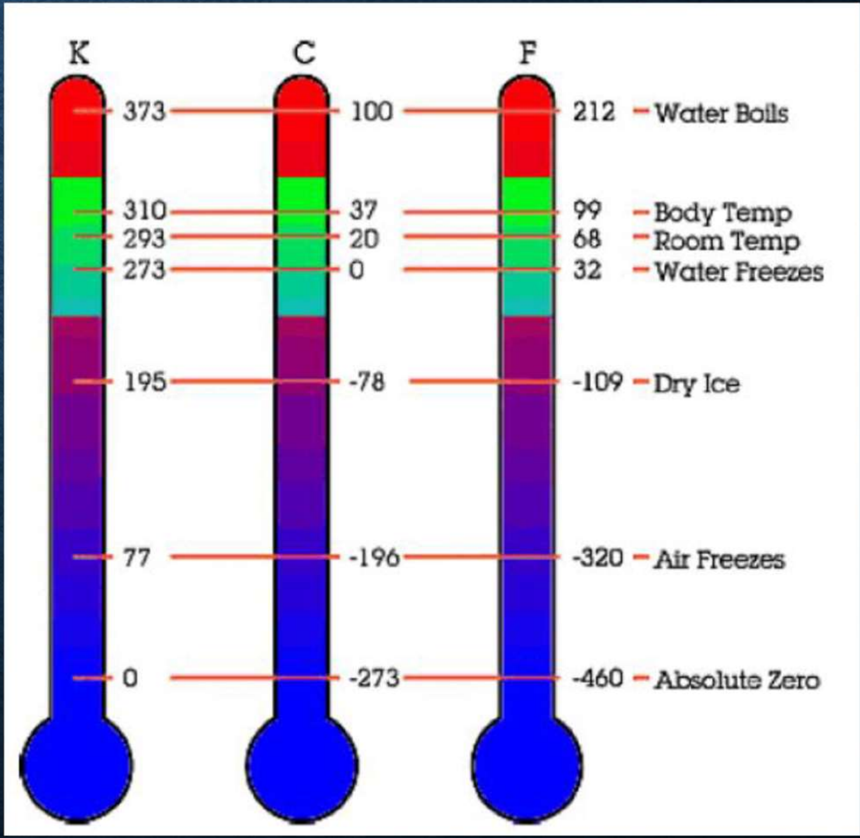
TEMPERATURE CONVERSION

$$^{\circ}C = \frac{\left(^{\circ}F - 32^{\circ}\right)}{1.8} \quad \rightarrow \quad ^{\circ}F = 1.8 \times {^{\circ}C} + 32^{\circ}$$

$$\cdot K = \frac{\left(^{\circ}R - 0.6^{\circ}\right)}{1.8} \quad \rightarrow \quad ^{\circ}R = 1.8 \times \cdot K + 0.6^{\circ}$$

$$^{\circ}R = {^{\circ}F} + 460^{\circ}$$

$$\cdot K = {^{\circ}C} + 273^{\circ}$$



PRACTICE

1. Convert 100 ^{0}F to ^{0}C
2. Convert 55 ^{0}C to ^{0}F
3. Convert 250 K to ^{0}R
4. Convert 500 ^{0}R to ^{0}K
5. Convert 500 ^{0}R to ^{0}F
6. Convert 289 K to ^{0}C

USEFUL CONVERSION

Length:

	cm	ft	in	yard	mile	meter	km
cm	1.0	0.0328084	0.3937008	0.01093613	6.213712E-6	0.01	1E-5
ft	30.48	1.0	12.0	0.3333333	0.0001893939	0.3048	0.0003048
in	2.54	0.08333333	1.0	0.02777778	1.578283E-5	0.0254	2.54E-5
yard	91.44	3.0	36.0	1.0	0.0005681818	0.9144	0.0009144
mile	160934.4	5280	63360	1760	1.0	1609.344	1.609344
meter	100.0	3.28084	39.37008	1.093613	0.0006213712	1.0	0.001
Km	100000	3280.84	39370.08	1093.613	0.6213712	1000	1.0

Volume:

	cm^3	ft^3	in^3	U.S Gallon	U.K Gallon	m^3	Liter
cm^3	1.0	3.531467e-5	0.061024	0.0002641721	0.0002199692	1e-6	0.001
ft^3	28316.85	1.0	1728	7.480519	6.228833	0.02831685	28.31685
in^3	16.38706	0.0005787037	1.0	0.004329004	0.003604649	1.6387e-5	0.016387
U.S Gallon	3785.412	0.1336806	231	1.0	0.8326738	0.00378541	3.785412
U.K Gallon	4546.092	0.1605437	277.4196	1.20095	1.0	4.5461e-3	4.5461
m^3	1000000	35.31467	61023.74	264.1721	219.9692	1.0	1000
Liter	1000	0.03531467	0.001	0.2641721	0.2199692	0.001	1.0

PRIMARY DIMENSIONS IN SI AND BG SYSTEMS

Big to small = *
Small to big = /

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 DIMENSIONS IN FLUID MECHANICS

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 $\{L^2T^{-2}\Theta^{-1}\}$	$m^2/(s^2 \cdot K)$	$ft^2/(s^2 \cdot °R)$	$1\ m^2/(s^2 \cdot K) = 5.980\ ft^2/(s^2 \cdot °R)$

■ TABLE

Conversion Factors from BG Units to SI Units[a]

	To convert from	to	Multiply by
Acceleration	ft/s^2	m/s^2	3.048 E − 1
Area	ft^2	m^2	9.290 E − 2
Density	$slugs/ft^3$	kg/m^3	5.154 E + 2
Energy	Btu	J	1.055 E + 3
	ft·lb	J	1.356
Force	lb	N	4.448
Length	ft	m	3.048 E − 1
	in.	m	2.540 E − 2
	mile	m	1.609 E + 3
Mass	slug	kg	1.459 E + 1
Power	ft·lb/s	W	1.356
	hp	W	7.457 E + 2
Pressure	in. Hg (60 °F)	N/m^2	3.377 E + 3
	lb/ft^2 (psf)	N/m^2	4.788 E + 1
	$lb/in.^2$ (psi)	N/m^2	6.895 E + 3
Specific weight	lb/ft^3	N/m^3	1.571 E + 2
Temperature	°F	°C	$T_C = (5/9)(T_F - 32°)$
	°R	K	5.556 E − 1
Velocity	ft/s	m/s	3.048 E − 1
	mi/hr (mph)	m/s	4.470 E − 1
Viscosity (dynamic)	$lb \cdot s/ft^2$	$N \cdot s/m^2$	4.788 E + 1
Viscosity (kinematic)	ft^2/s	m^2/s	9.290 E − 2
Volume flowrate	ft^3/s	m^3/s	2.832 E − 2
	gal/min (gpm)	m^3/s	6.309 E − 5

TABLE

Conversion Factors from SI Units to BG Units[a]

	To convert from	to	Multiply by
Acceleration	m/s^2	ft/s^2	3.281
Area	m^2	ft^2	1.076 E + 1
Density	kg/m^3	$slugs/ft^3$	1.940 E − 3
Energy	J	Btu	9.478 E − 4
	J	ft·lb	7.376 E − 1
Force	N	lb	2.248 E − 1
Length	m	ft	3.281
	m	in.	3.937 E + 1
	m	mile	6.214 E − 4
Mass	kg	slug	6.852 E − 2
Power	W	ft·lb/s	7.376 E − 1
	W	hp	1.341 E − 3
Pressure	N/m^2	in. Hg (60 °F)	2.961 E − 4
	N/m^2	lb/ft^2 (psf)	2.089 E − 2
	N/m^2	$lb/in.^2$ (psi)	1.450 E − 4
Specific weight	N/m^3	lb/ft^3	6.366 E − 3
Temperature	°C	°F	$T_F = 1.8\ T_C + 32°$
	K	°R	1.800
Velocity	m/s	ft/s	3.281
	m/s	mi/hr (mph)	2.237
Viscosity (dynamic)	$N \cdot s/m^2$	$lb \cdot s/ft^2$	2.089 E − 2
Viscosity (kinematic)	m^2/s	ft^2/s	1.076 E + 1
Volume flowrate	m^3/s	ft^3/s	3.531 E + 1
	m^3/s	gal/min (gpm)	1.585 E + 4

COMMONLY USED PREFIXES FOR SI UNITS

Commonly used prefixes for SI units:

Factor by which unit is multiplied	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n

EXAMPLE : 1

A body weighs 1000 lbf when exposed to a standard earth gravity g = 32.174 ft/s^2. What is its mass in kg?

Solution :

F = W = mg =1000 lbf = (m slugs)(32.174 ft/s^2)

m= 1000/32.174 = (31.08 slugs) *(14.59 kg/slug) = 453.6 kg.

The change from 31.08 slugs to 453.6 kg illustrates the proper use of the conversion factor 14.5939 kg/slug.

H.W (1): What will be 1.0 lbf equal in Newton's?

Answer (4.448 N)

H.W (2): What will be 1.0 ft.lb/s power equal to in SI units (Watt).

Answer (1.356 W)

DENSITY

The density of a fluid is its mass per unit volume.

$$\rho = \frac{Mass}{Volume} = \frac{m}{V} \qquad \text{slug/ft}^3\text{, or kg/m}^3$$

Density of water in SI units

$$\rho_w = 1000 \frac{kg}{m^3}$$

Density of water in BG units

$$\rho_w = \frac{62.42796 \frac{lb}{ft^3}}{32.17405 \frac{ft}{s^2}} = 1.94 \frac{lb.s^2 / ft}{ft^3} = 1.94 \frac{slug}{ft^3}$$

Density is calculated at standard temperature and pressure (usually at 60 F, and atmospheric Pressure)

	SI Units	BG (English) Units
ρ_{water}	1000 (kg/m^3) or 1.0 (ton/m^3)	1.94 slug/ft^3
ρ_{air}	1.23 kg/m^3	2.38×10^{-3} slug/ft^3
ρ_{oil}	Depends on type of oil	

SPECIFIC VOLUME

Specific volume of a fluid is the volume occupied by a unit mass of fluid.

$$\text{Specific Volume, } v = \frac{volume}{mass} = \frac{V\!\!\!/}{m} = \frac{1}{\rho} \qquad \text{ft}^3/\text{ slug, or m}^3/\text{kg}$$

SPECIFIC AND UNIT WEIGHT (SPECIFIC WEIGHT)

The specific or unit weight (γ) of a substance is the weight of a unit volume of the substance.

$$\gamma = \rho \, .g \quad (\text{lb/ft}^3\text{, or kN/m}^3)$$

● **Unit weight of water:**

BG units: $\gamma = \rho.g = 1.94 \frac{slug}{ft^3} \times 32.2 \frac{ft}{\sec^2} = 62.4 \text{ lb/ft3}.$

SI units: $\gamma = \rho.g = 1000 \frac{kg}{m^3} \times 9.81 \frac{m}{\sec^2} = 9810 \text{ N/m}^3\text{, or } 9.81 \text{ kN/m}^3.$

The specific weight of water for ordinary temperature variations = 62.4 lb/ft^3, or 9.81 kN/m^3.

SPECIFIC WEIGHT OF A GAS

The specific weight of a gas can be calculated using the equation of state:

$$p\forall = nR_oT$$

Where

p	is the absolute pressure
$\forall$	is the gas volume
n	is the number of moles present
R_o	is the universal gas constant
T	is the absolute temperature

If we divide both sides of equation of state on **molar mass** (formally called **Molecular Weight**), M

$$p\frac{V}{M} = n\frac{R_o}{M}T \qquad p = \frac{nM}{V}\times\frac{R_o}{M}\times T$$

The product of the number of moles, *n* and the molecular weight, *M* is the mass of gas, *m*.

$$nM = m \quad \rightarrow \quad p = \frac{m}{V}\times\frac{R_o}{M}\times T$$

$$p = \frac{RT}{v} \quad \text{or} \quad \rho = \frac{p}{RT}$$

Where:

p Absolute pressure

v Specific volume $= \frac{volume}{mass} = \frac{V}{m} = \frac{1}{\rho} = \frac{g}{\gamma}$

T Absolute temperature, $T = (t\ ^\circ F + 460)\ ^\circ R$ or $T = (t\ ^\circ C + 273)\ ^\circ K$

R Gas constant: $R = \frac{R_0}{M} = \frac{\text{Universal gas constant}}{\text{molecular weight}}$

$$v = \frac{g}{\gamma} \quad \rightarrow \quad \textbf{Then:} \quad p = \frac{\gamma RT}{g}$$

$$\gamma = \frac{p\times g}{R.T}$$

SPECIFIC GRAVITY

The specific gravity of a substance is the density of that substance divided by the density of a reference substance (usually water) in the same units. It can also be defined as the dimensionless ratio of the weight of the body to the weight of an equal volume of a substance taken as standard. Solids and liquids are referred to water (at 68 °F = 20 °C) as standard, while gases are often referred to air free of carbon dioxide or hydrogen (at 32 °F = 0 °C and 1 atmosphere = 14.7 lb/in^2 = 101.3 kPa pressure) as standard.

$$S = \frac{\rho}{\rho_{water}} = \frac{\rho / g}{\rho_{water} / g} = \frac{\gamma}{\gamma_{water}} \quad \text{(dimensionless)}$$

$$S.G = \frac{W}{\gamma_w} \times \frac{1}{V\!\!\!/} \qquad S.G = \text{constant} \times \frac{1}{V\!\!\!/}$$

$$\text{Weight, } W = (S.G \times \gamma_w) \times V\!\!\!/$$

Which means that, the higher the specific gravity, the lower the volume of displaced liquid?

EXAMPLES

Example: 2

If the specific weight of a liquid is 52lb/ft^3, what is its density?

Solution: $\gamma = \rho \, .g \rightarrow \rho = \gamma / g \rightarrow \rho = 52/32.2 = 1.615$ slugs/ ft^3

Example:3

If the specific weight of a liquid is 8.1 kN/m^3, what is its density?

Solution : $\gamma = \rho \, .g \rightarrow \rho = \gamma / g \rightarrow \rho = 8100/9.81 = 826$ kg/ m^3

Example:4

If the specific volume of a gas is 0.70 m^3/ kg, what is its specific weight in N/m^3

Solution :

$$\gamma = \rho g = \frac{g}{v} = \frac{9.81 \text{ m/s}^2}{0.70 \text{ m}^3/\text{kg}}\left(\frac{\text{N}}{\text{kg}\cdot\text{m/s}^2}\right) = 14.01 \text{ N/m}^3$$

EXAMPLES

Example: 5 . *If a certain weighs 8600 N/m*^{3}*, what are the values of its density, specific volume, and specific gravity relative to water at 15* ^0C*?.*

***Note water density at 15* ^0C *is 999.1 kg/m*^{3}

Solution:

ρ = 8600/9.81 = 877 kg/m^3

v = 1/877= 0.001141 m^3/kg

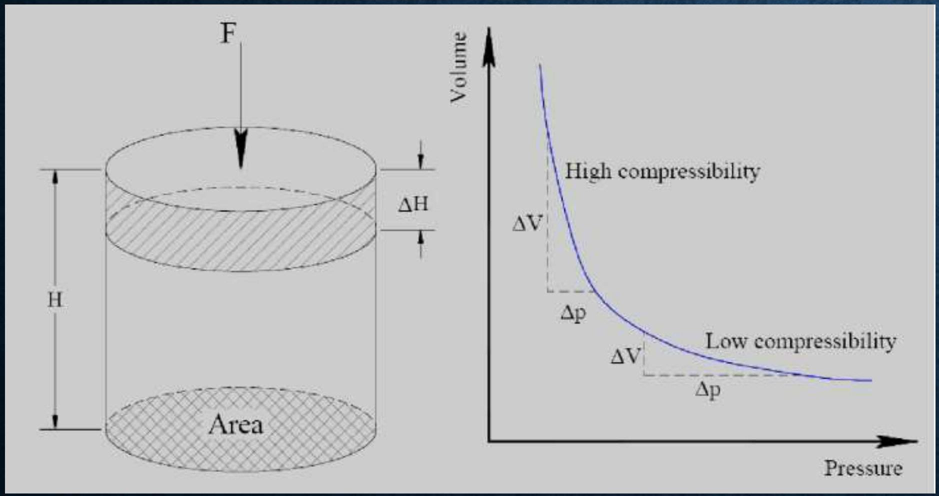
s= 877/999.1 = 0.877

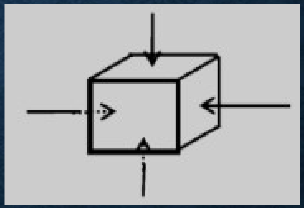
COMPRESSIBILITY

Compressibility reflects the stress-strain properties of a material.

Stress: internal response of a material to an external pressure

Strain: measure of the linear or volumetric deformation of a stressed material





Compressibility (β): **Compressibility** measures how much a substance's volume decreases when pressure increases.

$$\beta = -\frac{1}{V}\frac{dV}{dP}$$

Where:
V= volume
P= pressure
dV= change in volume
dP= change in pressure

Key Points:

It tells how easily a material can be compressed.
High compressibility → volume changes easily (e.g., gases).
Low compressibility → volume hardly changes (e.g., liquids and solids).

Units: Pa^{-1}

Example:
Air → highly compressible
Water → slightly compressible
Steel → almost incompressible

Bulk Modulus of Elasticity (K) : The **Bulk Modulus** measures a material's resistance to compression.

$$K = -V\frac{dP}{dV}$$

It is also defined as the reciprocal of compressibility:

$$K = \frac{1}{\beta}$$

Key Points:

Large K → material is stiff (hard to compress).
Small K → material is easily compressed.

Units: Pascal (Pa)

Examples:

Air → small bulk modulus (highly compressible)
Water → large bulk modulus (~2.2×10^9 Pa)
Steel → very large bulk modulus

RELATION BETWEEN COMPRESSIBILITY AND DENSITY

Density is:

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

If volume changes due to pressure, density also changes.
Since mass remains constant:

$$\frac{d\rho}{\rho} = -\frac{dV}{V}$$

Using the compressibility definition:

$$\beta = \frac{1}{\rho}\frac{d\rho}{dP}$$

And since $K = \frac{1}{\beta}$:

$$K = \rho\frac{dP}{d\rho}$$

PHYSICAL INTERPRETATION OF DENSITY RELATION

•When pressure increases → volume decreases → density increases.

•Materials with:
•**High bulk modulus** → density changes very little with pressure.
•**Low bulk modulus** → density changes significantly with pressure.

For Gases:
Large volume change
Large density change
High compressibility
Small bulk modulus

For Liquids:
Very small volume change
Very small density change
Low compressibility
Large bulk modulus

Summary for Compressibility Equations

$$\beta = -\frac{1}{V}\frac{dV}{dp}$$

(Relation between compressibility and volume)

And

$$\beta = \frac{1}{\rho}\frac{d\rho}{dp}$$

(Relation between compressibility and density)

$V = Volume, p = Pressure, \quad \rho = Density, K = Bulk\ Modulus$

β = Compressibilty

Liquids are usually considered to be incompressible, whereas gases are generally considered compressible

Example 6

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

$$K = -\frac{\Delta p}{\Delta V/V} = -\frac{2-1}{(995-1000)/1000} = 200\ \text{MPa}$$

Example 7

Find the bulk modulus of elasticity of a liquid if a pressure of 150 psi applied to 10 ft^3 of the liquid causes a volume reduction of 0.02 ft^3.

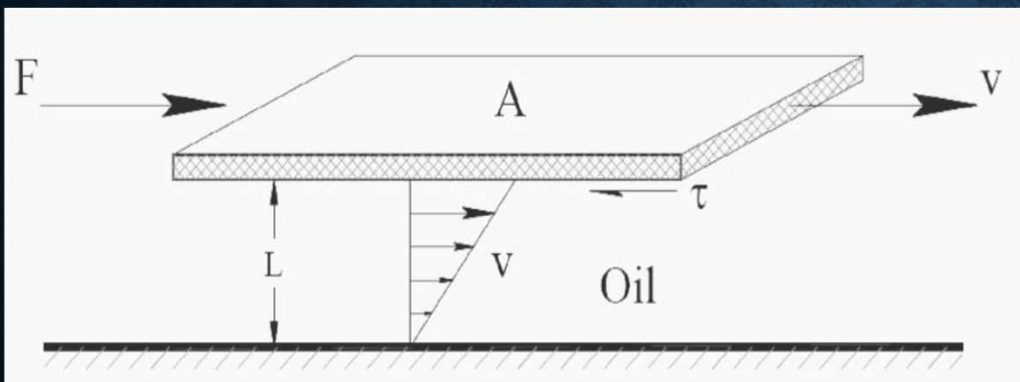
$$K = -\frac{\Delta p}{\Delta V/V} = -\frac{(150-0)(144)}{-0.02/10} = 10\,800\,000\ \text{lb/ft}^2 \quad \text{or} \quad 75\,000\ \text{psi}$$

1 psi=144 psf

VISCOSITY

Viscosity is the fluid property responsible for the resistance to any force tending to cause one layer to move over another. Or Viscosity measures a fluid's ability to resist shear stress

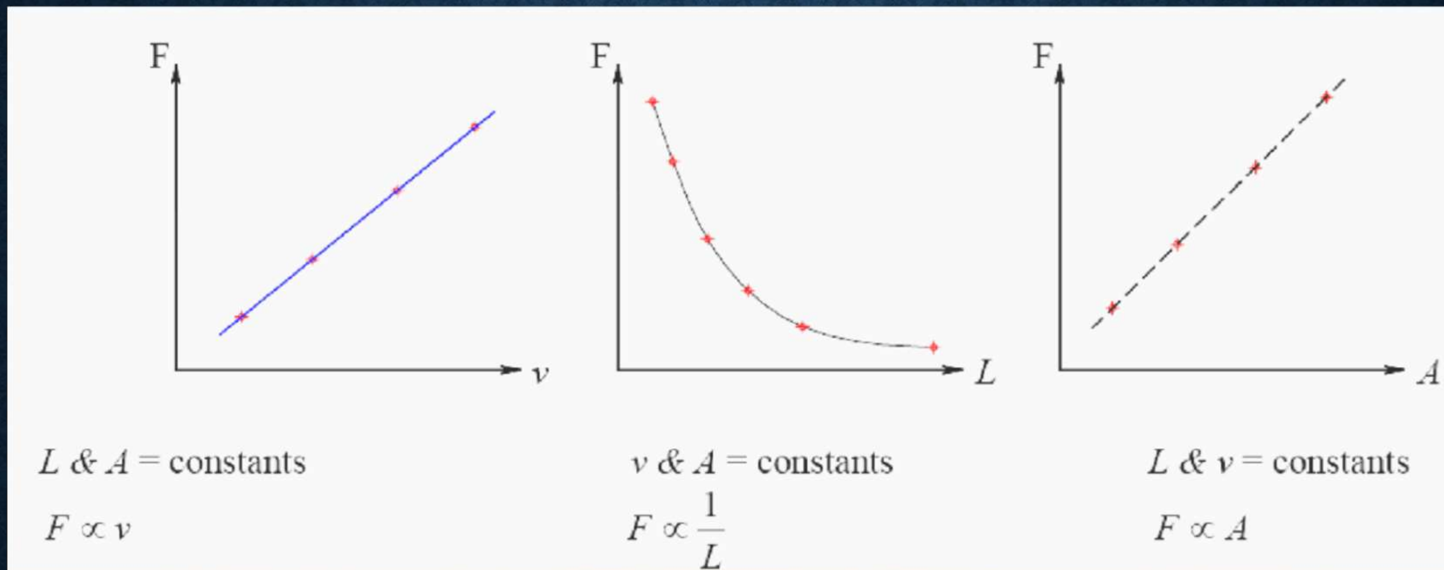
To understand this property, consider a hypothetical experiment in which a material is placed between two very wide parallel plates, as shown in Fig.



Where:

- v Velocity of the moving plate (varies linearly from 0 at the stationary surface to maximum at the contact surface between the moving plate and oil).
- A Contact area between the moving plate and oil.
- F Applied force to the moving plate.
- L Thickness of oil layer

Results:



$$F \propto A\frac{v}{L} \quad \rightarrow \quad F = \mu A\frac{v}{L}$$

Where μ is the proportional constant

BY OBSERVATION:

$$F = \mu A \frac{v}{L}$$

Where F is the external applied force.

Summation of forces: $\sum F_x = 0$

Driving forces – Resisting forces = 0

$$F - F_R = 0 \quad \rightarrow \quad F = F_R = \tau A$$

$$\frac{F}{A} = \mu \frac{v}{L} \quad \rightarrow \quad \tau = \mu \frac{v}{L}$$

Assumptions:

- Small gap thickness
- *v* is not too large

$$\frac{v}{L} = \frac{\Delta v}{\Delta L} = \text{Slope of the velocity distribution (assuming linear distribution)}$$

$$\text{as } \Delta L \rightarrow 0, \ \frac{\Delta v}{\Delta L} \rightarrow \frac{dv}{dy}$$

$$\tau = \mu \frac{dv}{dy} \qquad \text{.......... (Newton's law of viscosity)}$$

$$\text{Viscosity of the fluid, } \mu = \tau / \frac{dv}{dy} = \text{Shear stress / velocity gradient}$$

Where:

τ Shear stress (N/m²)

μ Absolute (dynamic) viscosity, which measures ability of a fluid to flow

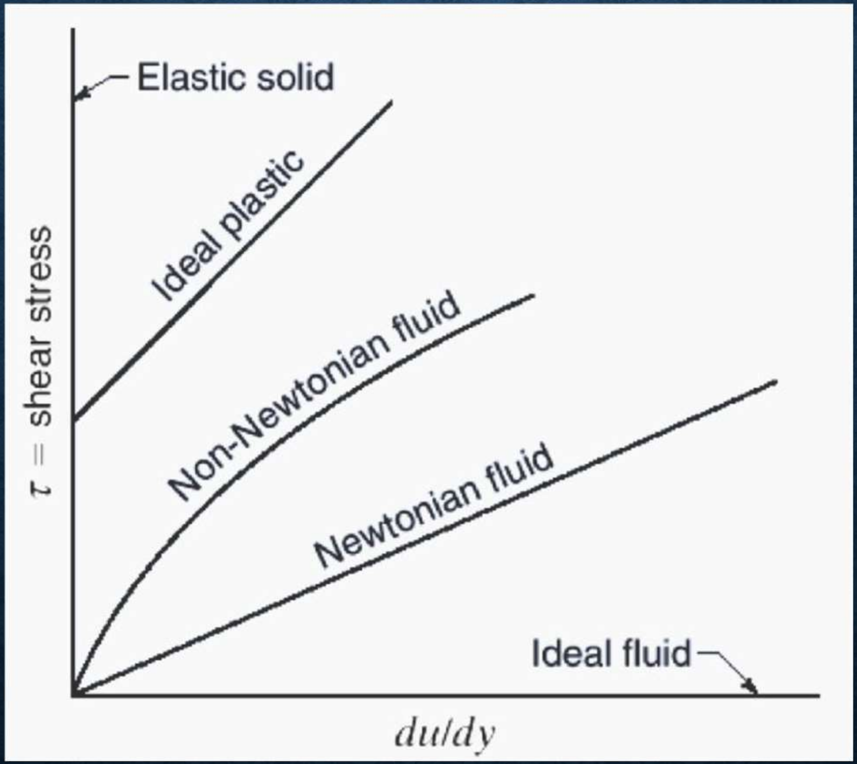
The units of μ are "Pa.s = $\frac{N.s}{m^2} = \frac{kg.m}{s^2}\frac{s}{m^2} = \frac{kg}{m.s}$" or $\frac{lb.\sec}{ft^2}$

Kinematic Viscosity = Absolute Viscosity/ density

$$\nu = \frac{\mu}{\rho} = \frac{N.s}{m^2} / \frac{kg}{m^3} = \frac{kg.m.s}{s^2 m^2}\frac{m^3}{kg} = \frac{m^2}{s}(stoke) \text{ , or } \frac{ft^2}{\sec}$$

	SI	English (BG)
μ_{water}	$\frac{N.s}{m^2}$ (poise), or $\frac{kg}{m.s}$	$\frac{lb.\sec}{ft^2}$
ν_{water}	$\frac{m^2}{s}$ (stoke)	$\frac{ft^2}{\sec}$

A fluid for which the constant of proportionality (i.e., the absolute viscosity, μ) does not change with rate of deformation is called a ***Newtonian fluid***, and this plots as a straight line in the following figure. The slope of this line is the absolute viscosity, μ.



The equation of a straight line, $y = mx$ is similar to Newton's law of viscosity, $\tau = \mu \, dv/dy$.

The ideal fluid **(term for any fluid which is incompressible and inviscid)**, with no viscosity ($\mu = 0$), falls on the horizontal axis,

while the true elastic solid plots along the vertical axis.

There are certain ***non-Newtonian fluids*** in which μ varies with the rate of deformation. These are relatively uncommon in engineering usage. Typical non-Newtonian fluids include paints, printer's ink, gels and emulsions, sludge's and slurries, and certain plastics.

Viscous and inviscid fluids are identified in the context of friction. A viscous fluid causes friction when it flows. If the friction is negligible, then the fluid is inviscid, and the flow is considered to be ideal.

EXAMPLES

Example :9

A space 16 mm wide between two large plane surfaces is filled with SAE 30 Western lubricating oil at 35°C (Fig. X2.11.8). What force F is required to drag a very thin plate of 0.4-m² area between the surfaces at a speed v = 0.25 m/s (a) if this plate is equally spaced between the two surfaces? (b) If t = 5 mm? Refer to Appendix A.

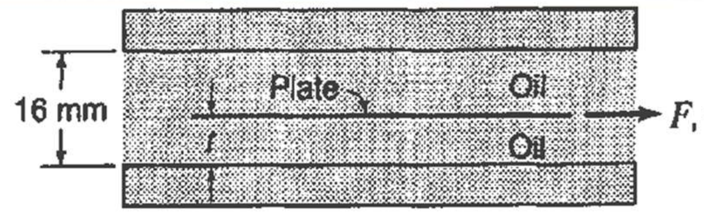


Figure X2.11.8

Fig. A.1 for SAE Western lubricating oil at 35°C:

$$\mu = 0.18 \ \text{N·s/m}^2$$

Solution

(*a*) Eq. 2.9: $\tau = 0.18\left(\frac{0.25}{8/1000}\right) = 5.63 \ \text{N/m}^2$; From Eq. 2.9: Force = 5.63(2)0.4 = 4.50 N ◀

(*b*) Eq. 2.9: $\tau_1 = 0.18\left(\frac{0.25}{5/1000}\right) = 9.00 \ \text{N/m}^2$; $\tau_2 = 0.18\left(\frac{0.25}{11/1000}\right) = 4.09 \ \text{N/m}^2$

From Eq. 2.9: $F_1 = \tau_1 A = 9.00(0.4) = 3.60$ N ; $F_2 = \tau_2 A = 4.09(0.4) = 1.636$ N

$\therefore$ Force $= F_1 + F_2 = 5.24$ N ◀

Example 10

A flat plate 200 mm × 750 mm slides on oil (μ = 0.85 N·s/m²) over a large plane surface (Fig. X2.11.4). What force F is required to drag the plate at a velocity v of 1.2 m/s, if the thickness t of the separating oil film is 0.6 mm?

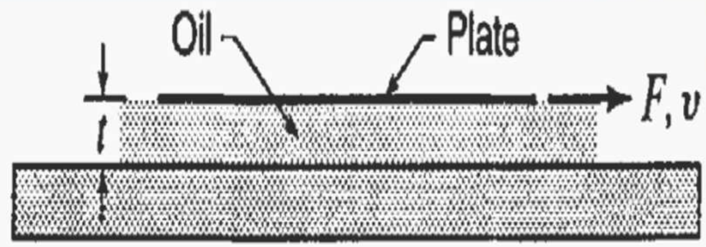


Figure X2.11.4

Solution

$$\tau = \mu \frac{dv}{dy} = 0.85 \frac{1.2}{0.0006} = 1700 \text{ N/m}^2$$

2.9: $F = \tau A = 1700(0.20 \times 0.75) = 255 \text{ N}$ ◄

OTHER FLUID PROPERTIES

1- Surface tension: a force that tends to pull adjacent parts of a liquid's surface together, thereby decreasing surface area to the smallest possible size

The symbol for surface tension is σ, and it has the dimensions $[MT^{-2}]$.

The higher the attraction forces (intermolecular forces), the higher the surface tension. Surface tension causes liquid droplets to take a spherical shape.

Most organic liquids have values between 0.020 and 0.030 $N \cdot m^{-1}$, and mercury has a value of about 0.48 $N \cdot m^{-1}$

The liquid in each case is in contact with air.

For all liquids, the surface tension decreases as the temperature rises.

Example of surface tension

- A **water droplet** forms a round shape.
- A **paper clip** can float on water if placed gently.
- Insects like water striders can walk on water.

COHESION

Cohesion is the attraction between **molecules of the same substance**.

👉 Water sticking to water.

Examples:

Water droplets sticking together.

Rain forming drops.

Surface tension happens because of cohesion.

ADHESION

Adhesion is the attraction between **different substances**.

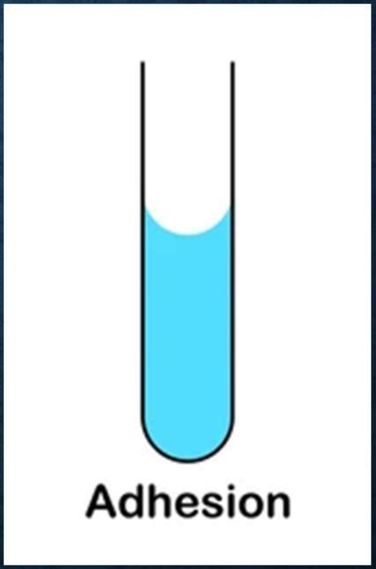
👉 Water sticking to something else.

Examples:

Water sticking to a glass surface.

Wet clothes sticking to your skin.

Water climbing up a plant stem.



CAPILLARY ACTION

Where:

h capillary rise in the tube

σ surface tension

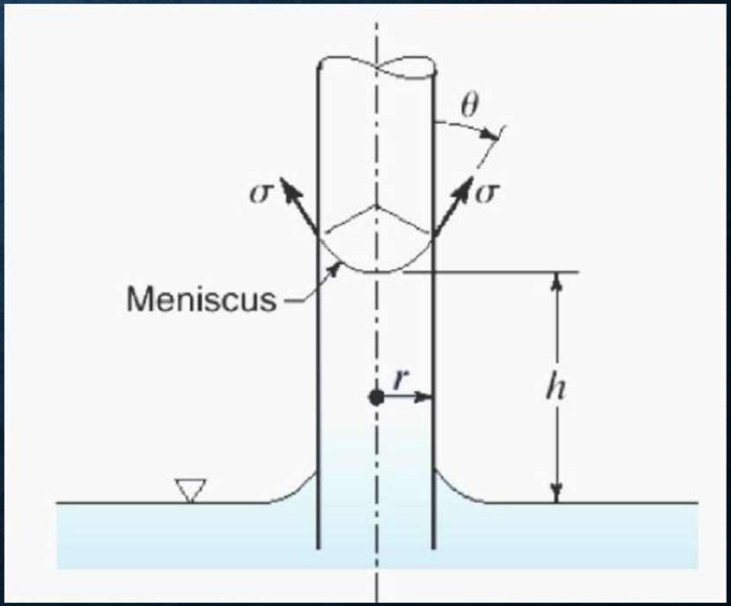
θ angle of contact between water, and tube.

γ specific weight of water

r radius of the tube.

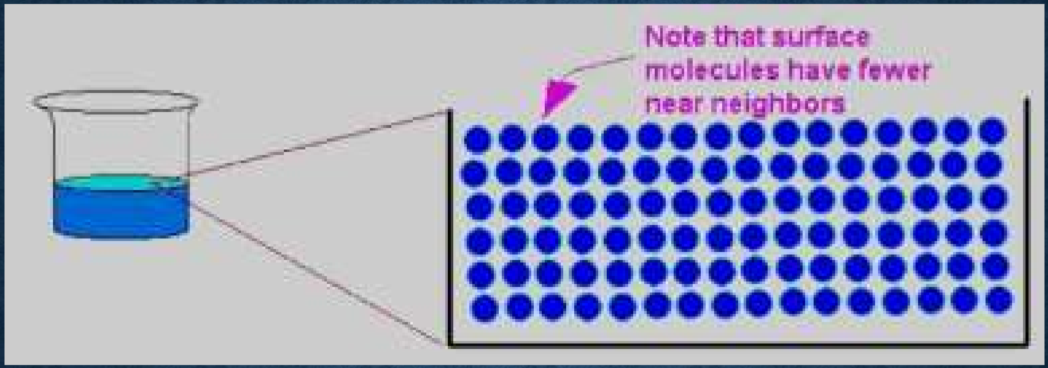
$$h = \frac{2\sigma\cos\theta}{\gamma . r}$$

****h is inversely proportional to r****

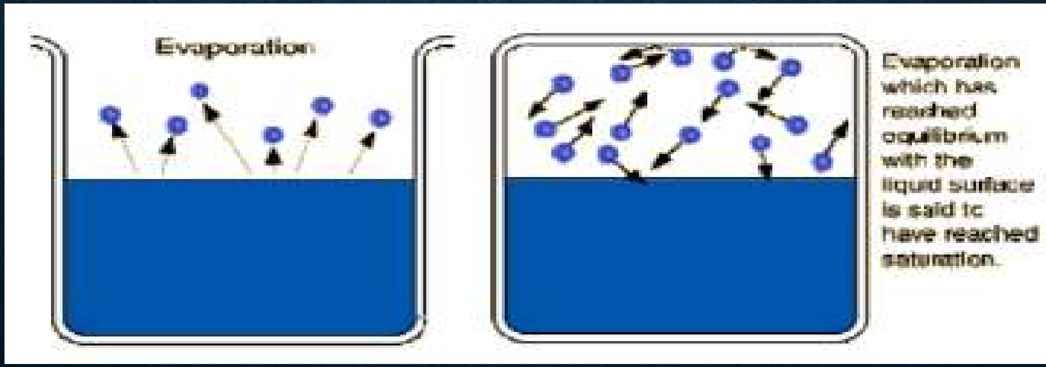


2- Vapor pressure

All liquids tend to evaporate or vaporize, which they do by projecting molecules into the space above their surfaces.



Ordinary evaporation is a surface phenomenon - some molecules have enough kinetic energy to escape. If the container is closed, equilibrium is reached where an equal number of molecules return to the surface. The pressure of this equilibrium is called the ***saturation vapor pressure***.



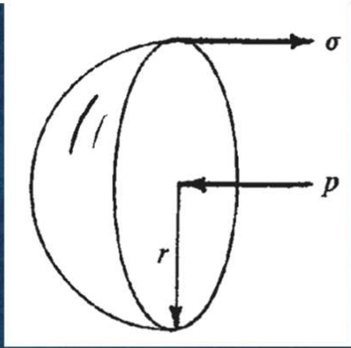
Definition: Vapor pressure:

The pressure at which a liquid will boil is called its vapor pressure. This pressure is a function of temperature (vapor pressure increases with temperature). In this context, we usually think about the temperature at which boiling occurs. For example, water boils at 100 °C at sea level atmospheric pressure (1 atm abs). However, in terms of vapor pressure, we can say that by increasing the temperature of water at sea level to 100 °C, we increase the vapor pressure to the point at which it is equal to the atmospheric pressure (1 atm abs), so that boiling occurs.

Example 11:

By how much does the pressure inside a 2-mm-diameter air bubble in 15°C water exceed the pressure in the surrounding water?

at 15°C: $\sigma = 0.0735$ N/m.



Solution

Cut the bubble on a plane through its center, consider force equilibrium.

$\sigma \times$ circumference $= p \times$ area; $\sigma(2\pi r) = p(\pi r^2)$

$$p = \frac{2\pi r\sigma}{\pi r^2} = \frac{2\sigma}{r} = \frac{2(0.0735\ \text{N/m})}{0.001\ \text{m}} = 147\ \text{N/m}^2 = 147\ \text{Pa} \quad ◀$$

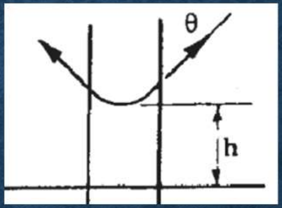
Example 12:

Compute the capillary rise in mm of pure water at 10°C expected in an 0.8-mm-diameter tube.

Table A.1 at 10°C: σ_{water} = 0.0742 N/m, γ = 9.804 kN/m^3

Solution

with $\theta = 0$:



$$h = \frac{2\sigma}{\gamma r} = \frac{2(0.0742\ \text{N/m})}{(9804\ \text{N/m}^3)(0.0004\ \text{m})} = 0.0378\ \text{m} = 37.8\ \text{mm}$$