CHARACTERISTIC OF FLUIDS

A fluid is defined as a substance that deforms continuously when acted on by a shearing stress at any magnitude.

In a fluid at rest, normal stress is called *"pressure"*.

Dimensions, Dimensional homogeneity and Units

Fluid has *qualitative* and *quantitative* characteristic.

Qualitative :

To identify the nature of fluid such as length, time, stress and velocity. Basically the qualitative aspects identities the nature or type of characteristic.

Quantitative :

Numerical measure of the characteristic. Quantitative requires both a number and a standard. Such standards are called *"unit"*.

3 kg

Number 3 is quantity and kg (kilogram) is a unit

Primary quantity :

L	: Length
T	: Time
M	: Mass
θ	: Temperature

Secondary quantity :

L^2	: Area
LT^{-1}	: Velocity
ML^{-3}	: Density

All theoretically derived equations are *"dimensionally homogeneous"*. The dimension of the left side of the equation must be the same as those on the right side, and all additive separate terms must have the same dimensions.

<u>Example :</u>

$$V = V_0 + at$$

$$LT^{-1} = LT^{-1} + (LT^{-2})(T)$$

TABLE 1.1

Dimensions Associated with Common Physical Quantities

	***FLT* System**	***MLT* System**
Acceleration	LT^{-2}	LT^{-2}
Angle	$F^0L^0T^0$	$M^0L^0T^0$
Angular acceleration	T^{-2}	T^{-2}
Angular velocity	T^{-1}	T^{-1}
Area	L^2	L^2
Density	$FL^{-4}T^2$	ML^{-3}
Energy	FL	ML^2T^{-2}
Force	F	MLT^{-2}
Frequency	T^{-1}	T^{-1}
Heat	FL	ML^2T^{-2}
Length	L	L
Mass	$FL^{-1}T^2$	M
Modulus of elasticity	FL^{-2}	$ML^{-1}T^{-2}$
Moment of a force	FL	ML^2T^{-2}
Moment of inertia (area)	L^4	L^4

UNIT

3 major systems that are commonly used in engineering.

1. *British Gravitational (BG) System*
   - Length – foot (ft)
   - Time – second (s)
   - Force – pound (lb)
   - Temperature – Fahrenheit (ºF)

2. *International System (SI)*
   - Length – meter (m)
   - Time – second (s)
   - Mass – kilogram (kg)
   - Temperature – Kelvin (K)

3. *English Engineering (EE) System*

- Length – foot (ft)
- Time – second (s)
- Mass – pound mass (lbm)
- Force – pound (lb or lbf)
- Temperature – Rankine (ºR)

The relation of Kelvin and Celsius is;

$$K = {}^\circ C + 273.15$$

TABLE 1.2

Prefixes for SI Units

Factor by Which Unit Is Multiplied	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

MEASURES OF FLUID MASS AND WEIGHT

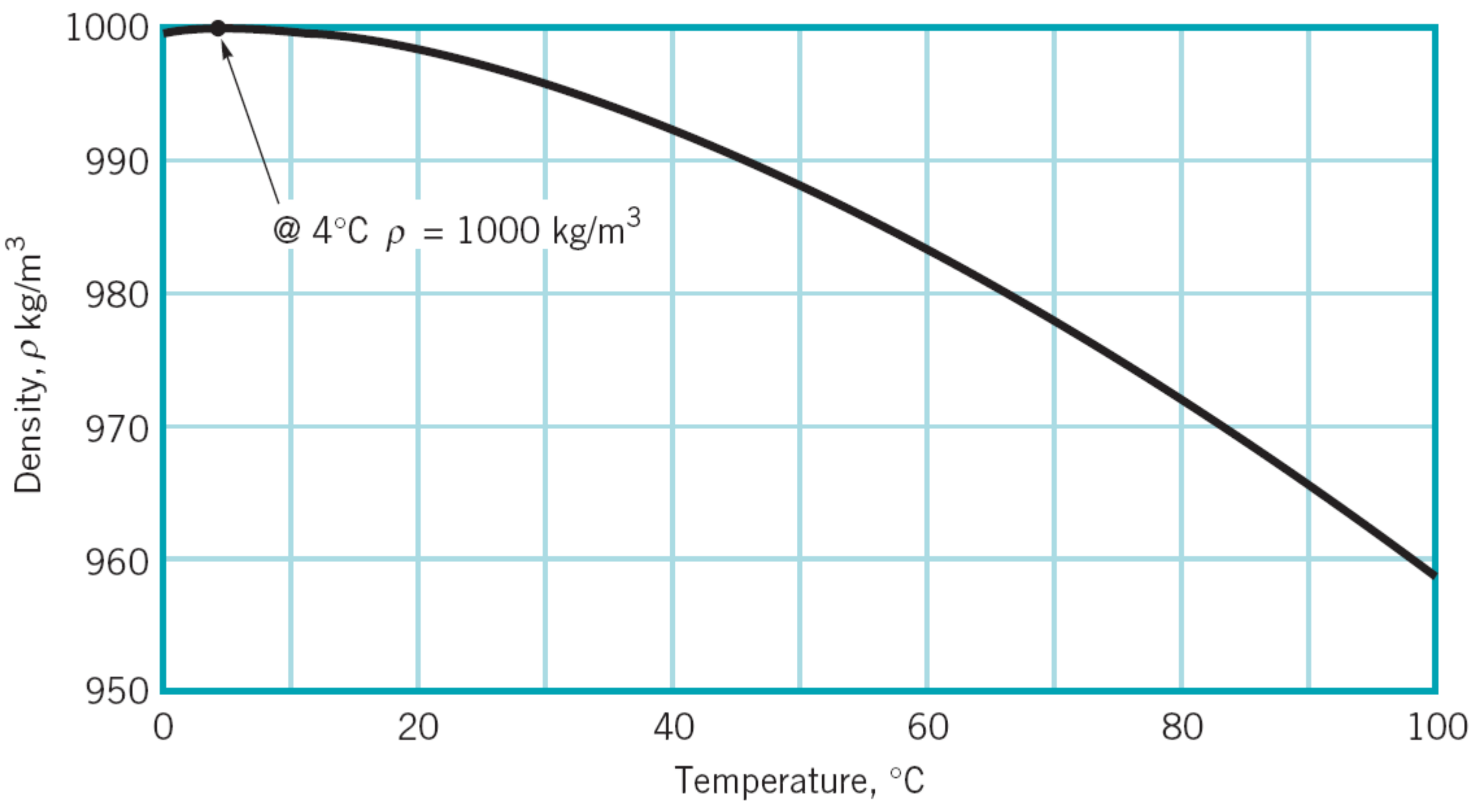
Density

Designated by the Greek symbol ρ (rho).
Defined as its mass per unit volume.

$$\rho = \frac{mass}{volume} = \frac{kg}{m^3}$$

Specific volume, is the volume per unit mass. This property is not commonly used in fluid mechanics but is used widely in thermodynamics.

$$\upsilon = \frac{volume}{mass} = \frac{1}{\rho}$$



The changes of density of water over temperatures.

If not given, we could take the density of water is 1000 kg/m^3

■ **TABLE 1.6**

Approximate Physical Properties of Some Common Liquids (SI Units)

Liquid	Temperature (°C)	Density, ρ (kg/m^3)	Specific Weight, γ (kN/m^3)	Dynamic Viscosity, μ (N · s/m^2)	Kinematic Viscosity, ν (m^2/s)	Surface Tension,[a] σ (N/m)	Vapor Pressure, p_v [N/m^2 (abs)]	Bulk Modulus,[b] E_v (N/m^2)
Carbon tetrachloride	20	1,590	15.6	9.58 E − 4	6.03 E − 7	2.69 E − 2	1.3 E + 4	1.31 E + 9
Ethyl alcohol	20	789	7.74	1.19 E − 3	1.51 E − 6	2.28 E − 2	5.9 E + 3	1.06 E + 9
Gasoline[c]	15.6	680	6.67	3.1 E − 4	4.6 E − 7	2.2 E − 2	5.5 E + 4	1.3 E + 9
Glycerin	20	1,260	12.4	1.50 E + 0	1.19 E − 3	6.33 E − 2	1.4 E − 2	4.52 E + 9
Mercury	20	13,600	133	1.57 E − 3	1.15 E − 7	4.66 E − 1	1.6 E − 1	2.85 E + 10
SAE 30 oil[c]	15.6	912	8.95	3.8 E − 1	4.2 E − 4	3.6 E − 2	—	1.5 E + 9
Seawater	15.6	1,030	10.1	1.20 E − 3	1.17 E − 6	7.34 E − 2	1.77 E + 3	2.34 E + 9
Water	15.6	999	9.80	1.12 E − 3	1.12 E − 6	7.34 E − 2	1.77 E + 3	2.15 E + 9

[a]In contact with air.

[b]Isentropic bulk modulus calculated from speed of sound.

[c]Typical values. Properties of petroleum products vary.

Specific weight

Designated by the Greek symbol γ (gamma).

Defined as its weight per unit volume.

$$\gamma = \frac{weight}{volume} = \frac{mg}{volume} = \frac{kg \cdot g}{m^3} = \rho g$$

Specific gravity

Designated as SG.

Defined as the ratio of the density of the fluid to the density of water at some specified temperature.

Usually, the specified temperature is taken as 4ºC.

$$SG = \frac{\rho}{\rho_{H_2O@4^\circ C}}$$

Ideal gas law

Gases are highly compressible in comparison to liquids, with changes in gas density directly related to changes in pressure and temperature through the equation.

$$P = \rho R T$$

P : pressure

ρ : density

R : gas constant

T : temperature

The pressure in the ideal gas law must be expressed as an absolute pressure (abs), which means that it is measured relative to absolute zero pressure (a pressure that would only occur in a perfect vacuum).

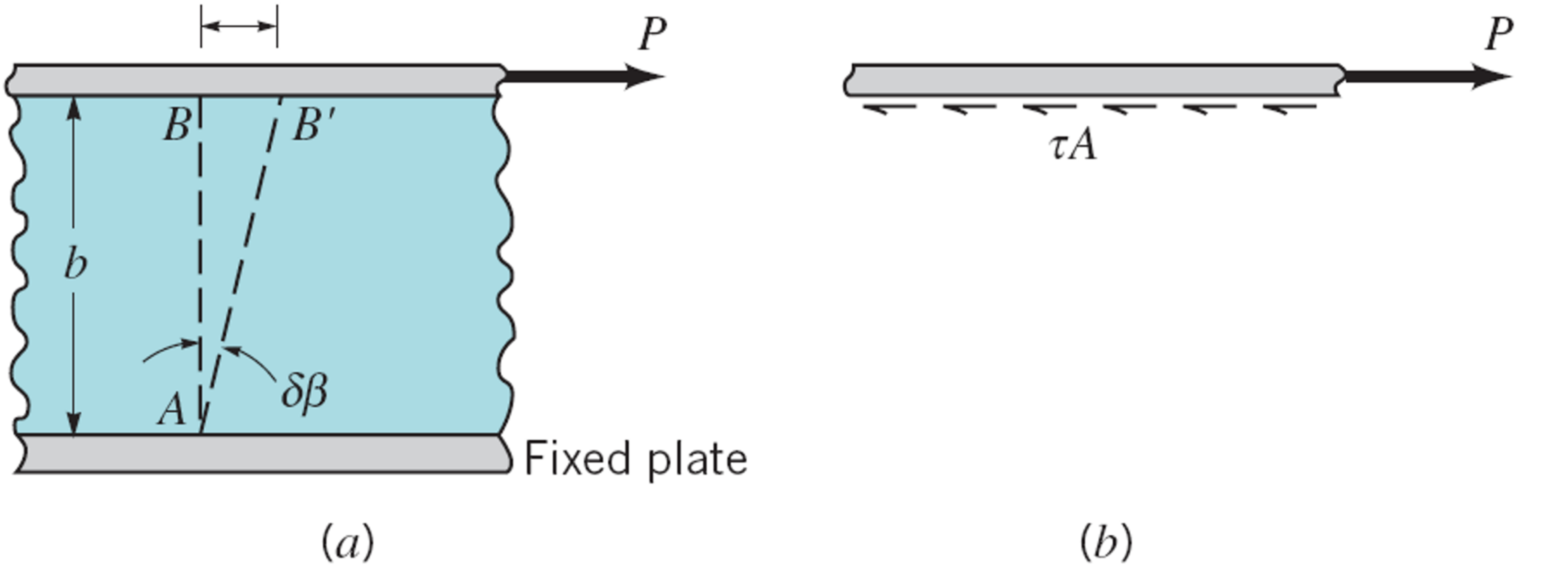
Standard sea-level atmospheric pressure is 14.696 psi and 101.325 kPa, respectively.

$$P_{atm} = 101.325 \text{ kPa}$$

VISCOSITY

The property of viscosity is described the *"fluidity"* of the fluid.

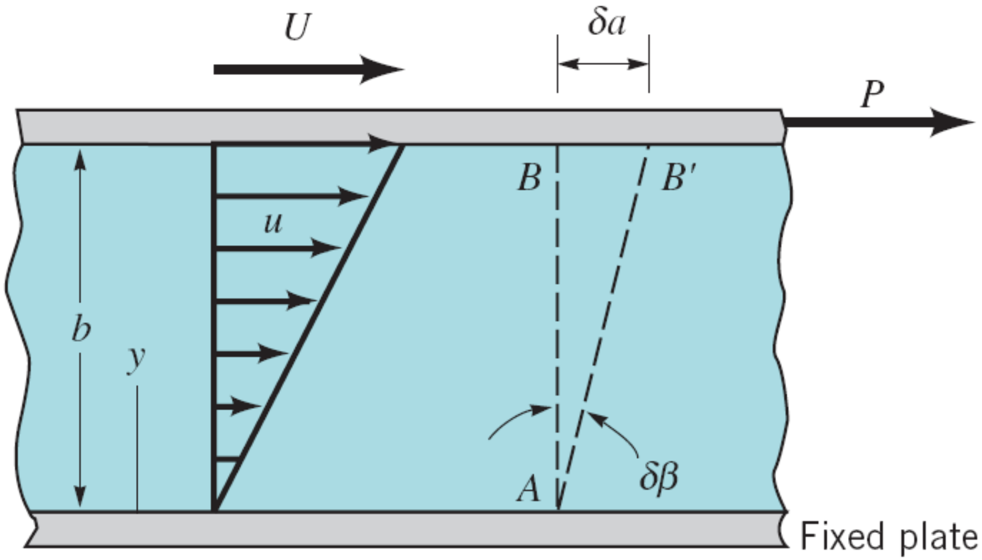
To resist the applied force, P, a shearing stress, τ, would be developed at the plate-material interface.



The equilibrium is ;

$$P = \tau A$$

It revealed that as the shearing stress, τ, is increased by increasing P.



We can say that shear stress, τ, has direct proportion with the velocity gradient – that is ;

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

The shearing stress and velocity gradient can be related with a relationship of the form ;

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

μ (miu) is a dynamic viscosity. Dynamic viscosity also called as absolute viscosity.

Unit is kg/m.s or N.s/m^2 or Pa.s or Poise (P) or centipoise (cP)

1 Pa.s = 10 Poise

Relation between dynamic viscosity and kinematic viscosity can be written as ;

$$\mu = \rho \upsilon$$

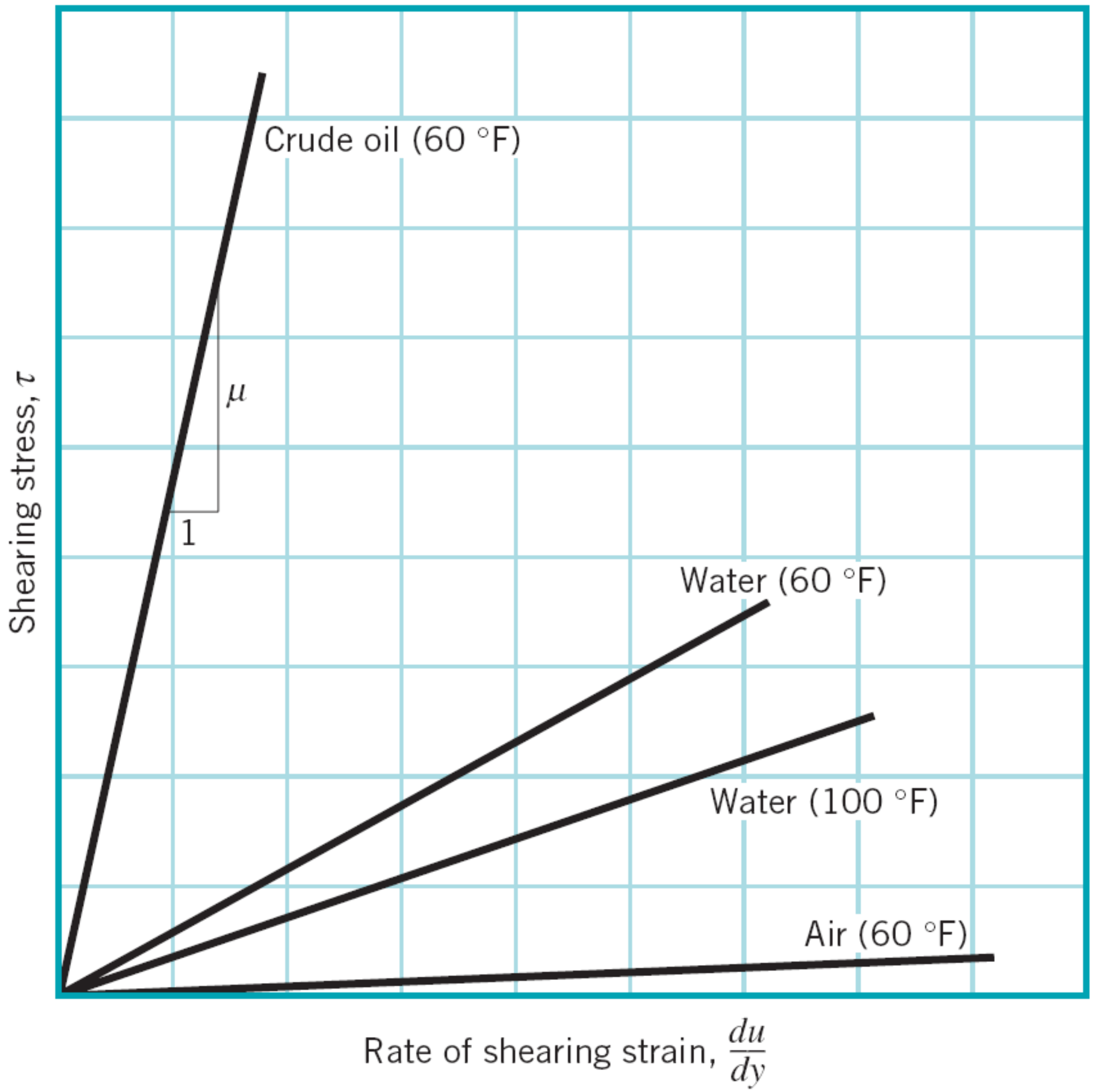
υ (nu) is a kinematic viscosity.

Unit is m^2/s or Stokes (St) or centiStokes (cSt)

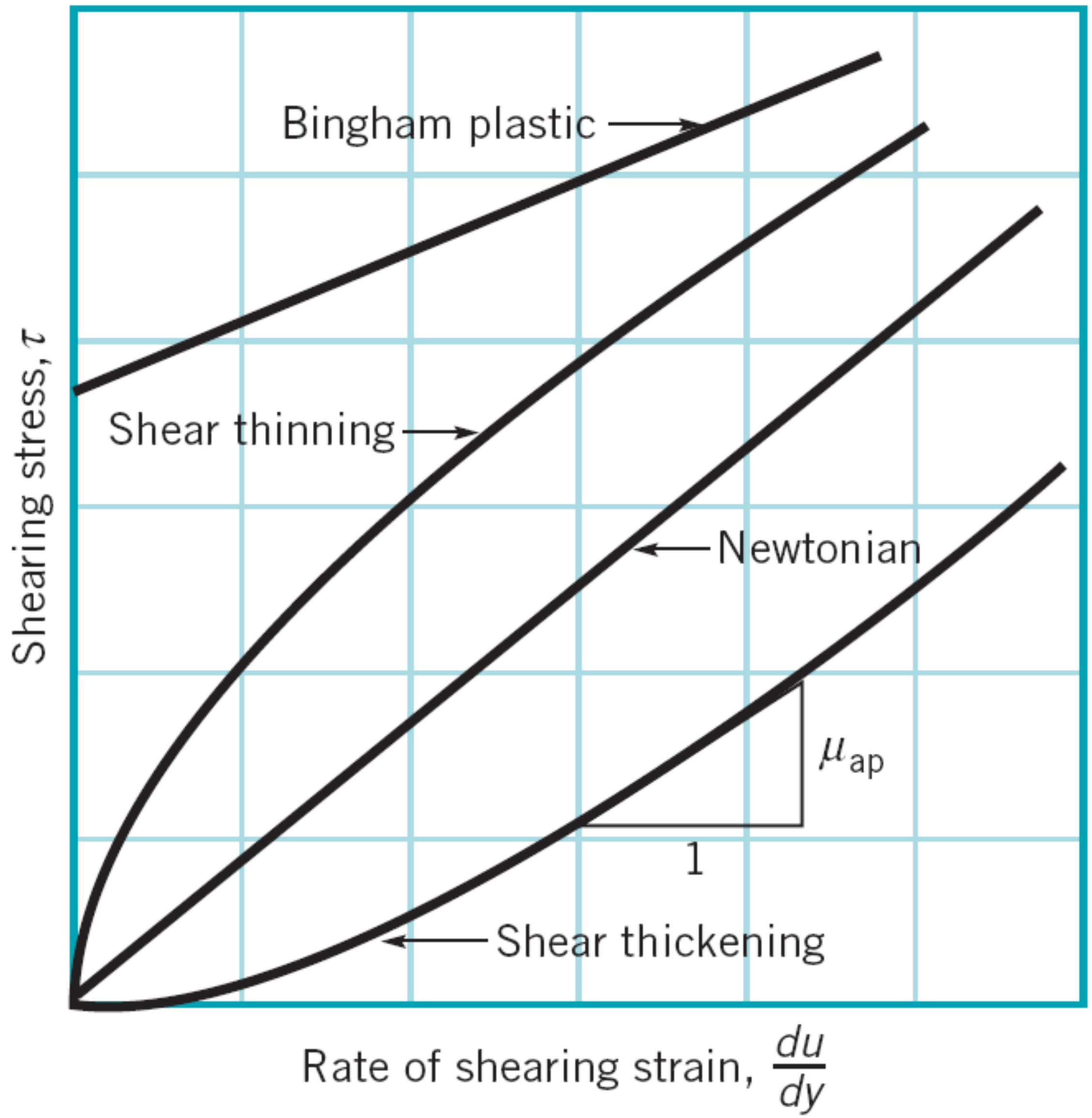
$$1 \quad m^2/s \quad = \quad 10{,}000 \quad cSt$$

Fluids for which the shearing stress is *linearly* related to the rate of shearing strain are designated as *Newtonian fluids*.

Fluids for which the shearing stress is not linearly related to the rate of shearing strain are designated as *non-Newtonian fluids*.



Crude oil (60 °F)
μ
1
Water (60 °F)
Water (100 °F)
Air (60 °F)
Shearing stress, τ
Rate of shearing strain, du/dy


Bingham plastic
Shear thinning
Newtonian
μ_{ap}
1
Shear thickening
Shearing stress, τ
Rate of shearing strain, $\frac{du}{dy}$

BULK MODULUS

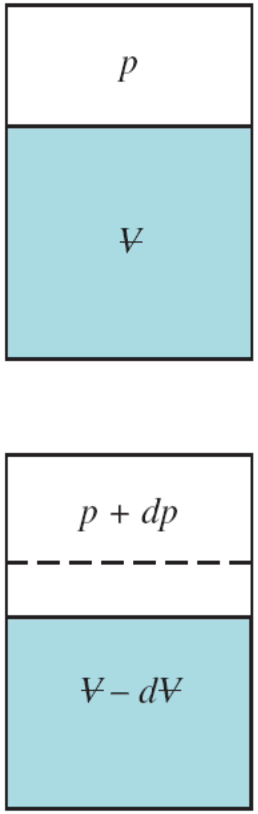
A property that is commonly used to characterize compressibility is the bulk modulus.

Defined as ;

$$E_\upsilon = -\frac{dP}{dV/V} = \frac{dP}{d\rho/\rho}$$

we conclude that liquids can be considered as *incompressible* for most practical engineering applications.

COMPRESSION & EXPANSION OF GAS



When gases are compressed (or expanded) the relationship between pressure and density depends on the nature of the process.

If the compression or expansion takes place under constant temperature conditions (isothermal process), then ;

$$\frac{P}{\rho} = \text{constant}$$

If the compression or expansion is frictionless and no heat is exchanged with the surroundings (isentropic process), then ;

$$\frac{P}{\rho^k} = \text{constant}$$

k is the ratio of the specific heat at constant pressure, c_p, to the specific heat at constant volume, c_v.

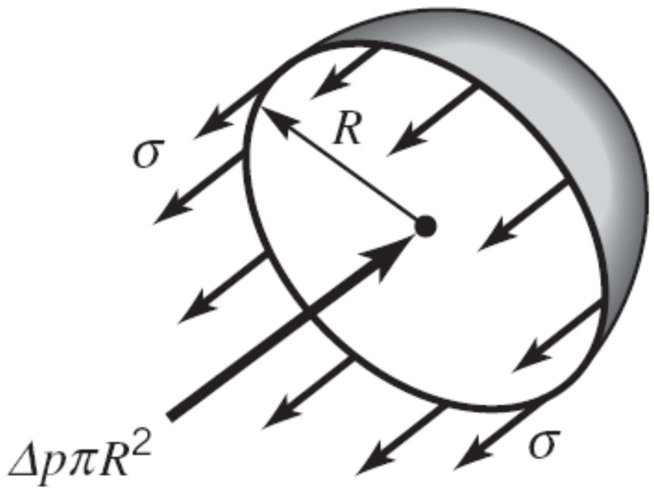
$$k = {c_p}/{c_v}$$

SURFACE TENSION

The intensity of the molecular attraction per unit length along any line in the surface is called the surface tension.

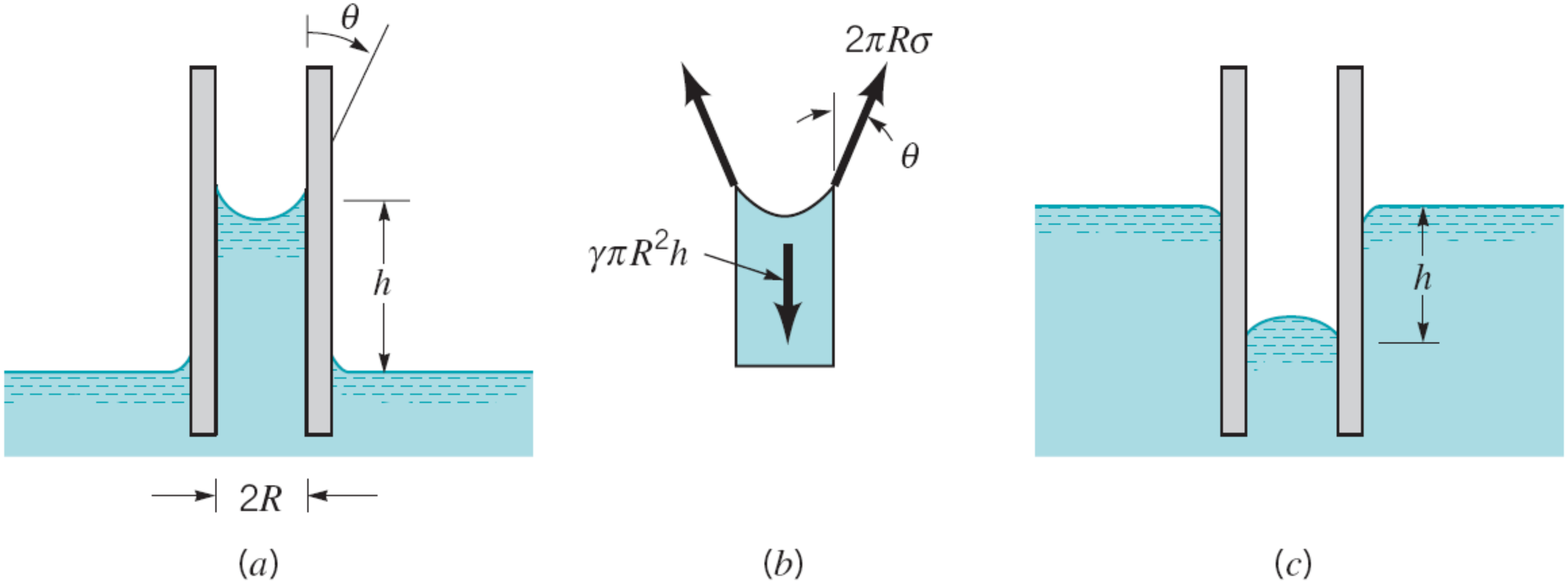
Designated by the Greek symbol, σ (sigma)

Unit is N/m.



The forces balance of half-cut spherical is shown as ;

$$2\pi \mathrm{R} \sigma = \Delta P \pi R^2$$



The forces balance of capillary action is shown as ;

$$2\pi R \sigma \cos\theta = \rho g h \pi R^2$$