FLUID MECHANICS

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LECTURE 2

1- Measures of Fluid Mass and Weight
   a. Density
   b. Specific Weight
   c. Specific Gravity
2 - Ideal Gas Law
3- Viscosity

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1- Measures of Fluid Mass and Weight

a- Density (الكثافة)

The density of a fluid, designated by the Greek symbol ρ (rho), is defined as its **mass per unit volume**. Density is typically used to characterize the mass of a fluid system.

$$\rho = \frac{Mass}{Volume}$$

The **dimension** of density in **MLT** system is (ML^{-3}) and in **FLT** system is $FL^{-4}T^{2}$.

And the **units** of density ρ in **SI** system is (kg/m^3) and in **BG** system is ($slugs/ft^3$).

The value of density can vary widely between different fluids, but for liquids, variations in pressure and temperature generally have only a small effect on the value of density ρ .

The small change in the density of water with large variations in temperature is illustrated in Fig. 2.

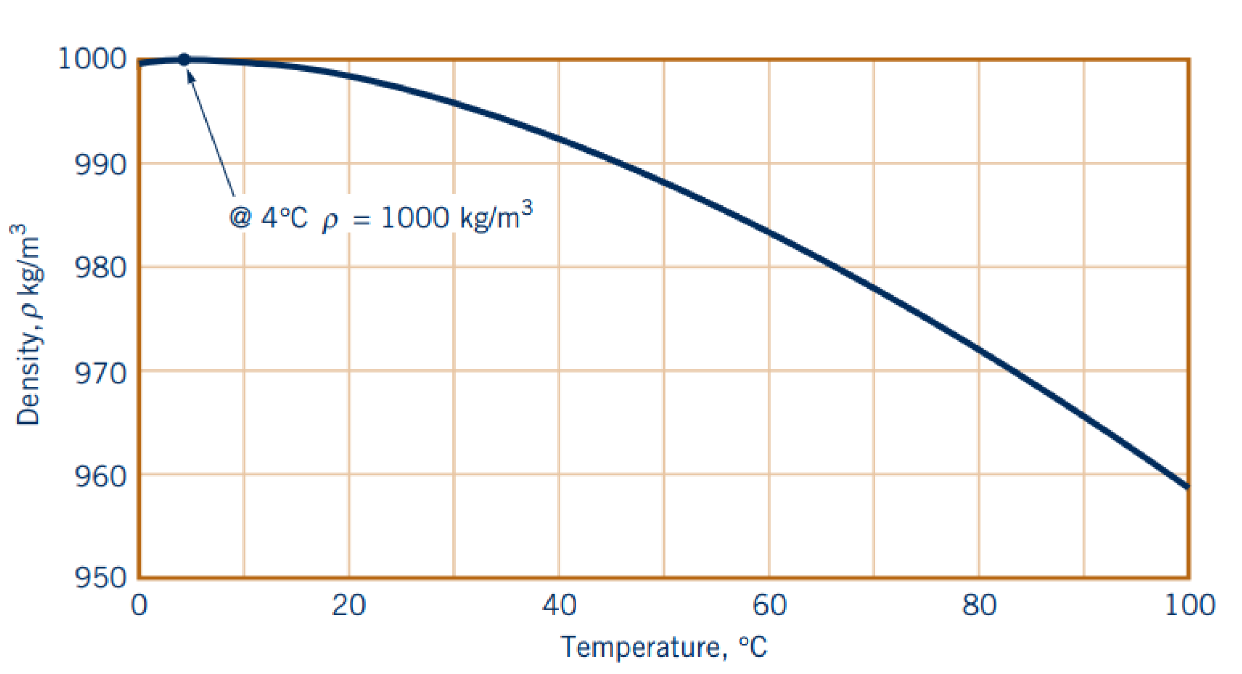


Figure 2, Density of water as a function of temperature.

Tables 7 and 8 list values of density for several common liquids. The density of water at 60 °F is 1.94 slugs/ft^3 or 999 kg/m^3.

The large difference between those two values illustrates the importance of paying attention to units!

Unlike liquids, the density of a gas is strongly influenced by both pressure and temperature, and this difference will be discussed in the next section.

The **specific volume (الحجم النوعي)**, **ν** (**nu**), is the **volume per unit mass** and is therefore the reciprocal of the density—that is,

$$\nu = \frac{1}{\rho} = \rho^{-1}$$

The dimensions of specific volume in **(MLT)** system is L^3M^{-1} and if **(BG)** system is $F^{-1}L^4T^{-2}$.

And the unites of specific volume in SI system and BG system are:

$$\nu = \frac{m^3}{kg}, \frac{ft^3}{Ib}, \frac{ft^3}{slug}$$

Note: The unite of force in English Engineering (EE) system is pound (Ib).

Table 7

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.

Table 8

Approximate Physical Properties of Some Common Liquids (BG Units)

Liquid	Temperature (°F)	Density, ρ (slugs/ft^3)	Specific Weight, γ (lb/ft^3)	Dynamic Viscosity, μ (lb · s/ft^2)	Kinematic Viscosity, ν (ft^2/s)	Surface Tension,[a] σ (lb/ft)	Vapor Pressure, p_v [lb/in.^{2} (abs)]	Bulk Modulus,[b] E_v (lb/in.^{2})
Carbon tetrachloride	68	3.09	99.5	2.00 E − 5	6.47 E − 6	1.84 E − 3	1.9 E + 0	1.91 E + 5
Ethyl alcohol	68	1.53	49.3	2.49 E − 5	1.63 E − 5	1.56 E − 3	8.5 E − 1	1.54 E + 5
Gasoline[c]	60	1.32	42.5	6.5 E − 6	4.9 E − 6	1.5 E − 3	8.0 E + 0	1.9 E + 5
Glycerin	68	2.44	78.6	3.13 E − 2	1.28 E − 2	4.34 E − 3	2.0 E − 6	6.56 E + 5
Mercury	68	26.3	847	3.28 E − 5	1.25 E − 6	3.19 E − 2	2.3 E − 5	4.14 E + 6
SAE 30 oil[c]	60	1.77	57.0	8.0 E − 3	4.5 E − 3	2.5 E − 3	—	2.2 E + 5
Seawater	60	1.99	64.0	2.51 E − 5	1.26 E − 5	5.03 E − 3	2.56 E − 1	3.39 E + 5
Water	60	1.94	62.4	2.34 E − 5	1.21 E − 5	5.03 E − 3	2.56 E − 1	3.12 E + 5

[a]In contact with air.
[b]Isentropic bulk modulus calculated from speed of sound.
[c]Typical values. Properties of petroleum products vary.

b- Specific Weight (ɣ)

The *specific weight (الوزن النوعي)* of a fluid, designated by the Greek symbol ɣ (gamma), is defined as its weight per unit volume. Thus, specific weight is related to density through the equation:

$$\gamma = \rho g$$

Where g is the local acceleration of gravity.
Just as density is used to characterize the mass of a fluid system, the specific weight is used to characterize the weight of the system.

Under conditions of standard gravity ($g = 9.807 m/s^2 = 32.174 ft/s^2$) water at 60°F has a specific weight $9.80\ kN/m^3$ and $62.4\ lb/ft^3$.

The dimension of Specific weight (γ) in MLT system is ($ML^{-2}T^{-2}$) and in FLT system is FL^{-3}. ($F \doteq MLT^{-2}$) and ($M \doteq FL^{-1} T^{2}$).

And the units of Specific weight (γ) in SI system is (kN/m^3) and in BG system is (lb/ft^3).

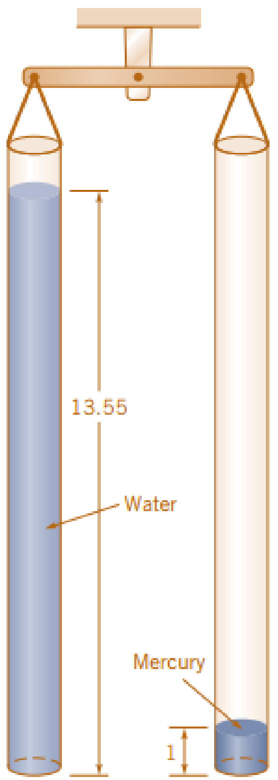
Tables 7 and 8 list values of specific weight for several common liquids (based on standard gravity).

c- Specific Gravity (SG)

The *specific gravity* of a fluid, designated as *SG*, is 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 4°c (39.2°F), and at this temperature the density of water is 1.94 slugs/ft^3 or 1000 kg/m^3 In equation form, specific gravity is expressed as

$$SG = \frac{\rho}{\rho_{H_2O\;@\;4^oc}}$$

Specific weight is weight per unit volume; specific gravity is the ratio of fluid density to the density of water at a certain temperature.



$$SG = \frac{\rho}{\rho_{H_2O\ @\ 4^o c}}$$

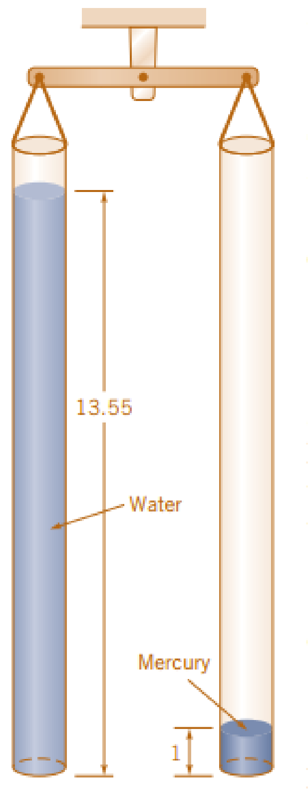
Since it is the **ratio of densities**, the value of SG does **not** depend on the system of units used.
For example, the specific gravity of mercury at 20°c is 13.55.
This is illustrated by the figure beside.
Thus, the density of mercury can be readily calculated in either BG or SI units through the use the equation above.

$$\rho_{Hg} = (13.55) \times (1000\ kg/m^3) = 13.6 \times 10^3\ kg/m^3$$

$$\rho_{Hg} = (13.55) \times (1.94\ slugs/ft^3) = 26.3 \times 10^3\ slugs/ft^3$$

It is clear that density, specific weight, and specific gravity are all interrelated, and from a knowledge of any one of the three the others can be calculated.

Specific weight is weight per unit volume; specific gravity is the ratio of fluid density to the density of water at a certain temperature.



2- 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

$$\rho = \frac{P}{RT}$$

Where *P* the absolute pressure, ρ the density of gas, *T* the absolute temperature, and *R* is a gas constant.

The equation above commonly termed the *ideal* or perfect *gas law*, or the equation of state for an ideal gas.

A gas is considered ideal if its particles are so far apart that they do not exert any attractive forces upon one another. In real life, there is no such thing as a truly ideal gas, but at high temperatures and low pressures (conditions in which individual particles will be moving very quickly and be very far apart from one another so that their interaction is almost zero), gases behave close to ideally; this is why the Ideal Gas Law is such a useful approximation.

Pressure in a fluid at rest is defined as the **normal force per unit area** exerted on a plane surface (real or imaginary) immersed in a fluid and is created by the bombardment of the surface with the fluid molecules.

$$P = Force / Area$$

The dimension of Pressure that comes from definition is **(FL^{-2})**.

The unite of pressure in **SI** units is **N/m^2** (newton/square meter). And $1N/m^2$ defined as ***pascal (Pa)***.

While in **BG** unites is expressed as **lb/ft^2 (psf)** (Pounds Force per Square Foot) or **lb/in^2 (psi)** (pound-force per square inch).

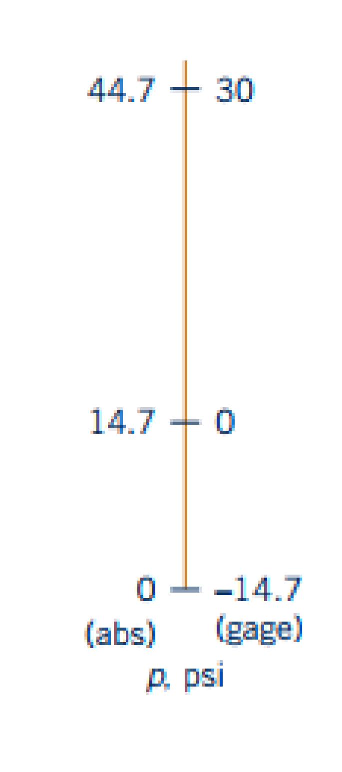
The pressure in the ideal gas law must be expressed as an **absolute pressure**, denoted **(abs)**, which means that it is measured relative to absolute zero pressure (a pressure that would only occur in a perfect vacuum).

Standard **sea-level atmospheric pressure** (by international agreement) is 14.696 psi (abs) or 101.33 kPa (abs).

For most calculations these pressures can be rounded to 14.7 psi (pound per square inch) and 101 kPa, respectively.

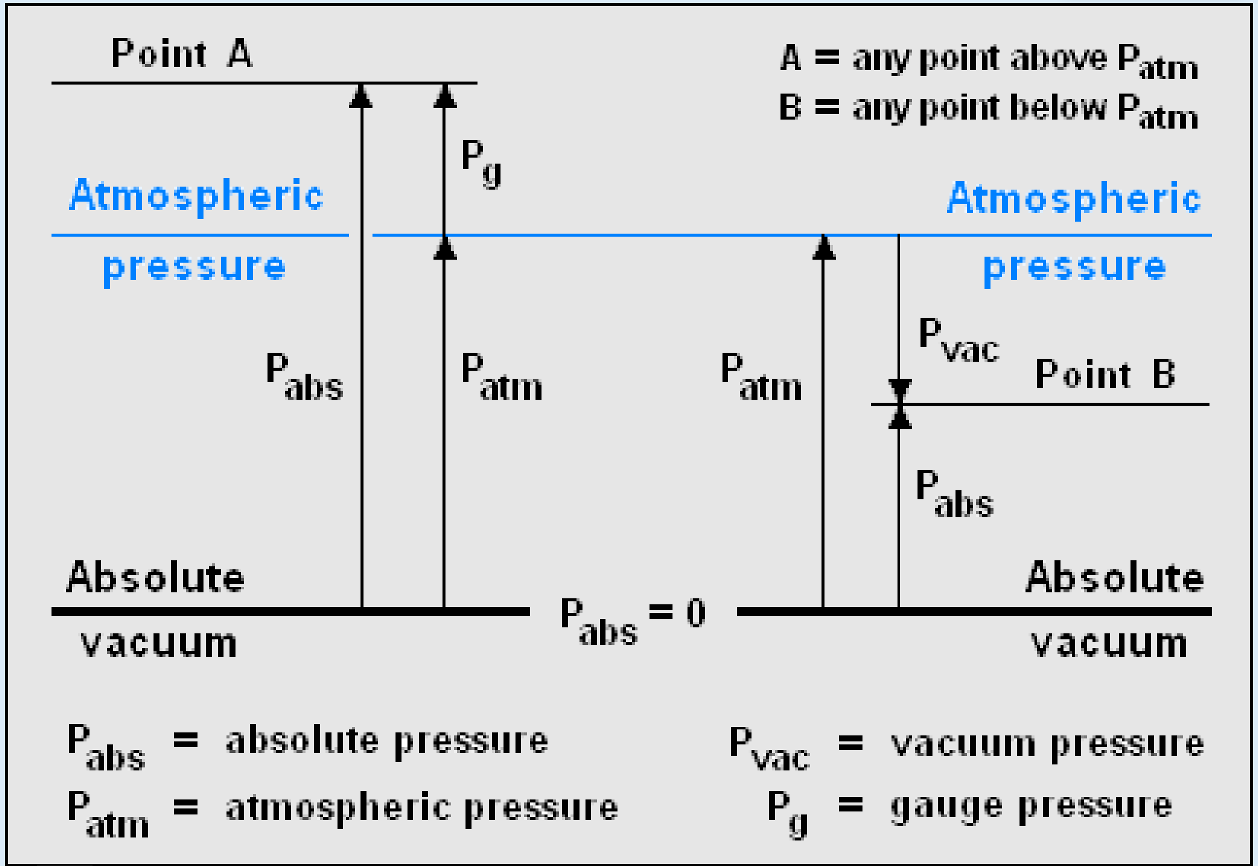
In engineering it is common practice to measure pressure relative to the local atmospheric pressure, and when measured in this fashion it is called ***gage pressure***. Thus, the **absolute pressure** can be obtained from the **gage pressure by adding the value of the atmospheric pressure**.

For example, as shown by the figure, a pressure of 30 psi (gage) in a tire is equal to 44.7 psi (abs) at standard atmospheric pressure.



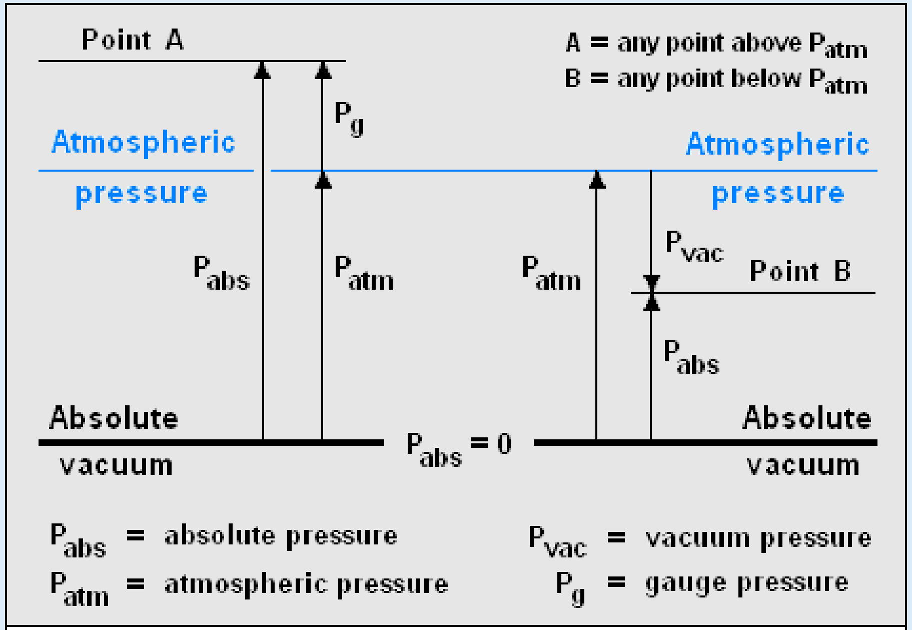
Atmospheric Pressure: Is the pressure of the atmosphere around us, or it is a pressure in the surrounding atmosphere .

Absolute Vacuum: The pressure is zero like a space completely vacuum which means no pressure is extended.



The relationship between absolute, gauge and vacuum pressures.

Absolute Pressure: Is the pressure that measures from the absolute vacuum.



The relationship between absolute, gauge and vacuum pressures.

Gauge pressure: It is the pressure that measured with measuring instruments. And it is above Atmospheric pressure.

Vacuum pressure: It is the negative pressure or the pressure measured below atmospheric pressure.

EXAMPLE 1.3 Ideal Gas Law

GIVEN The compressed air tank shown in Fig. E1.3*a* has a volume of 0.84 ft^3. The temperature is 70 °F and the atmospheric pressure is 14.7 psi (abs).

FIND When the tank is filled with air at a gage pressure of 50 psi, determine the density of the air and the weight of air in the tank.

■ **Figure E1.3*a*** (Photograph courtesy of Jenny Products, Inc.)

SOLUTION

The air density can be obtained from the ideal gas law (Eq. 1.8)

$$\rho = \frac{p}{RT}$$

so that

$$\rho = \frac{(50 \text{ lb/in.}^2 + 14.7 \text{ lb/in.}^2)(144 \text{ in.}^2/\text{ft}^2)}{(1716 \text{ ft} \cdot \text{lb/slug} \cdot {}^\circ\text{R})[(70 + 460)^\circ\text{R}]}$$

$$= 0.0102 \text{ slugs/ft}^3 \qquad \textbf{(Ans)}$$

Note that both the pressure and temperature were changed to absolute values.

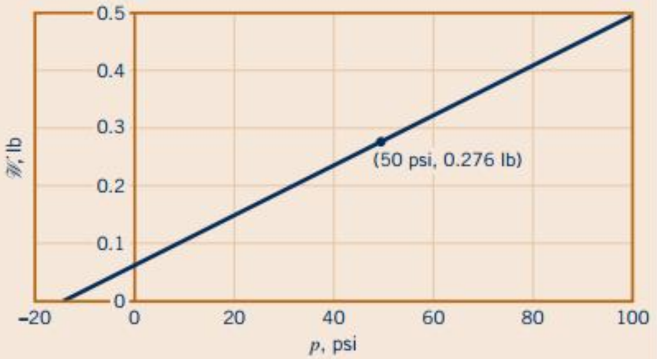
The weight, $\mathcal{W}$, of the air is equal to

$$\mathcal{W} = \rho g \times (\text{volume})$$
$$= (0.0102 \text{ slug/ft}^3)(32.2 \text{ ft/s}^2)(0.84 \text{ ft}^3)$$
$$= 0.276 \text{ slug} \cdot \text{ft/s}^2$$

so that since 1 lb = 1 slug · ft /s^2

$$\mathcal{W} = 0.276 \text{ lb} \qquad \textbf{(Ans)}$$

COMMENT By repeating the calculations for various values of the pressure, p, the results shown in Fig. E1.3*b* are obtained. Note that doubling the gage pressure does not double the amount of air in the tank, but doubling the absolute pressure does. Thus, a scuba diving tank at a gage pressure of 100 psi does not contain twice the amount of air as when the gage reads 50 psi.



■ **Figure E1.3*b***

3- Viscosity (اللزوجة)

The fluid properties such as density and specific weight are measures of the "heaviness" of a fluid. These properties are not sufficient to characterize how fluids behave. Two fluids like water and oil can have approximately the same value of density but behave quite differently when flowing.

So, there are certain secondary variables which characterize specific behavior. The most important of this is *viscosity*, which relates the local stresses in moving fluid to the strain rate of the fluid element.

اللزوجة : مقياس مقاومة المائع لجهد القص او التشوه الزاوي.

The viscosity of a fluid is a measure of its resistance to deformation at a given rate.

To add additional property, consider a hypothetical experiment in which a material is placed between two very wide parallel plates as shown in Figure (a) below.
The bottom plate is rigidly fixed, but the upper plate is free to move.

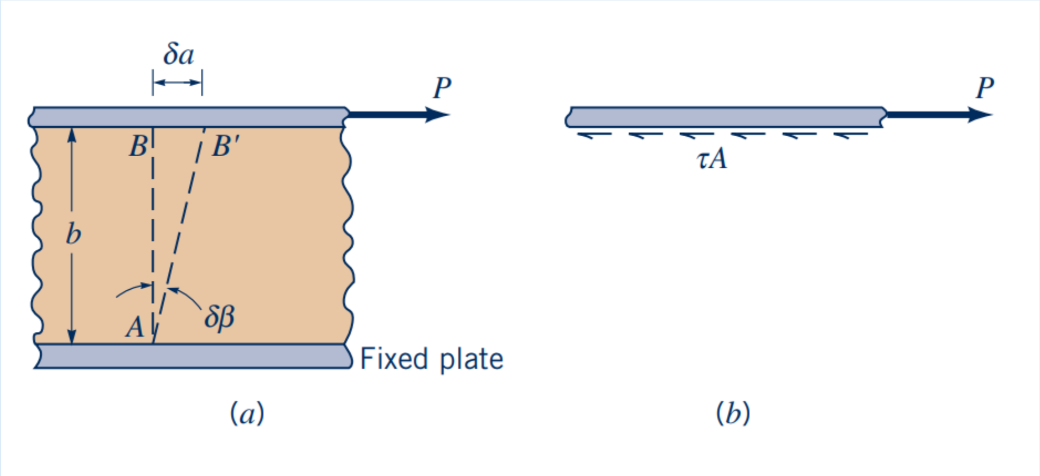
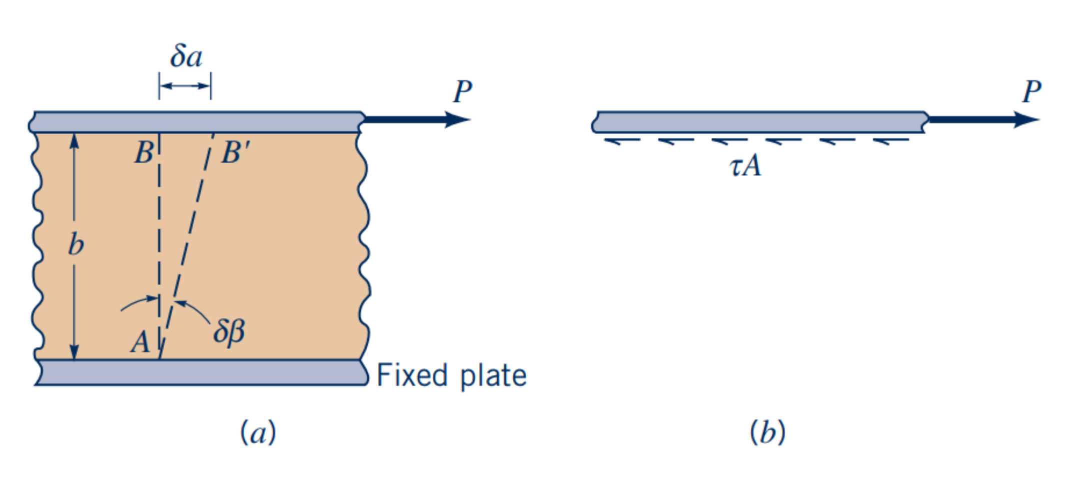


Figure (a) Deformation of material placed between two parallel plates.
Figure (b) Forces acting on upper plate.

If a solid, such as steel, were placed between the two plates and loaded with the force P as shown, the top plate would be displaced through some small distance, δa. The vertical line AB would be rotated through the small angle, $\delta\beta$, to the new position AB'.

We note that to resist the applied force, P, a shearing stress τ (جهد القص), would be developed at the plate–material interface, and for equilibrium to occur, $P = \tau A$ where A is the effective upper plate area (Fig. b).



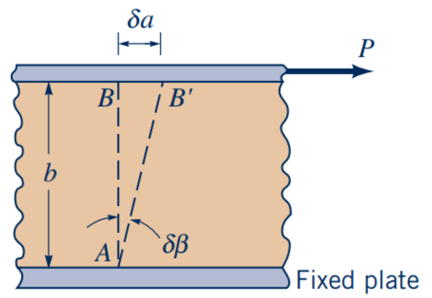
Shear stress τ (Tau)
SI unit Pascal (N/m^2)

The formula to calculate average shear stress is force per unit area $\tau = \frac{F}{A}$

Shear stress, Force acts parallel to the area.

جهد القص يكون بنفس مقطع المادة العرضي. وينشأ من تطبيق القوة بشكل موازي للمقطع العرضي للمادة.

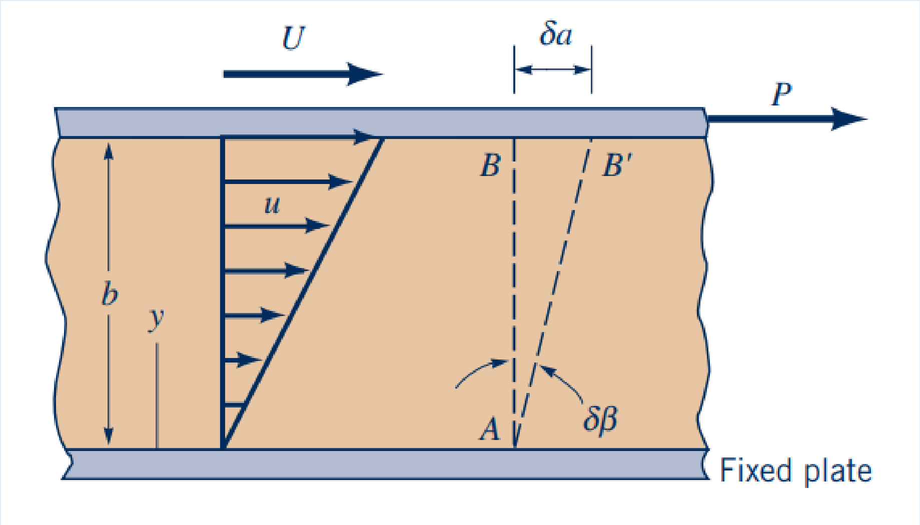
For elastic solids, such as steel, the small angular displacement $\delta\beta$, called the (*shearing strain*) جهد الالتواء, is proportional to the shearing stress τ, that is developed in the material.



(a)

يتناسب الـ Shear strain مع الـ Shear stress.

If there is a fluid such as water between the plates, what happens?
When the force ***P*** is applied to the upper plate, it will move continuously with a velocity, U.
If a shearing stress is applied to a fluid, it will deform continuously.



Behavior of fluid placed between two parallel plates

U - Upper plate velocity.
Zero velocity for the fluid which contact with the bottom fixed plate.
u=u(y) the velocity of fluid between the two plates.
$u = Uy/b$
$du/du = U/b$ (velocity gradient)
(انحدار السرعة)

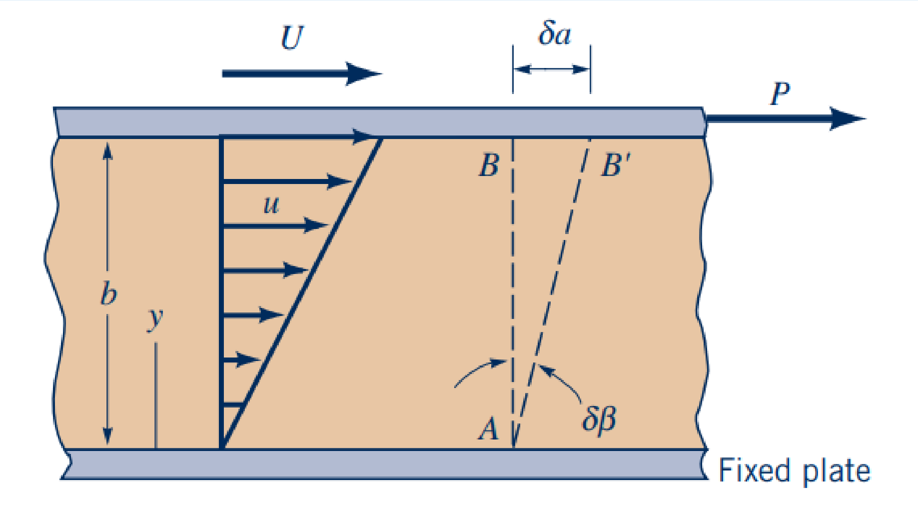
In a small time increment, δt ,an imaginary vertical line AB in the fluid would rotate through an angle, $\delta\beta$, so that

$$tan\delta\beta \approx \delta\beta = \frac{\delta a}{b}$$

Since $\delta a = U\,\delta t\ldots$

$$\delta\beta = \frac{U\delta t}{b}$$

We note that in this case, $\delta\beta$ is a function not only of the force P (which governs U) but also of time.



Behavior of fluid placed between two parallel plates we consider the rate at which is changing and define the *rate of shearing strain*, as

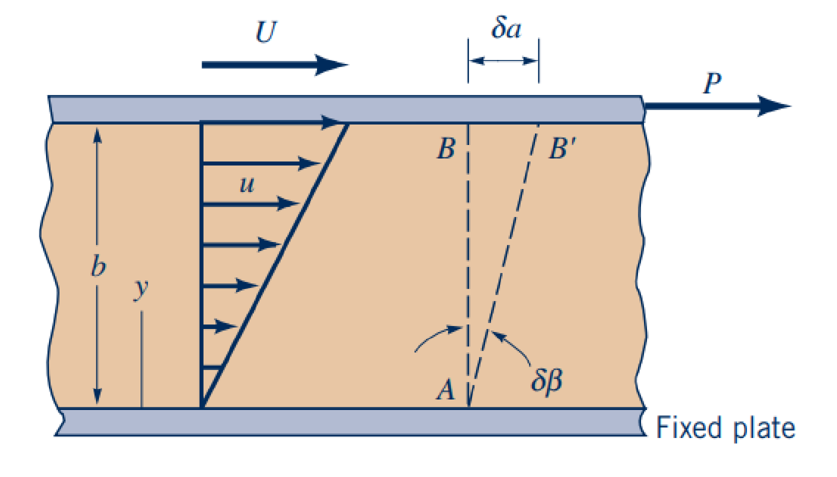
$$\dot{\gamma} = \frac{U}{b} = \frac{du}{dy}$$

Shearing stress τ, is increased by increasing *P* (*τ =P/A*) , and the *rate of shearing strain* is increased also.

$$\tau \propto \dot{\gamma}$$

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

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

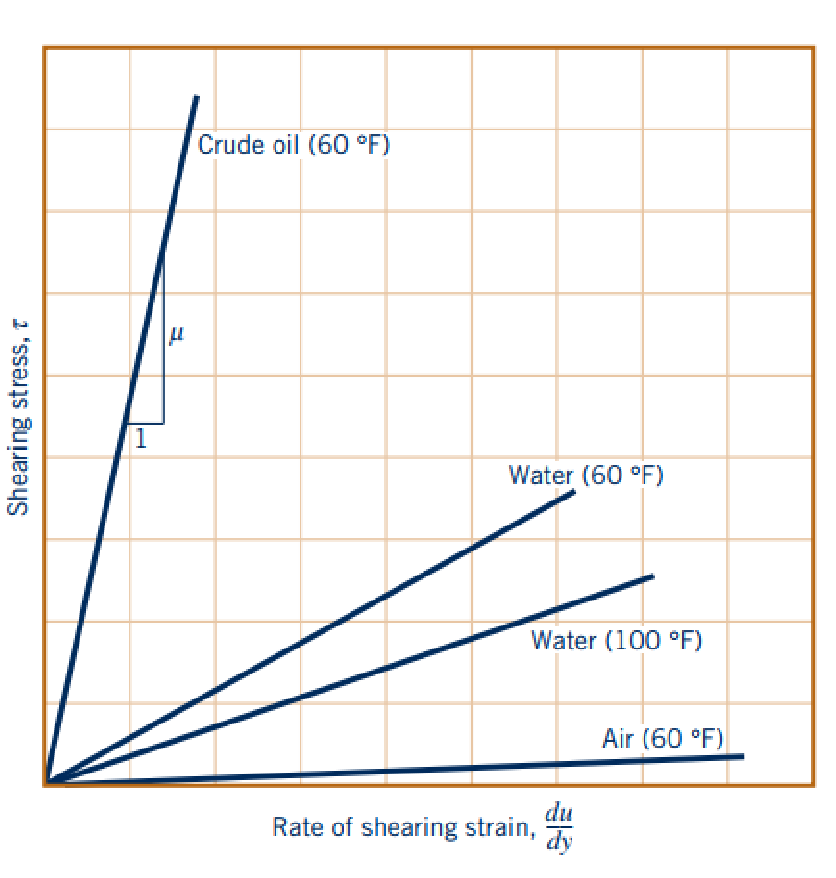


Behavior of fluid placed between two parallel plates

where the constant of proportionality is designated by the Greek symbol μ (mu) and is called the *absolute viscosity*, *dynamic viscosity* , or simply the *viscosity* of the fluid.

The plots of τ versus du/dy should be linear with the slope equal to the viscosity as illustrated in figure.

Newtonian fluids: Fluids for which the shearing stress is linearly related to the rate of shearing strain (also referred to as rate of angular deformation).
Most common fluids, both liquids and gases, are **Newtonian**.



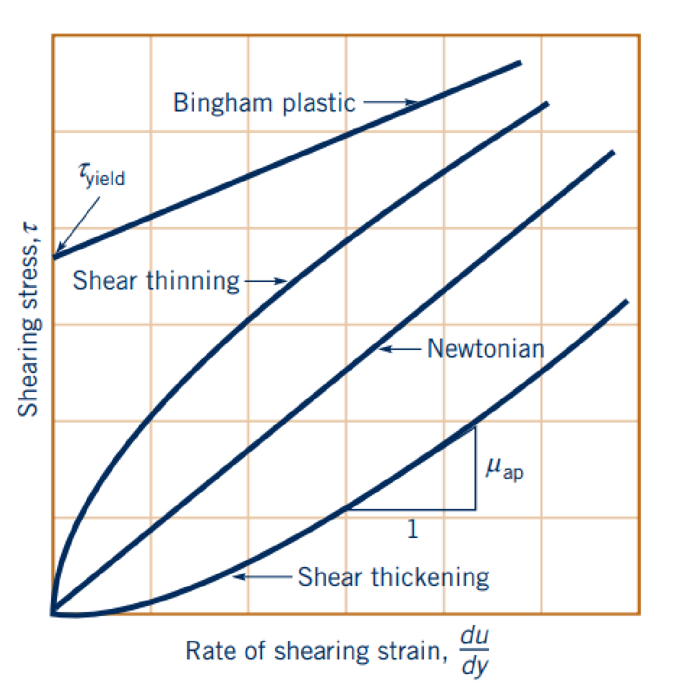
Linear variation of shearing stress with rate of shearing strain for common fluids

Non-Newtonian fluids: **Fluids for which the shearing stress is not linearly related to the rate of shearing strain.**

Bingham plastics **are materials that behave as neither a fluid nor a solid. At shear stresses less than yield stress, Bingham plastics behave as a solid and at shear stresses higher than yield stress it behaves as a fluid.**

The dimensions of viscosity are FTL^{-2}.
The units of viscosity in BG system is given as $lb.s/ft^2$ and in SI units as $N.s/m^2$.

Table 7 & 8 show the value of Viscosity for different liquids.



Variation of shearing stress with rate of shearing strain for several types of fluids, including common non-Newtonian fluids