Dept. of Chem. & Petrochemical Engineering
Subject : Physics
First Stage

Physics

Chapter 8– Fluid Mechanics

lecturer
Dr. Mohammed Jasim

States of Matter

Solid

- Has a definite volume and shape

Liquid

- Has a definite volume but not a definite shape

Gas – unconfined

- Has neither a definite volume nor shape

Fluids

A fluid is a collection of molecules that are randomly arranged and held together by weak cohesive forces and by forces exerted by the walls of a container.

Both liquids and gases are fluids.

Fluids do not sustain shearing stresses or tensile stresses.

The only stress that can be exerted on an object submerged in a static fluid is one that tends to compress the object from all sides.

The force exerted by a static fluid on an object is always perpendicular to the surfaces of the object.

Viscosity

Real fluids (especially liquids) exhibit a kind of internal friction called *viscosity*. Fluids that flow easily (like water and gasoline) have a fairly low viscosity; liquids like molasses that are "thick" and flow with difficulty have a high viscosity.

There are two different types of viscosity defined. The more common is *dynamic viscosity*, the other is *kinematic viscosity*.

Dynamic Viscosity

When a body is placed under transverse (shear) stress σ = Ft/A, the resulting strain ε is the tangential displacement x divided by the transverse distance l:

$$\sigma = E\varepsilon$$

$$\frac{F_t}{A} = S\,\frac{x}{l}$$

where S is the shear modulus. Fluid flow undergoes a similar kind of shear stress; however, with fluids, we find that the stress is not proportional to the strain, but to the *rate of change* of strain:

$$\frac{F_t}{A} = \mu\frac{d}{dt}\frac{x}{l} = \mu\frac{v}{l}$$

Dynamic Viscosity

where v is the fluid velocity. The proportionality constant , which takes the place of the shear modulus, is the *dynamic viscosity*. The SI units of dynamic viscosity are Pascal-seconds (Pa s). Other common units are the *poise* (1 P = 0.1 Pa s) and the *centipoise* (1 cP = 0.001 Pa s).

Viscosity, especially liquid viscosity, is temperature dependent. You've probably noticed this from everyday experience: refrigerated maple syrup is fairly thick (high viscosity), but if you warm it on the stove it becomes much thinner (low viscosity).

Kinematic Viscosity ν.

The kinematic viscosity is defined as the dynamic viscosity divided by the density:

$$\nu = \frac{\mu}{\rho}$$

SI units for kinematic viscosity are m^2/s. Other common units are *stokes* (1 St = 10^{-4} m^2/s) and *centistokes* (1 cSt = 10^{-6} m^2/s).

Viscosities of common liquids (room temperature).

Liquid	Dynamic viscosity μ (Pa s)	(cP)
gasoline	5×10^{-4}	0.5
water	8.9×10^{-4}	0.89
mercury	0.0016	1.6
olive oil	0.09	90
ketchup	1.3	1300
honey	5	5000
molasses	7	7000
peanut butter	250	250,000

Surface tension

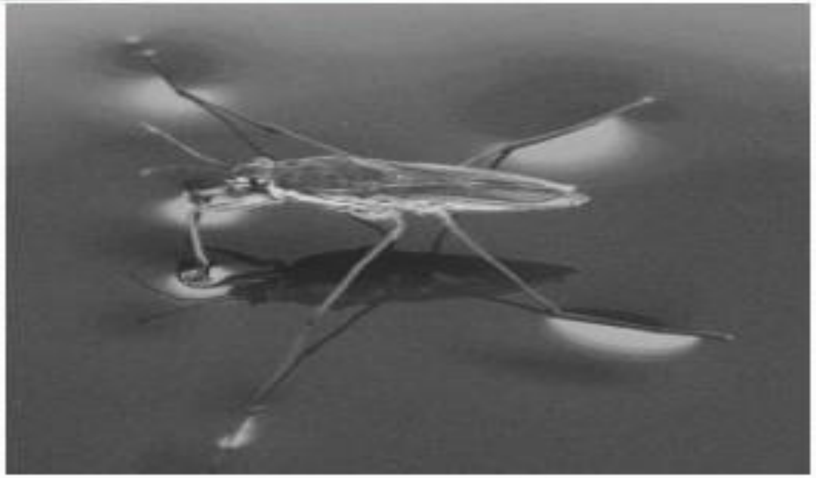
A fluid is matter that has no definite shape and adjusts to the container that it is placed in.

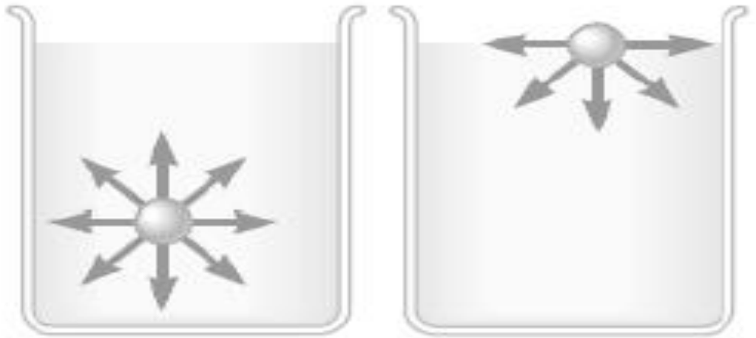
Gases and liquids are both fluids. All fluids are made of molecules. Every molecules attracts other molecules around it.

Liquids exhibit surface tension. A liquid has the property that its free surface tends to contract to minimum possible area and is therefore in a state of tension.

The surface tension of the water allows the insect to walk on the water without sinking.

The molecules of the liquid exerts attractive forces on each other, which is called **cohesive forces**. Deep inside a liquid, a molecule is surrounded by other molecules in all directions. Therefore there is no net force on it. At the surface, a molecule is surrounded by only half as many molecules of the liquid, because there are no molecules above the surface.





Surface tension, definition

The force of contraction is at right angles to an imaginary line of unit length, tangential to the surface of a liquid, is called its **surface tension**:

$$\gamma = \frac{F}{L}$$

. Here F is the force exerted by the "skin" of the Liquid. The SI unit of the surface tension is N/m.

Liquid	Surface Tension γ (N/m)
Benzene (20 °C)	0.029
Blood (37 °C)	0.058
Glycerin (20 °C)	0.063
Mercury (20 °C)	0.47
Water (20 °C)	0.073
Water (100 °C)	0.059

Why are soap bubbles spherical?

Generally, a system under the influence of forces moves towards an equilibrium configuration that corresponds to minimum potential energy. The sphere contains the most volume for the least area ⇒ minimum surface potential energy. There are no cubic raindrops.

Capillary Action

The molecules of the liquid exerts attractive forces on each other, which is called **cohesive forces**.

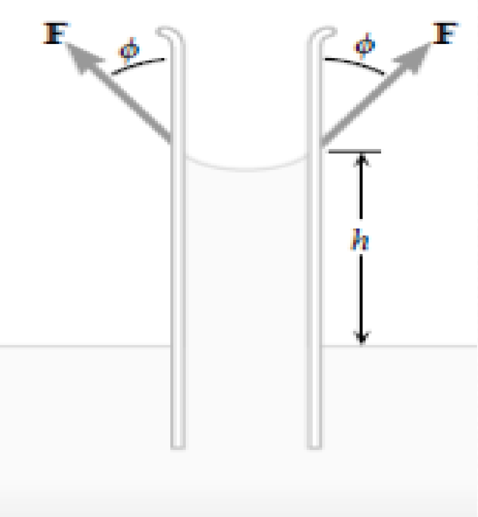
When liquids come into contact with a solid surface, the liquid's molecules are attracted by the solid's molecules (called **adhesive forces**).

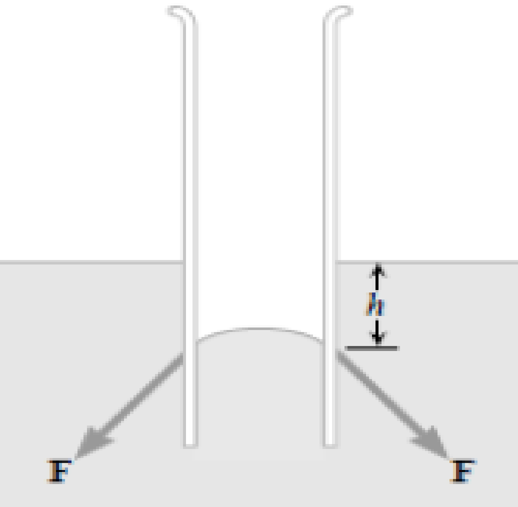
If these adhesive forces are stronger than the cohesive forces, the liquid's molecules are pulled towards the solid surface and liquid surface becomes curved inward (e.g. water in a narrow tube).

If cohesive forces are stronger the surface becomes curved outwards (e.g. with mercury instead).

This also explains why certain liquids spread when placed on the solid surface and wet it (e.g., water on glass) while others do not spread but form globules (e.g., mercury on glass).

The behavior of the liquids in both Figures is called ***capillary action***.





Pressure

The **pressure** *P* of the fluid at the level to which the device has been submerged is the ratio of the force to the area.

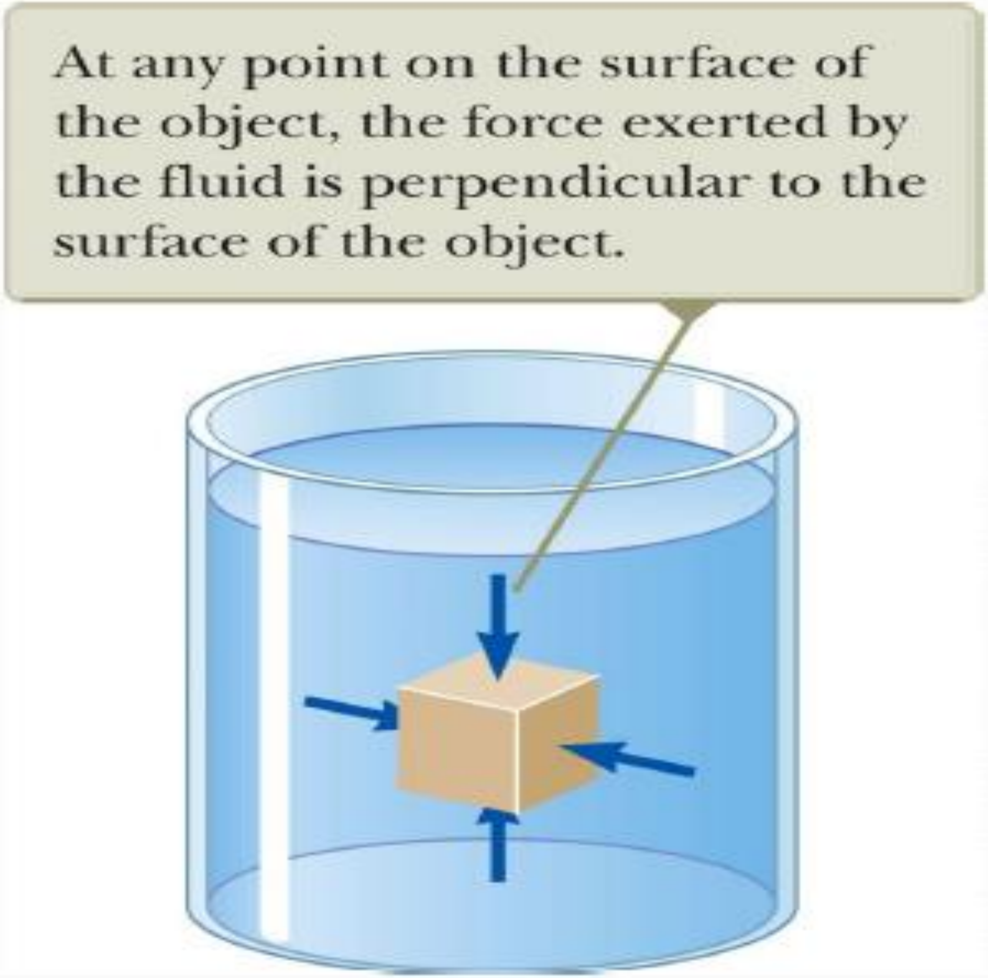
Pressure is a scalar quantity.

- Because it is proportional to the magnitude of the force.

If the pressure varies over an area, evaluate *dF* on a surface of area *dA* as $dF = P\,dA$.

Unit of pressure is **pascal** (Pa)

$1\,\text{Pa} = 1\,\text{N/m}^2$



Density Notes

Density is defined as the mass per unit volume of the substance.

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

where r is the density, m is the mass of the substance and V is the Volume. The unit of density in SI unit system is kg/m^3.

The values of density for a substance vary slightly with temperature since volume is temperature dependent.

The various densities indicate the average molecular spacing in a gas is much greater than that in a solid or liquid.

Substance	ρ (kg/m^3)	Substance	ρ (kg/m^3)
Ice	0.917×10^3	Water	1×10^3
Aluminum	2.7×10^3	Glycerine	1.26×10^3
Iron	7.86×10^3	Ethyl alcohol	0.8×10^3
Copper	8.92×10^3	Benzene	0.88×10^3
Silver	10.5×10^3	Mercury	13.6×10^3
Lead	11.3×10^3	Air	1.29
Gold	19.3×10^3	Oxygen	1.43
Platinum	21.4×10^3	Hydrogen	910^3
		Helium	1.8×10^3

Variation of Pressure with Depth

If a fluid is at rest in a container, all portions of the fluid must be in static equilibrium.

All points at the same depth must be at the same pressure.

Examine the darker region, a sample of liquid within a cylinder.

- It has a cross-sectional area A.
- Extends from depth d to d + h below the surface.

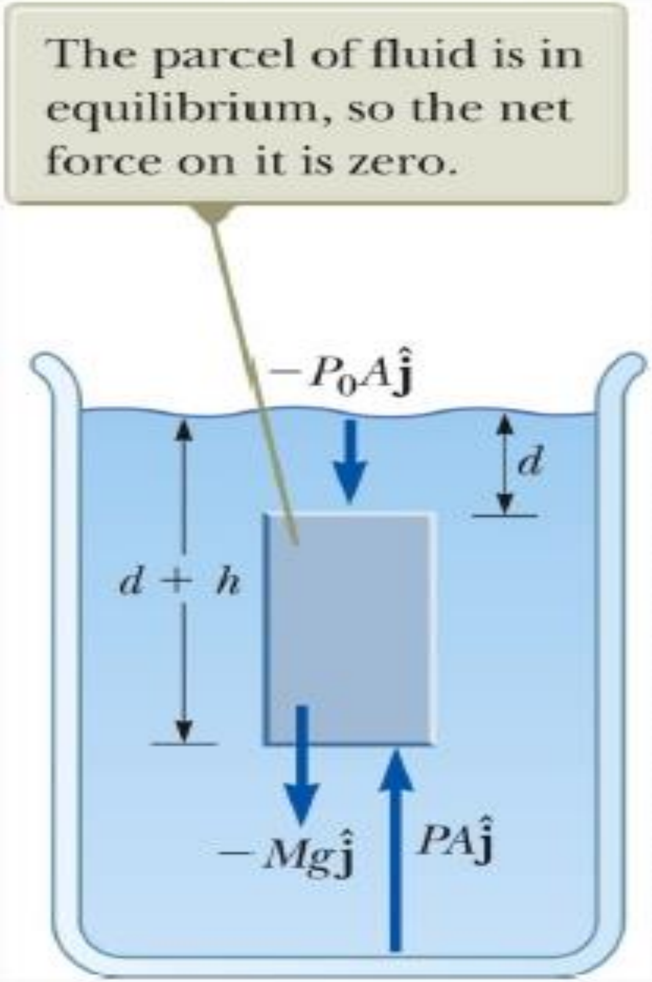
Three external forces act on the region.

The liquid has a density of ρ.

- Assume the density is the same throughout the fluid.

The three forces are:

- Downward force on the top, P_0A
- Upward on the bottom, PA
- Gravity acting downward, Mg
  - The mass can be found from the density: $M = \rho V = \rho A h$.



Pressure and Depth, final

Since the net force must be zero:

$$\sum \vec{\mathbf{F}} = PA\hat{\mathbf{j}} - P_o A\hat{\mathbf{j}} - Mg\hat{\mathbf{j}} = 0$$

- This chooses upward as positive.

Solving for the pressure gives

- $P = P_0 + \rho g h$

The pressure P at a depth h below a point in the liquid at which the pressure is P_0 is greater by an amount $\rho g h$.

Atmospheric Pressure

If the liquid is open to the atmosphere, and P_0 is the pressure at the surface of the liquid, then P_0 is *atmospheric pressure.*

$P_0 = 1.00 \text{ atm} = 1.013 \times 10^5 \text{ Pa}$