LECTURE 5

18 - JAN - 2016

SECONDARY PROPERTIES OF FLUID

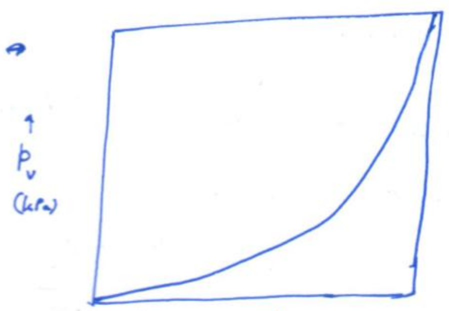
* In the last class, we described about <u>viscosity</u>.
* Subsequently we mentioned about Newtonian and Non-Newtonian fluids.
* We worked out an example problem on <u>shear stress</u>.
* In the class notes, we described about another fluid property — <u>vapor pressure</u>.
* Due to time constraint, that portion was not lectured. However, I hope that you might have gone through those portions in the lecture notes.

Revisiting them:

Vapor Pressure

→ It is the pressure at which a liquid boils and is in equilibrium with its own vapor.

→



→ The curve here shows the equilibrium vapor pressure at which liquid boils.

→ This vapor pressure curve is also called <u>saturated vapor pressure curve</u>.

→ If the liquid pressure is greater than the saturated vapor pressure, the only exchange between liquid and vapor is evaporation at interface

→ If the liquid pressure (or ambient pressure) falls below the vapor pressure, vapor bubbles begin to appear in the liquid.

→ When the liquid pressure drops below the saturated vapor pressure due to flow phenomenon, the process is called <u>CAVITATION</u>.

Note: → If water is accelerated from rest to approx- -imately 15 m/s, the pressure of it drops by nearly 1 atm.

You know, $1 \text{ atm} = 1.01325 \times 10^5 \ N/m^2$
$= 101.325 \ kPa$

→ When water is heated to 100°c, its vapor pressure will be 101.325 kPa.

→ As told earlier, there can be flow induced reduction in ~~vapor~~ ambient pressure.

Cavitation Number, $C_a = \dfrac{P_a - P_v}{\frac{1}{2} \rho V^2}$

P_a → ambient liquid pressure
P_v → vapor pressure
V → characteristic flow velocity
ρ → density of fluid.

Example: (As adopted from FM White's "Fluid Mechanics")

A torpedo moving in fresh water at 15°c. The minimum pressure point is $p_{min} = p_o - 0.35\rho V^2$, where p_o is given as 120 kPa, ρ is water density, V is torpedo velocity. Estimate the velocity at which cavitation bubbles will form on torpedo. The density vs temperature as well as vapor pressure vs temperature data are as given.

T°c	ρ (kg/m³)
0	1000
10	1000
20	998
30	996

T°c	p_v (kPa)
0	0.611
10	1.227
20	2.337
30	4.242
40	7.375
⋮	⋮

Solution

Cavitation bubbles start to form when liquid pressure equals the vapor pressure at that temperature.

→ So let $p_{min} = p_v$ for this problem.

$$p_{min} = p_o - 0.35\,\rho V^2 = 120\times10^3 - 0.35 * 999 * V^2$$

$$p_v \text{ at } 15°c \approx 1.80 \text{ kPa} = 1800 \text{ Pa}$$

$$\therefore\ 1800 = 120\times10^3 - 0.35 * 999 * V^2$$

$$\therefore\ V^2 = 338, \text{ or } \underline{\underline{V = 18.4 \text{ m/s}}}$$

Surface Tension

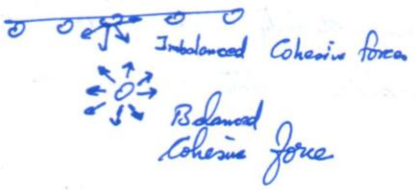
It is the maximum energy level a fluid can store without breaking apart.

→ It describes the interface between two fluids

* say air - water interface

oil - water interface, etc.

→ Interfacial tension acts between two fluids

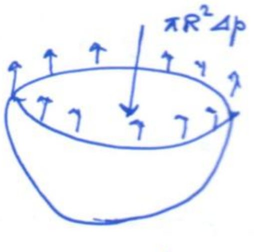


→ You can see imbalanced cohesive forces for the fluid molecules at the interface.

→ These imbalanced forces create tension in the interface. It can be given as σ (N/m).

→ At static equilibrium the interface forces and other forces should balance.

e.g. If the interface is curved, the mechanical balance shows that there is a pressure difference across the interface.

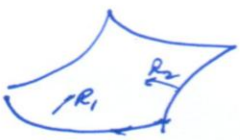


$$\pi R^2 \Delta p = 2\pi R \sigma$$

or $$\Delta p = \frac{2\sigma}{R}$$

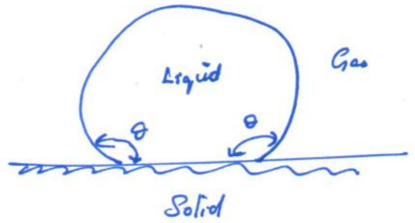
e.g: In a ~~soap bubble~~ droplet

$$\Delta p_{droplet} = \frac{2\sigma}{R}.$$



Balancing force, $$\Delta p = \sigma\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

→ The droplet on a solid surface will be having contact angle, θ.



→ The contact angle θ suggests something about liquid - gas - solid interface.

If $\theta < 90^\circ$; liquid wets the solid

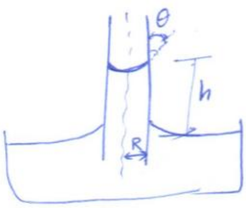
If $\theta > 90^\circ$; liquid is non-wetting

→ While doing equilibrium (or static) force balance, the contact angle also needs to be taken.

→ The capillary rise in tubes also depends on surface tension. See the following example.

Example (Adopted from FM WHITE's Fluid Mechanics)

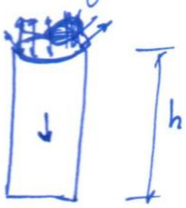
Derive the expression for change in height 'h' in a circular tube of liquid with surface tension, σ and contact angle θ.



Solution.

In static equilibrium, the forces should balance in each direction.

Let us balance forces in vertical direction ~~at the interface~~ in the free body diagram



Force due to weight $= \rho g \pi R^2 h$

Surface tension force $= 2\pi R \sigma \cos\theta$

$\Sigma F_y = 0$; $2\pi R\sigma \cos\theta - \rho g \pi R^2 h = 0$

or $$h = \frac{2\sigma \cos\theta}{\rho g R}$$

→ The capillary height increases inversely with the capillary tube radius R.

⇒ In due course, you will see what is

* Streamline
* Pathline
* Streakline

⇒ We will be using

* Control-volume or integral analysis
* Infinitesimal system or differential analysis
* Experimental study or the dimensional analysis

for studying fluid mechanics

⇒ Recall the fundamental laws like:

* Conservation of mass
* Conservation of linear momentum
* Conservation of energy, etc.

LECTURE 6

19-JAN-2016

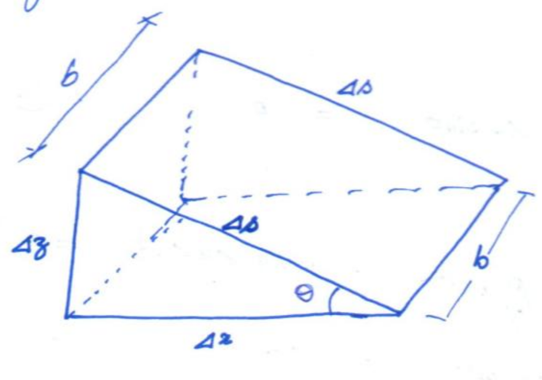
PRESSURE DISTRIBUTION IN A FLUID

→ When the fluid velocity is zero, we call it as hydrostatic conditions.

→ The pressure of the liquid varies with respect to the weight of fluid.

→ As discussed earlier, a fluid at rest cannot support shear stress

→ Let us describe the equilibrium of forces (static liquid) of a small wedge of fluid at rest.



→ Recall your engineering mechanics study about free body diagrams. As this is static liquid all the forces need to be balanced.

Obvious, from the figure, the forces in y-direction balance. Still we can work it out.

$\Sigma F_x = 0$; $\Sigma F_y = 0$; $\Sigma F_z = 0$.

As it is a static liquid, let us suggest that forces act into the plane in respective directions.

→ Let p_x be force per unit area acting on the plane $b\Delta z$.

→ Let p_z be the force per unit area acting on the plane $b\Delta x$

→ p_y be the force per unit area acting on the planes $\Delta x \Delta z$ in front side and $\Delta x \Delta z$ in back side.

→ p_s be the force per unit area on the plane $b\Delta s$.

∴ For $\Sigma F_y = 0$

$$p_y \Delta x \Delta z - p_y \Delta x \Delta z = 0 \rightarrow (1)$$

(Both forces are same)

For $\Sigma F_x = 0$;

$$p_x b \Delta z - p_s b \Delta s \sin\theta = 0 \rightarrow (2)$$

For $\Sigma F_z = 0$;

$$-p_s b \Delta s \cos\theta + p_z b \Delta x - \frac{1}{2} \rho g \Delta x \Delta z b = 0 \rightarrow (3)$$

From geometry, $\Delta s \cos\theta = \Delta x$

$\Delta s \sin\theta = \Delta z$

∴ In (2); $p_x b \Delta z - p_s b \Delta z = 0$; or $p_x = p_s$

In (3); $-p_s b \Delta x + p_z b \Delta x - \frac{1}{2} \rho g b \Delta x \Delta z = 0$

or $p_z = p_s + \frac{1}{2} \rho g \Delta z$

In $\lim_{\substack{\Delta z \to 0 \\ \Delta x \to 0}}$; $p_z = p_s = p_x = p_y = p$ = pressure

That is at a static point, pressure is a ~~static~~ scalar property without any orientation.