Introduction to Fluid Mechanics:

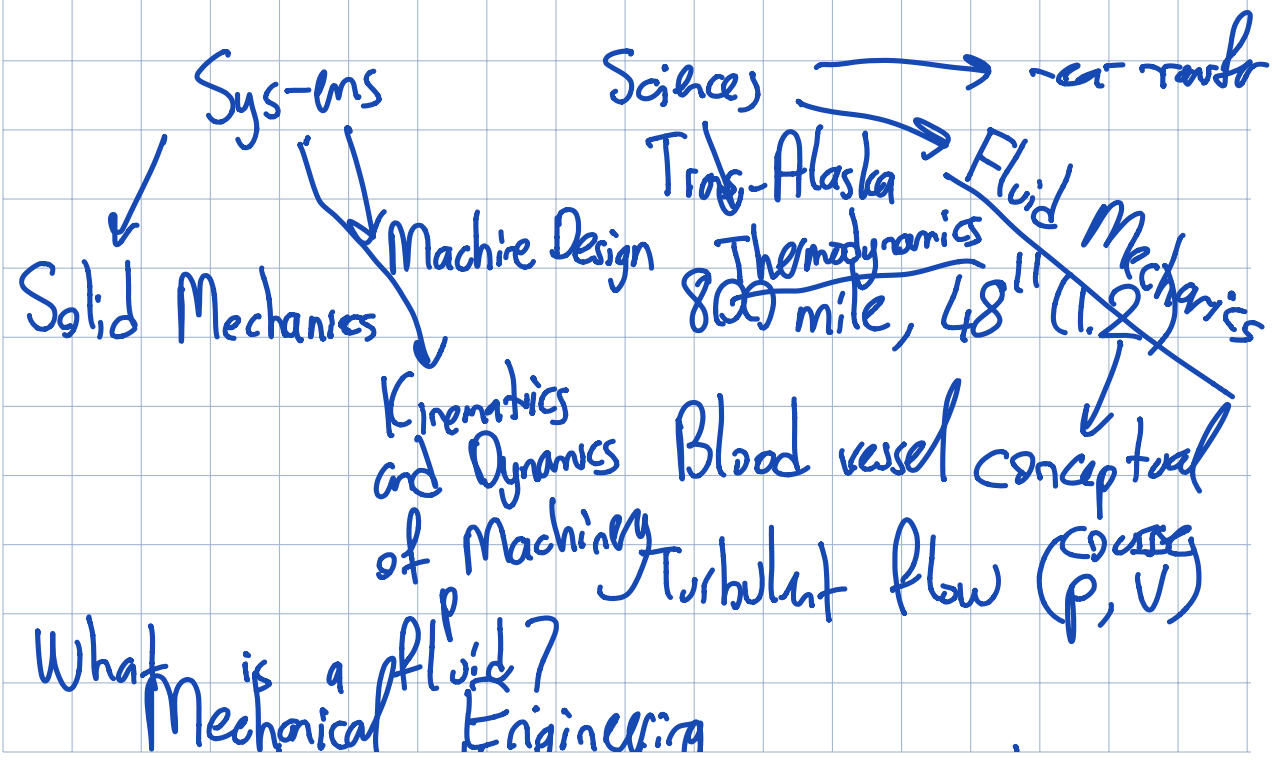
Aerospace

civil

mechanical

electrical/computer

chemical



What is a fluid?

Mechanical Engineering

a substance that deforms continuously when sheared tangential forces

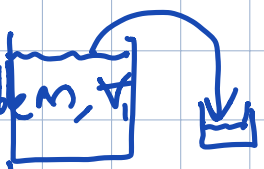
Water, Oil, air, honey, toothpaste, paint

Solid ↔ fluids

shear stress → small deformation in solids
→ fluids infinite deformations

intermolecular forces → strong in solids
weaker in fluids

Fluids → liquids, incompressible
→ gases, compressible



no liquids

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

Systems of Units

→ (SI)

force → Newton (N)
length → meter (m)
time → seconds
mass → kg

→ (BG)

force → pounds (lb)
length → foot (ft)
time → seconds
mass → slug

Important Fluid Properties and Definitions:

Density (ρ) $\quad \rho = \frac{m}{\forall}$ (velocity, volume)

liquids — mass → volume — density is constant for liquids

gases — mass → {range of volume} — density is variable for gases

Specific Weight: (γ)

$\gamma = \rho \cdot g$ → accel. due to gravity

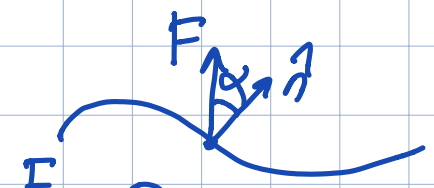
Specific Gravity (S.G.)

$S.G. = \frac{\rho}{\rho_{water\ at\ 4^\circ C}}$

$\rho = 13{,}600$

$S.G. = 13.6$

Pressure (P) ~~force / area~~



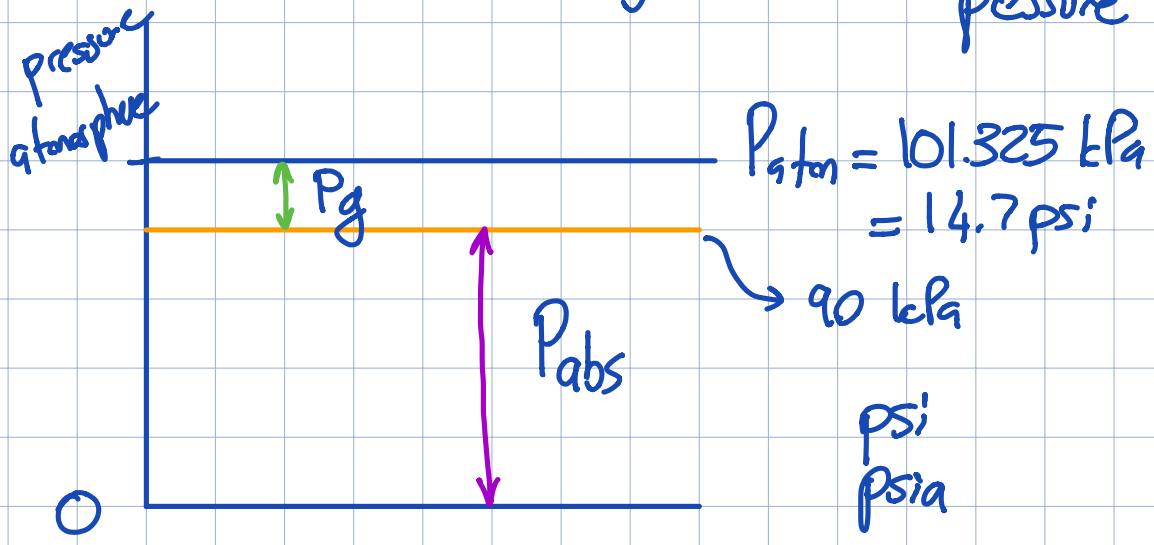
$\frac{F}{A} = P$ $\quad P = \frac{F \cdot \cos\alpha}{A}$

$\frac{\text{normal force component}}{\text{area}} = P$

2 ways of representing pressure

1) Absolute pressure (P_{abs}) datum zero pressure vacuum

2) Gage pressure (P_g) datum atmospheric pressure



$P_{abs} = 90$ kPa

$P_g = P_{abs} - P_{atm}$

(90 − 101.325)

$= (90 - 101.325)$

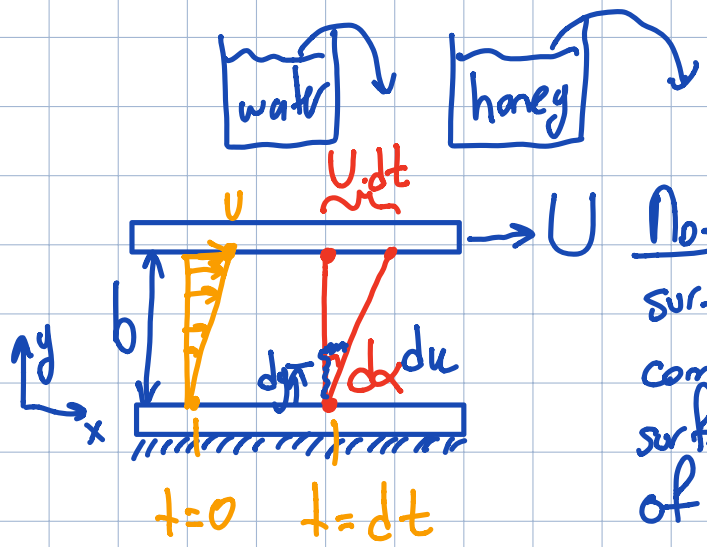
$= -11.325$ kPa

$(P_{atm})_{abs} = 101.325$ kPa

$(P_{atm})_g = 0$ Pa

Viscosity: Fluidity 5W30 0W40

Quantifies the resistance of a fluid being sheared.



No-slip condition: At a solid surface, the fluid velocity component tangent to the surface is equal to that of the surface

$$\tan d\alpha = \frac{U dt}{b} = \frac{du.dt}{dy} \qquad \tan d\alpha = d\alpha$$

$$d\alpha = \frac{du.dt}{dy} \qquad \frac{d\alpha}{dt} = \frac{du}{dy} = \frac{U}{b}$$

Newton's law of viscosity: the shear stress on a surface tangent to the flow direction is proportional to the rate of change shear strain $\left(\frac{d\alpha}{dt}\right)$

$$\tau_w \propto \frac{d\alpha}{dt} = \frac{du}{dy}$$

$$\boxed{\tau_w = \mu \cdot \frac{du}{dy}}$$ for newtonian liquids

$\mu \rightarrow$ absolute viscosity, dynamic viscosity

$\frac{\partial \mu}{\partial T}$ → liquid $\frac{\partial \mu}{\partial T} < 0$

→ gases $\frac{\partial \mu}{\partial T} > 0$

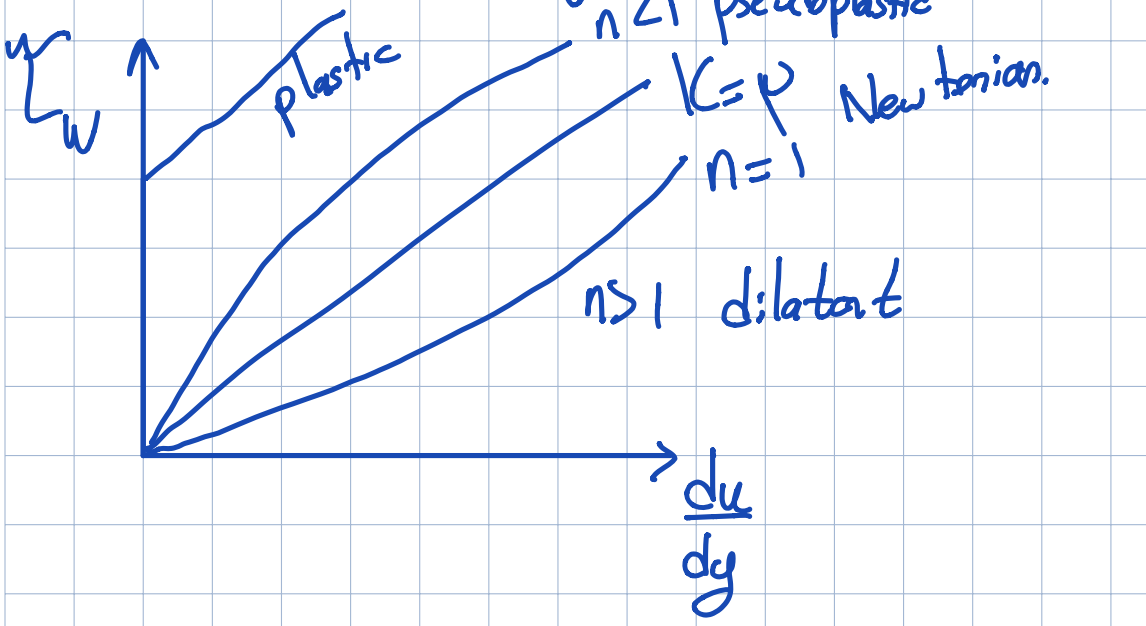
$\nu = \frac{\mu}{\rho}$ kinematic viscosity

Inviscid flow $\Rightarrow (\mu = 0)$

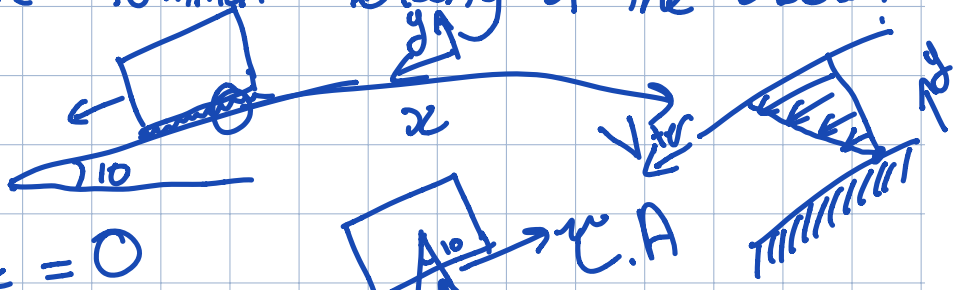
Ostwald-de Waele power-law

$$\tau_w = K \left(\frac{\partial u}{\partial y} \right)^n$$

$K = \mu$ $\quad n = 1$



Example: A 1 kg block slides down 10° inclined surface with 1 mm thick glycerin between the block and the inclined surface. If the block makes a $1 m^2$ contact with the oil, find the terminal velocity of the block?



$$\Sigma F_x = 0$$

$$W.\sin 10 - \tau.A = 0$$

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

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

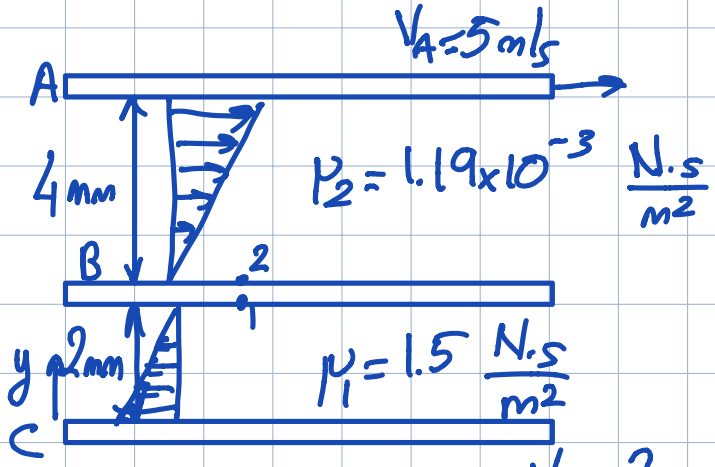
$$W.\sin 10 - \mu.\left(\frac{du}{dy}\right).A = 0$$

$$mg \sin 10 - (1.5)\frac{V_{ter}}{(10^{-3})}.(1) = 0$$

m: 1, g: (9.81)

$$\boxed{V_{ter} = 0.0011 \ m/s}$$

There are three parallel plates in the system as illustrated in the figure below. The top plate A moves to the right with a constant velocity of 5 m/s, while the plates B is stationary. All the neccessary fluid properties and parametes are illustrated in the figure. What should be the speed and direction of plate C?



$$\tau_1 = \mu_1 \cdot \frac{du_1}{dy} \qquad \tau_1 \cdot A = F$$

$$\tau_2 = \mu_2 \cdot \frac{du_2}{dy} \qquad \tau_2 \cdot A = F$$

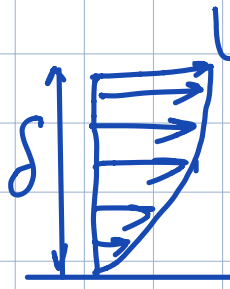
$$\left(\mu_1 \cdot \frac{du_1}{dy}\right) = \left(\mu_2 \cdot \frac{du_2}{dy}\right)$$

$$\left(\mu_1 \cdot \frac{5}{2}\right) = \left(\mu_2 \cdot \frac{}{}\right)$$

$$(1.5)\left(\frac{0-V}{2\times10^{-3}}\right)=(1.19\times10^{-3})\left(\frac{5-0}{\frac{1.4\times10^{-3}}{2}}\right)$$

$$-3V=(5)(1.19\times10^{-3}) \Rightarrow \boxed{V=-0.02\ m/s}$$

Wind passing the top of a building creates a boundary layer. The velocity profile within the boundary layer is as shown in the figure below. Determine the magnitude of the force exerted on the building as a function of the boundary layer thickness (δ), wind velocity (U) and the surface area of the building (A). Take the viscosity of air as $18\times10^{-6}\ \frac{N.s}{m^2}$.



$$\frac{u(y)}{U}=2\left(\frac{y}{\delta}\right)-\left(\frac{y}{\delta}\right)^2$$

$$\tau=\mu.\frac{du}{dy} \qquad u(y)=\left[2\left(\frac{y}{\delta}\right)-\left(\frac{y}{\delta}\right)^2\right]U$$

$$\frac{du}{dy}=U.\left[\frac{2}{\delta}-\frac{2y}{\delta^2}\right]$$

$$\tau = \mu . U . \left[\frac{2}{\delta} - \frac{2y}{\delta^2} \right]$$

$$\tau . A = F = \mu . U . A \left[\frac{2}{\delta} - \frac{2}{\delta^2} . y \right]$$

$$F \Big|_{y=0} = \mu . U . A \left[\frac{2}{\delta} - \cancel{\frac{2}{\delta^2} y} \right] \Bigg|_{y=0}$$

$$F = \frac{2 . \overset{18 \times 10^{-6}}{\mu} . U . A}{\delta}$$

$$\boxed{F = \frac{(36 \times 10^{-6}) U . A}{\delta}}$$

Compressibility of Fluids:

Measure of how the volume ($\forall$) of a given mass of a fluid changes w.r.t Pressure.

Characterized by bulk modulus, $E_v = -\frac{dp}{\frac{d\forall}{\forall}}$

Gases are highly compressible.

Liquids are incompressible

Compression/Expansion ⟶ constant T
isothermal process

$$\frac{p}{\rho} = \text{const}$$

Compression/Expansion ⟶ frictionless, no heat exchange with the surrounding
isentropic process

$$\frac{p}{\rho^k} = \text{const} \qquad k = \frac{c_p}{c_v}$$

k: specific heat ratio

c_p: specific heat at constant T

c_v: specific heat at constant Volume

$$R = c_p - c_v$$

Mach Number $M = \frac{V}{c}$

$$c = \sqrt{\frac{E_v}{\rho}} \qquad c = \sqrt{kRT}$$ isentropic process

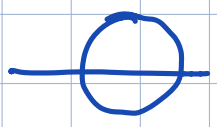
$c = 343$ m/s air

$c = 1481$ m/s water

$M < 0.3$ compressibility effects are negligible.

Surface Tension: σ

measure of the force at the interface between 2 immiscible fluids



liquid drop

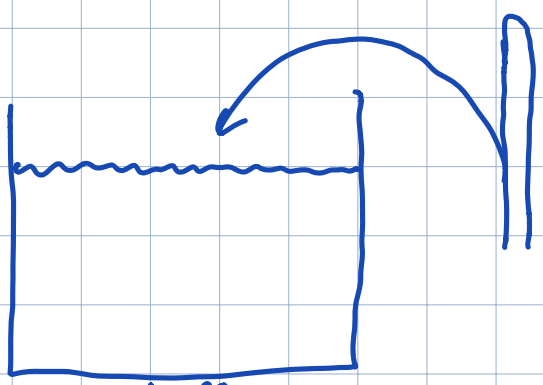
$\sigma \cdot (2\pi r)$

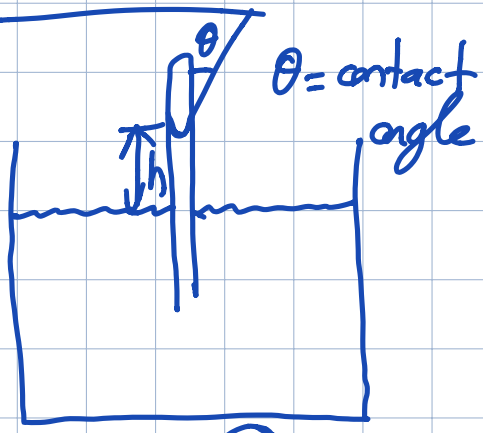
$\Delta p \cdot \pi r^2$

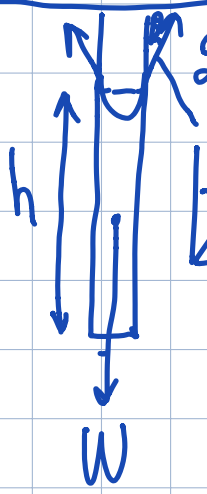
$\sigma \cdot 2\pi r = \Delta p \cdot \pi r^2$

$$\Delta p = \frac{2V}{r}$$

$$\Delta p = \frac{4V}{D}$$







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

$$\text{weight} = mg = \rho . \forall . g = \gamma . \forall$$

$$\forall = (\pi r^2) . h$$

$$2\pi r . \gamma . \cos\theta = \gamma . \pi r^2 . h$$

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