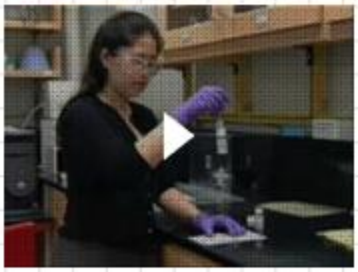
First Lecture

Who is stronger a solid or a fluid?

Cutting An Anvil In Half With A 60,000 PSI Waterjet - whats inside an Anvil? - Scandal

Watch from min 2:10 onwards

Liquid Bullet-Proof Armour



Our Goals for Today (lect. 2)

1. Understand shear stress in liquids
2. Viscosity & its temperature and pressure dependance

Before we start... What are we after in Studying Fluid Dynamics?

1. Pressure field/values
2. Velocity Field
    a. Work
    b. Forces
    c. Power
    d. Losses
        i. Pressure
        ii. Drag/resistive force

What is the main difference between a solid and a liquid?

- Fluids do not keep their shape under any stress
- Stems from ability of liquid molecules to move around

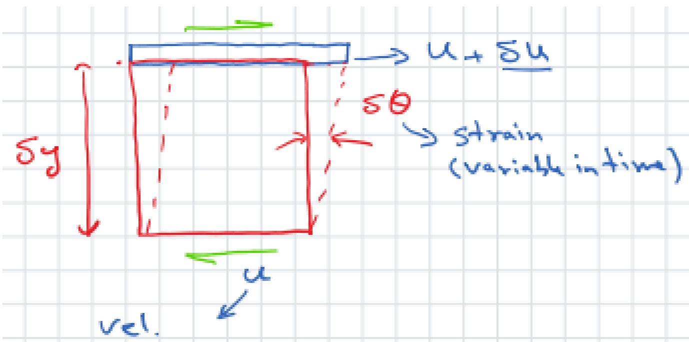
Aside: the terms Fluid Dynamics and Fluid Mechanics are used interchangeably in this course and mean largely the same thing

Solid vs Fluid

A solid can resist a shear stress (τ) by a static deformation, but a fluid cannot!

What happens when a fluid experiences a shear stress?

It flows!



At a given time, δt, The larger the τ, the larger will be $\delta\theta$, so $\tau \propto \frac{1}{\delta t}$

$$\therefore \tau \propto \frac{\delta\theta}{\delta t} \ (1)$$

A constant shear stress, causes a strain ($\delta\theta$) that is changing with time, at a rate of $\frac{\delta\theta}{\delta t}$.

Eq (1) → $\tau = \mu \frac{\delta\theta}{\delta t}$ (2) Newton's law for viscosity

Where μ is the viscosity (proportionality constant)

Viscosity is the resistance of a fluid to motion.

$\frac{N}{m^2} = \mu \frac{\theta}{\delta}$ → μ unit is $\frac{N \cdot s}{m^2}$ or $\frac{kg}{m \cdot s}$

$\mu_{water} = 1 \times 10^{-3} kg/m \cdot s$ or 1 cP (centi-poise)

$\mu_{air} = 1.8 \times 10^{-5} kg/m \cdot s$

Viscosity is a thermodynamic property, so: $\mu = \mu(T, P)$

Where T = temperature and P = Pressure

μ changes significantly with temperature.

For gases,

$$\frac{\mu}{\mu_O} = (\frac{T}{T_O})^n$$

Known μ_O at T_O (273K)

n is a constant (for air 0.7)

But for liquids, μ decreases with temperature

$$\mu \approx ae^{-bT}$$

a and b are constants that depend on the type of liquid

why different between gas & liquid?

$\mu \propto P$, and P↑ so does μ <u>for all fluids</u>.

If μ is divided by fluid density (ρ), it is called kinematic viscosity (v).

$v = \frac{\mu}{\rho}(\frac{m^2}{s})$

For water v = 1cδt or $1 \times 10^{-6}\frac{m^2}{s}$

In fluid mechanics, we're not interested in strain rate (unlike solid mechanics), but care about velocity distribution with in the fluid. Let's see how we can match strain to velocity.

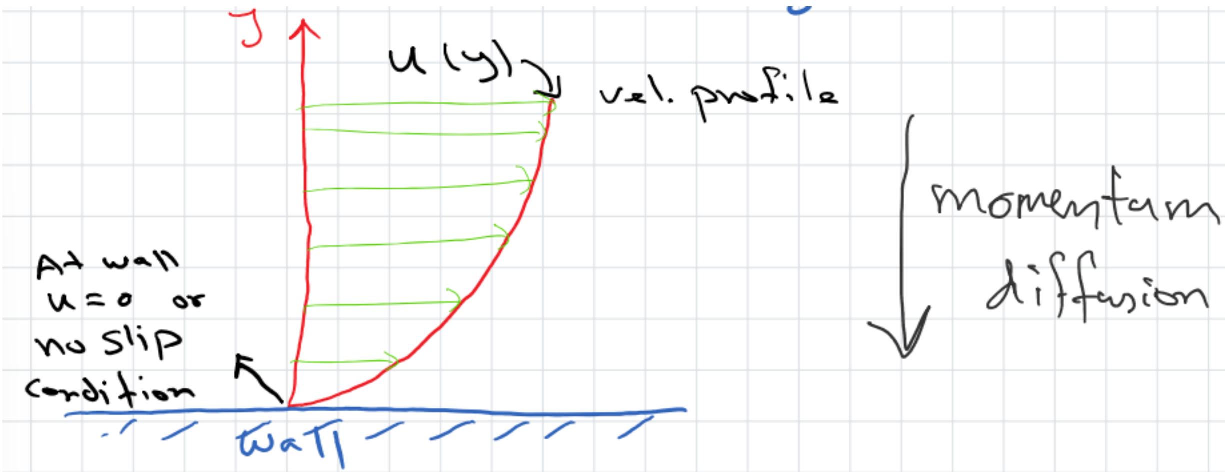
$tan\ \delta\theta = \frac{\delta x}{\delta y}$ → (for small strains & elements) $\delta\theta = \frac{\delta x}{\delta y}$

$$\delta x = \delta u \delta t \qquad \rightarrow \delta\theta = \frac{\delta u \delta t}{\delta y}$$

$$\frac{\delta\theta}{\delta t} = \frac{\delta x}{\delta y}(3)$$

From Eqs. (2 & 3):

$$\tau = \mu \frac{\delta \mathrm{u}}{\delta \mathrm{y}} (4)$$



$$\delta_m \mu \ \equiv momentum$$

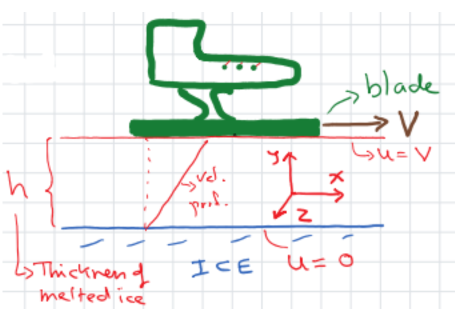
$$q = k \frac{dT}{dx}$$

$$\tau = -\mu \frac{dv}{dy}$$

$$\dot{m} = D \frac{ds}{dx}$$

Example: Skating on ICE!

Let's assume ice between skate and surface is melted. What is the relative profile within the liquid film?

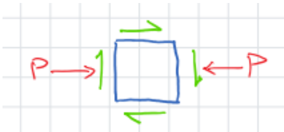


Assumption:

1 – The flow is one dimensional in x-direction, i.e. u(x) = u(z) = 0, u(y) ≠ 0

2 – no pressure variation in x direction

Let's consider force balance over a fluid element



From force balance $\frac{du}{dy} = \frac{\tau}{\mu}$

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

If the person is not accelerating, then τ is a constant, μ is a constant (water), then the integral can be solved as:

$$u = a + \frac{\tau}{\mu}y$$

<u>B.C.</u>

at y = 0 → u = 0 ➔ a = 0

at y = h → u = v ➔ v = 0 + $\frac{\tau}{\mu}h$ ➔ $\frac{\tau}{\mu} = \frac{v}{h}$

$u = \frac{v}{h}y$ (linear velocity profile)

Summary for today's lecture

1. Viscosity charge with T&P
2. Intermolecular forces is the origin if viscosity
3. Difference between solid & liquid in terms of strain
4. Proportionality between velocity & shear stress

Our Goals for Today (lect. 3)

1. Non-Newtonian Fluids
2. Various ways to study fluid dynamics

Newtonian vs Non-Newtonian Fluid