ChE 374–Lecture 2–Fluid Properties

Q: What is a fluid?

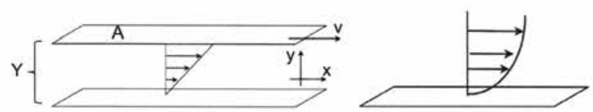
- Shear stress
- Gas properties
- Liquid properties

• Continuum assumption

• Basic Fluid Properties

- Density
  * Water 1000 kg/m^3, 62.3 lbm/ft^3
  * Specific gravity
  * Specific weight
  * Industries: Degree API, Degree Baume
  * Ideal Gas
  * Liquid: Water: T=0-100^oC $\rightarrow$ 4% variation! P=1-210 atm $\rightarrow$ 1% variation!
- Variation of ρ with P, T:
  * Pressure: κ = Coeffient of compressibility: $\kappa = \rho\left(\frac{\partial P}{\partial \rho}\right)_T \rightarrow \frac{\Delta P}{\Delta\rho/\rho} \rightarrow \frac{\Delta\rho}{\rho} = \frac{\Delta P}{\kappa}$.
    · I.G.?
  * Temperature: β = Coeffient of volume expansion: $\beta = -\frac{1}{\rho}\left(\frac{\partial \rho}{\partial T}\right)_P \rightarrow -\frac{\Delta\rho/\rho}{\Delta T} \rightarrow \frac{\Delta\rho}{\rho} = \beta\Delta T$.
  * $\frac{\Delta\rho}{\rho} = \frac{1}{\kappa}\Delta P - \beta\Delta T$.
- Viscosity

  Q: How to quantify it?



  * Shear Stress: $\tau = \mu\frac{dv}{dy}$
    · Sign convention F
    · Momentum Flux: $\tau = F/A$: Force is a Rate of Momentum!
      $F = ma = m\frac{dv}{dt} = \frac{dmv}{dt} = \frac{dmom}{dt}$.
    · Stress at wall $\rightarrow$ force at wall $\rightarrow$ mom. flx at wall $\rightarrow$ SLOPE AT WALL.
  * Non-Newtonian fluids
    · τ vs dv/dx is nonlinear.
    · μ depends on strain rate
    · (Newtonian)
    · Bingham plastic
    · Pseudo-plastic
    · Dilitant
  * Temperature effect
    · Liquids
    · Gases
  * Pressure effect small for liquids and gases
- Kinematic viscosity: $\nu = \frac{\mu}{\rho}$ (=) m^2/s.
  * μ (=) kg/m·s.

Class 2 - Fluid Properties

Q: What is a fluid?

- Gas or Liquid
- Deforms continuously under applied shear stress
  - → What is a shear stress (more later)
    - Compressive → ←
    - Tensile ← →
    - Shear ⇉ (Force parallel to surface)
    - Stress = F/A (Like pressure)
- Glass?
- Asphalt?

Liquids: Form a free surface

Gases: Fill volume, no free surface, mix w/ other gases

Continuum:

- Fluids made of distinct molecules.
- Study fluids → normally ignore molecules. Homogenous.
- Continuum is valid when <u>Scales</u> of interest >> space between molecules, or time between collisions.
- mean free path of O_2 at 1atm → 10^{-8} m
- Invalid at low P, or high speed, or small channels.

Basic Properties

- Name / List some, then discuss
- **Density** — ρ — kg/m³ — Memorize water/air
  - 1000 kg/m³, 62.3 lbm/ft³   1.2 kg/m³, 0.0752 lbm/ft³
- <u>Specific Gravity</u>

$$SG = \rho/\rho_{H_2O}$$

- ρ_{H_2O} @ 4°C = 1000
- need T for careful work.

Specific Weight

$\gamma = \rho g$: N/m^3 weight per unit volume

$$\frac{F}{V} = \frac{m \cdot a}{V} = \frac{mg}{V} = \rho g$$

Industries

- Degree API : American Petroleum Inst.

  $\text{Deg API} = \frac{141.5}{SG} - 131.5 \rightarrow \frac{141.5\,\rho_{H_2O}}{\rho} - 131.5$

  Q: Why? $\rightarrow \frac{1}{\rho} \rightarrow$ lighter oils higher Deg API

  $\rightarrow$ float above, more valuable.

- Deg. Baumé
- Brix Gravity
- etc.

Ideal Gas

$\rho = \frac{MP}{RT}$ Mech. Eng. use $R \rightarrow \frac{R}{M}$

$\rho \propto P, \quad \rho \propto \frac{1}{T}$

Liquids

$\rho \approx$ Constant WRT P, not T

4% variation $T = 0 - 100°C$

1% variation $P = 1 - 210$ atm

See Slides!

K - coef. of Compressibility

$$K = \rho \left(\frac{\partial P}{\partial \rho}\right)_T \approx \frac{\Delta P}{\Delta\rho/\rho} \rightarrow \frac{\Delta\rho}{\rho} = \frac{1}{K}\Delta P$$

K (=) P

K $\rightarrow$ measures fractional change in Density (Volume) w/P

also $\frac{\Delta V}{V} = -\frac{\Delta P}{K}$

K = P for ideal Gas.

β : Coef of Volume Expansion

$$\beta = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P \rightarrow -\frac{\Delta\rho/\rho}{\Delta T} \longrightarrow \frac{\Delta V}{V} = \beta \Delta T$$

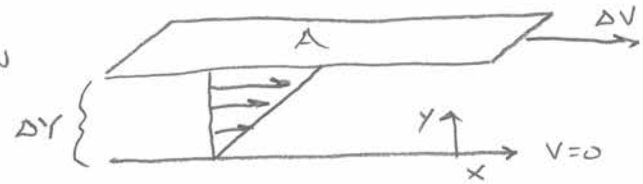
measures fractional change in volume (Density) with T

Viscosity

Q: what is visc? Honey vs water. Movie

Q: How to Quantify it.

* Class activity : Draw



Force needed to keep plate moving
- in terms of ΔV, A, ΔY
- Talk w/ neighbor → Discuss

$F \propto A$, $F \propto \Delta V$, $F \propto \frac{1}{\Delta Y}$, μ is the $\propto$ const.

$\rightarrow F = \mu A \frac{\Delta V}{\Delta Y} \longrightarrow \frac{F}{A} = \tau = \mu \frac{\Delta V}{\Delta Y}$

For curved profile $\lim \Delta Y \rightarrow 0 \rightarrow \tau = \mu \frac{dV}{dy}$

Force of Fluid on Plate = − F of Plate on Fluid

$\longrightarrow$ $\boxed{\tau = -\mu \frac{dV}{dy}}$ Memorize, know its Parts

- μ is resistance to flow
- Newtonian Fluid → $\mu = \mu(T, P, \text{Fluid})$ $\mu \neq \mu(V)$
- τ = Momentum Flux : $\frac{F}{A} = \frac{\text{Rate of momentum}}{\text{Area}}$

  Flux is Stuff Per time Per area.

  $F = ma = m\frac{dV}{dt} = \frac{dmV}{dt}$ = Rate of momentum.

T - effect on μ

Liquids : molecules always in the way
inc. T, molecules speed up → motion easier
→ μ Dec.

Gases : molecules "never" in each others way, but
inc T → in way → μ inc.

P - effect on μ

Small for Gases & Liquids.

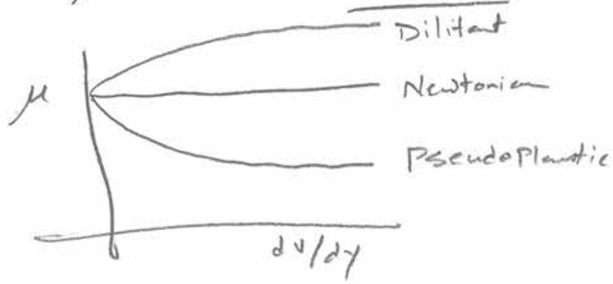
$\frac{\mu}{\rho} = \nu$ is kinematic viscosity $(=) \frac{m^2}{s}$

μ air vs water Factor 100

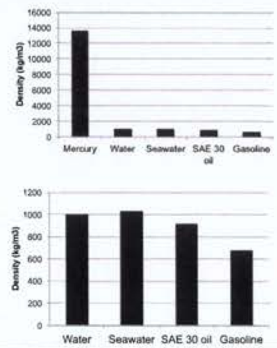
ρ air vs water Factor 1000

Non-Newtonian Fluids

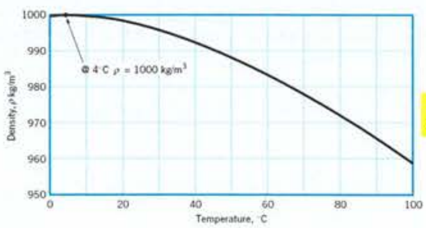
μ is a function of $\frac{dv}{dy}$ (shear).



Density



Density of water versus temperature

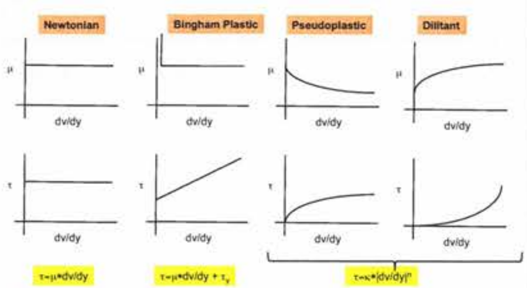


4% variation

Fundamentals of Fluid Mechanics, 5/E by Bruce Munson, Donald Young, and Theodore Okiishi

Viscosity

Non-Newtonian Fluids



Non-Newtonian