Ch 2 – Properties of Fluids - II

Prepared for
CEE 3500 – *CEE Fluid Mechanics*
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Ideal Fluids

- Ideal fluid: a fluid with no friction
- Also referred to as an *inviscid* (zero viscosity) fluid
- Internal forces at any section within are normal (pressure forces)
- Practical applications: many flows approximate frictionless flow away from solid boundaries.
- Do not confuse ideal fluid with a perfect (ideal) gas.

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Real Fluids

- Tangential or shearing forces always develop where there is motion relative to solid body
- Thus, fluid friction is created
- Shear forces oppose motion of one particle past another
- Friction forces gives rise to a fluid property called *viscosity*

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Viscosity (1)

- A measure of a fluid's resistance to angular deformation, e.g.,
  - Motor oil: high viscosity, feels sticky
  - Gasoline: low viscosity, flows "faster"
- Friction forces result from cohesion and momentum interchange between molecules.

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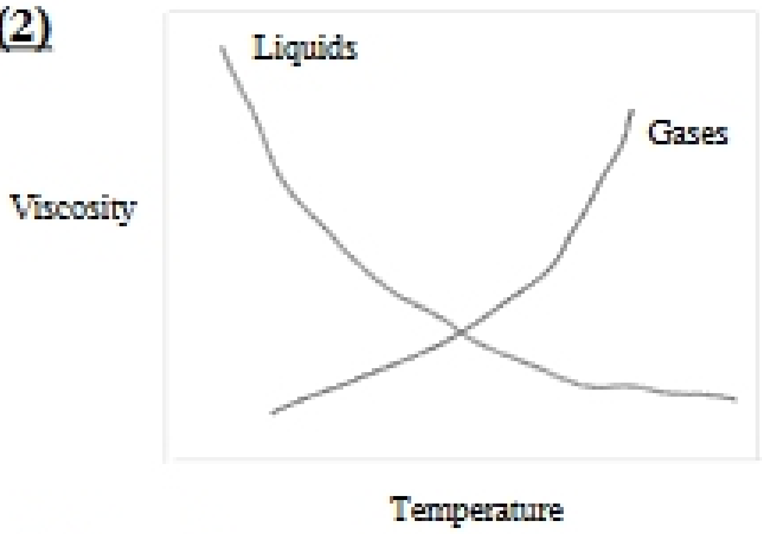
Viscosity (2)



Variation with temperature:
Liquids: viscosity decreases as temperature increases
Gases: viscosity increases as temperature increases
See Figures A.1 & A.2, Appendix A, for absolute and kinematic viscosities of fluids

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Viscosity (3)

- Mechanisms of viscous action:
  - Liquids: cohesion forces (diminish with temperature)
  - Gases: molecular interchange between moving layers
- Molecular interchange in gases:
  - Molecular interchange ➔ shear/friction between layers
  - As T increases, so does molecular activity ➔ increasing viscosity in gases as T increases

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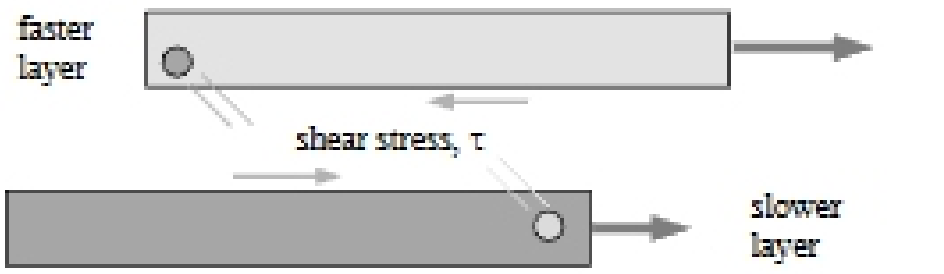
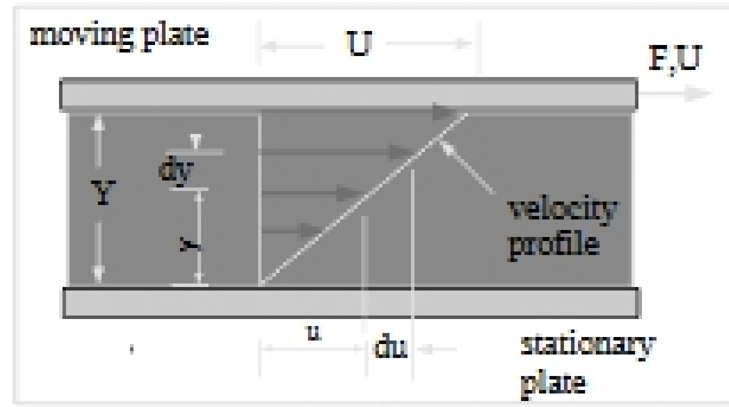
Viscosity (4)



- Rapidly-moving molecule into slowly-moving layer ➔ speeds up the layer.
- Slow-moving molecule into faster-moving layer ➔ slows down the layer

Viscosity (5) - Moving & stationary parallel plates



- Fluid particles adhere to walls: ***no-slip condition***
- Velocities: zero at (1), U at (2) ➔ velocity profile
- For small U, Y, and no net flow ➔ linear velocity profile
- Experiments show that ***F ~ A·U/Y***

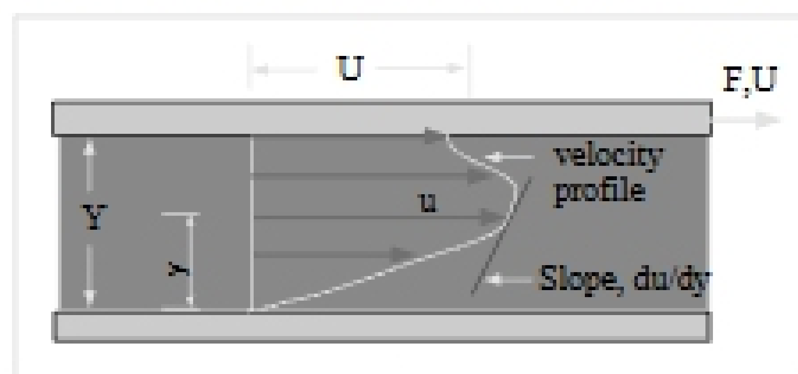
Viscosity (6) – Newton's equation

- From previous slide: F ~ A·U/Y
- $\tau = F/A$ = shear stress between layers
- Newton's equation of viscosity (for the linear velocity profile)

$$\tau = \frac{F}{A} = \mu \frac{U}{V} = \mu \frac{du}{dy}$$

- μ = *coefficient of viscosity, absolute viscosity, dynamic viscosity,* or simply *viscosity*

Viscosity (7) - Moving parallel plate with net flow



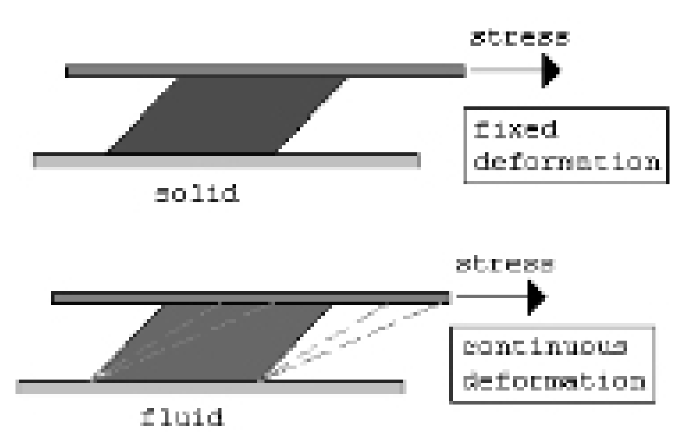
- **Velocity profile when small bulk flow present:**
  - **Combination of linear + parabolic profile**
  - **Non-linear profile**
    - **adds zero velocities at the walls**
    - **Shows maximum velocity at center line**

Viscosity (8) – Newton's equation

- For non-linear profile, use the slope of the velocity profile at position *y*, i.e., *du/dy*, to calculate the shear stress between layers

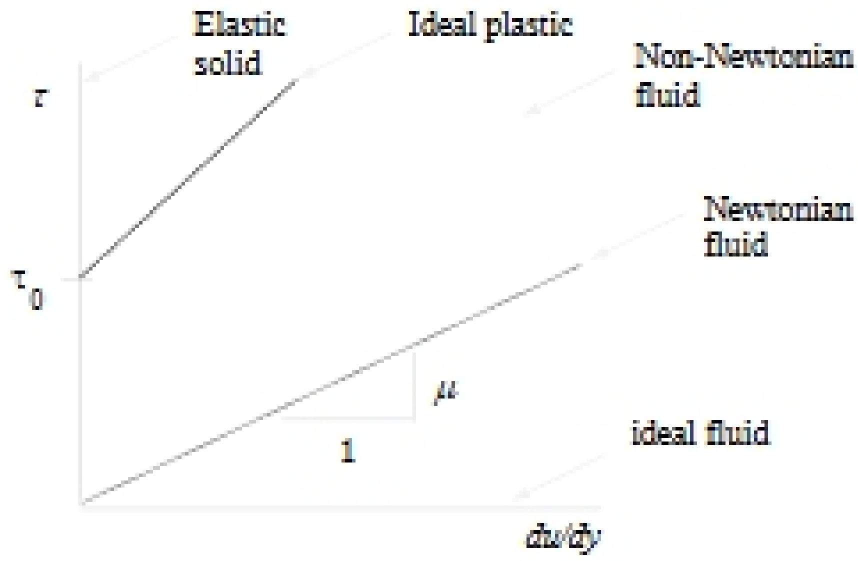
$$\tau = \mu \frac{du}{dy}$$

- μ = *coefficient of viscosity, absolute viscosity, dynamic viscosity,* or simply *viscosity*



1 - For solids, shear stress depends on magnitude of angular deformation (τ ~ *angular deformation*)
2 – For many fluids shear stress is proportional to the *time rate* of angular deformation (τ ~ *du/dy*)

Viscosity (9) – τ - vs.- (du/dy) behavior



Viscosity (10) – Different materials

- Newtonian fluid: μ is constant
  - Air, water are Newtonian fluids
- Ideal fluid has $\mu = 0$
- Ideal plastic: requires a threshold stress τ_0 before it flows
- Non-Newtonian fluids: μ varies with velocity gradient (du/dy)
  - Paints, printer's ink, gels, emulsions are Non-Newtonian fluids.

Viscosity (11) – Journal bearing

- See Figure 2.6, p. 32, for sketch of journal bearing
- Lubricating fluid fills small annular space between a shaft and its surrounding support
- For coaxial cylinders with constant angular velocity (ω), resisting torque = driving torque
- Because radii at inner and outer walls are different ➔ shear stresses at the walls must be different
- Shear stresses vary continuously and velocity profile in gap must be curve
- For very small gaps, velocity is linear $\tau = \mu \cdot U/Y$

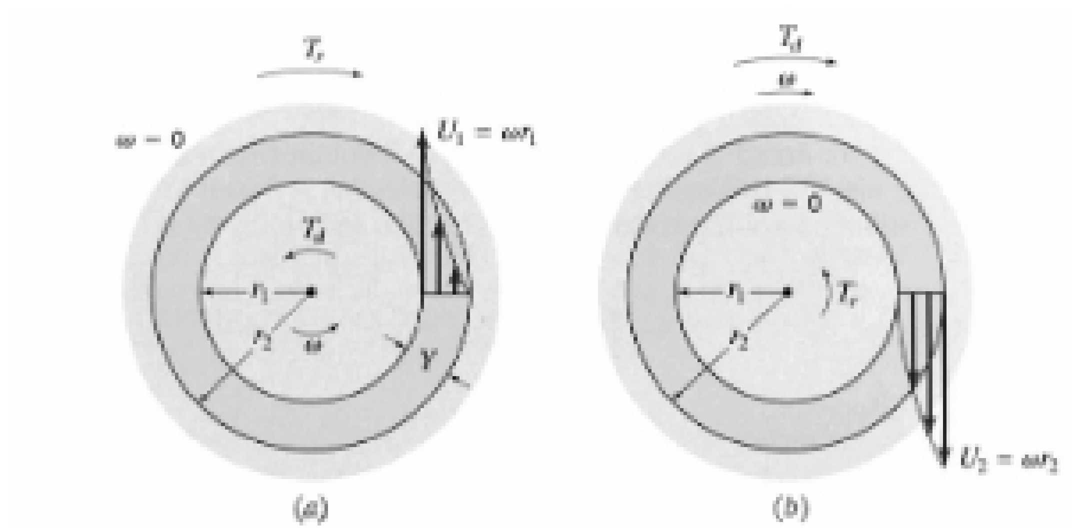


Figure 2.6
Velocity profile, rotating coaxial cylinders with gap completely filled with liquid. (a) Inner cylinder rotating. (b) Outer cylinder rotating. Z is the dimension at right angles to the plane of the sketch. Resisting torque = driving torque and $\tau \propto (du/dy)$.

Viscosity (11) – Units of viscosity

- In B.G. Units

$$[\mu] = \frac{[\tau]}{[du/dy]} = \frac{lb/ft^2}{fps/ft} = \frac{lb\,sec}{ft^2}$$

- In S.I. Units

$$[\mu] = \frac{[\tau]}{[du/dy]} = \frac{N/m^2}{s^{-1}} = \frac{N\,s}{m^2}$$

- The *poise* (P):
  - Metric unit of viscosity
  - Named after Jean Louis Poiseuille (1799-1869)
  - The poise: $1\ P = 0.10\ N{\cdot}s/m^2$
  - The *centipoise*: $1\ cP = 0.01\ P = 1\ mN{\cdot}s/m^2$
  - For water at $68.4°F$ ($20.22°C$), $\mu = 1\ cP$

Viscosity (12) – Kinematic viscosity

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

- Ratio of absolute viscosity to density
- Appears in many problems in fluids
- Called *kinematic viscosity* because it involves no force (dynamic) dimensions
- B.G. Units = ft^2/sec, S.I. Units = m^2/s
- The *stoke* (St)
  - Metric unit of kinematic viscosity
  - Named after Sir George Stokes (1819-1903)
  - The *centistoke*: $1\ cSt = 0.01\ St = 10^{-6}\ m^2/s$