Hydraulics I

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Course Content

- Properties of Fluids
- Hydrostatics
- Fluid Kinematics
- Basics of Fluid Dynamics

Chapter 1 Properties of Fluids

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Definitions

- **Fluids (liquids and gases):** a substance which deforms continuously, or flows, when subjected to shear stress.
- **Fluid Mechanics**: The study of liquids and gasses at rest (statics) and in motion (dynamics)
- **Engineering applications**
  - Dams and reservoirs
  - Water supply pipelines
  - Groundwater movement
  - Runoff in parking lots
  - Pumps, filters, rivers, etc.

Fluid Properties

Density

Density: mass of substance per unit volume (kg/m^3)

- Mass per unit volume (e.g., @ 20 ^oC, 1 atm)
  - Water ρ_{water} = 1000 kg/m^3
  - Mercury ρ_{Hg} = 13,500 kg/m^3
  - Air ρ_{air} = 1.22 kg/m^3
- Densities of liquids are nearly constant (incompressible) for constant temperature
- **Specific volume = 1/density**

Specific Weight

Specific Weight : the force exerted by the earth's gravity up on a unit volume of substance

$$\gamma = \rho g \qquad [N/m^3]$$

- Weight per unit volume (e.g., @ 20 °C, 1 atm)

γ_{water} = (998 kg/m^3)(9.807 m^2/s)
= 9790 N/m^3

γ_{air} = (1.205 kg/m^3)(9.807 m^2/s)
= 11.8 N/m^3

Specific Gravity/Relative density

Ratio of fluid density to that of water at STP (@ 20 °C, 1 atm)

$$SG_{liquid} = \frac{\rho_{liquid}}{\rho_{water}} = \frac{\rho_{liquid}}{9790\ kg/m^3}$$

$$SG_{gas} = \frac{\rho_{gas}}{\rho_{air}} = \frac{\rho_{gas}}{1.205\ kg/m^3}$$

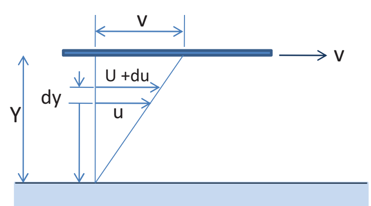
- Water SG_{water} = 1
- Mercury SG_{Hg} = 13.6
- Air SG_{air} = 1

Viscosity

- By the virtue of cohesion and interaction between fluid molecules offers resistance to relative motion (shear deformation).
- Newton's law of viscosity: shear stress and viscosity

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

τ is shear stress N/m^2, μ is coefficient of dynamic viscosity (Ns/m^2), and du/dy velocity of gradient (radians/s)



Viscosity

Dynamic viscosity (μ). It is the shear force per unit area required to drag one layer of fluid with unit velocity past another layer a unit distance away.

Unit = kg/m.s or N.s/m^2

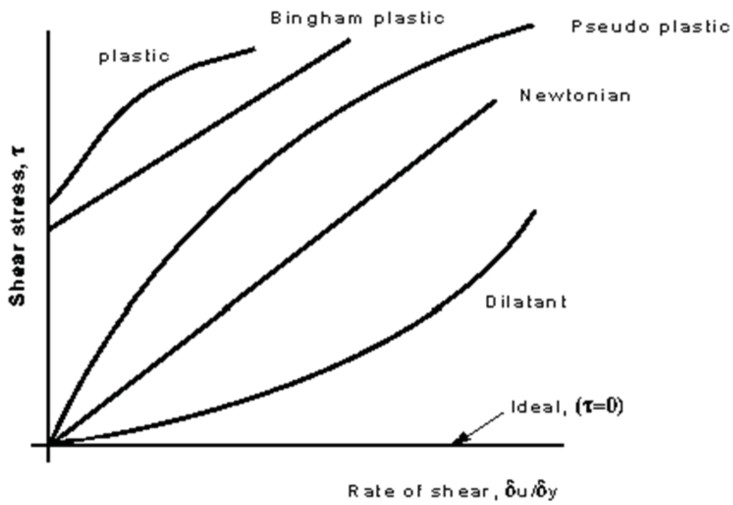
Poise (p) = 0.1 kg/m.s

Kinematic viscosity (v): defined as the ratio dynamic viscosity to mass density.

Unit: m^2/s

Stokes (st) = 0.0001 m^2/s

Newtonian and Non-Newtonian Fluids



Compressibility and elasticity

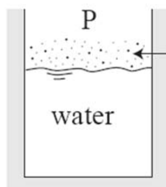
- **Deformation per unit of pressure change**
- Bulk modulus of elasticity= $E_v = -\frac{dp}{dV/V} = \frac{dp}{d\rho/\rho}$
- For water E_v = 2.2 GPa,

  1 MPa pressure change = 0.05% volume change

  Water is relatively incompressible

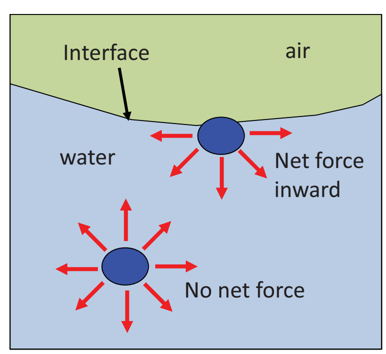
Vapor Pressure

- Partial pressure of liquid escaping molecules
- Vapor pressure increases with temperature
- Pressure at which a liquid will boil for given temp.
- The saturated vapor pressure for water at 20°C is 2.45×10^5 N/m^2



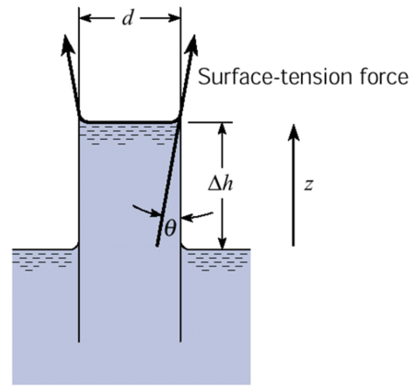
Surface Tension

- Cohesion → small tensile forces at the interface between liquid and air called surface tension
- Adhesion > Cohesion → capillary rise
- Adhesion < cohesion → capillary depression
- σ*, water*= 0.073 N/m (@ 20°C)



Capillary Rise/depression

$$\Delta h = \frac{4\sigma \cos\theta}{\gamma d}$$



Example 1

- **Given:** Pressure of 2 MPa is applied to a mass of water that initially filled 1000-cm^3 volume.
  E = 2.2x10^9 Pa
- **Find:** Volume after the pressure is applied.

Solution

$$E_v = -\frac{\Delta p}{\Delta V / V}$$

$$\Delta V = -\frac{\Delta p}{E_v} V$$

$$= -\frac{2x10^6\,Pa}{2.2x10^9\,Pa} 1000\,cm^3$$

$$= -0.909\,cm^3$$

$$V_{final} = V + \Delta V$$

$$= 1000 - 0.909$$

$$V_{final} = 999.01\,cm^3$$

Example 2

The density of an oil at 20°C is 850 kg/m^3. Find its relative density and kinematic viscosity if the dynamic viscosity is 5 x 10^{-3} kg/ms.

- **Solution:**
- Relative density, $\sigma = \rho$ of oil/ρ of water

  $= 850/10^3$

  $= 0.85$
- Kinematic viscosity, $\nu = \mu/\rho$

  $= 5 \times 10^{-3}/850$

  $= 5.88 \times 10^{-6} m^2/s$

Example 3

IF the velocity distribution of a viscous liquid ($\mu = 0.9$ Ns/m^2) over a fixed boundary is given by $u = 0.68y - y^2$ in which u is the velocity in m/s at a distance y metres above the boundary surface, determine the shear stress at the surface and at y = 0.34 m.

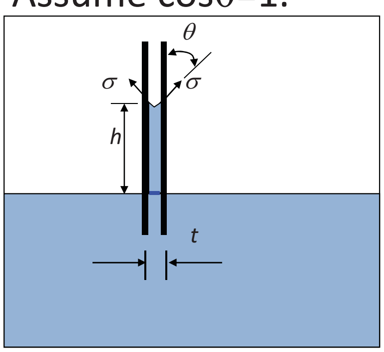
If the above velocity distribution occurred in a pipe of 3 cm diameter, find the total resistance over a length of 100 m.

Example 3 Solution

- u = 0.68y - y^2
- du/dy = 0.68 - 2y; hence $(du/dy)_{y=0}$ = 0.68 s^{-1}
  and $(du/dy)_{y=0.34}$ = 0
- Dynamic viscosity of the fluid, u = 0.9 Ns/m^2
- From Newton's equation
  $\tau = \mu(du/dy)$, shear stress $(y)_{y=o}$ = 0.9 x 0.68
  = 0.612 N/m^2
  and at y = 0.34 m, τ = 0.

Example 4

- **Find:** Capillary rise between two vertical glass plates 1 mm apart. σ = 7.3x10^{-2} N/m. L is into the page. Assume cosθ=1.



$$\sum F_{vertical} = 0$$

$$2\sigma l - hlt\gamma = 0$$

$$h = \frac{2\sigma}{t\gamma}$$

$$= \frac{2*7.3x10^{-2}}{0.001*9810}$$

$$h = 0.0149\,m$$

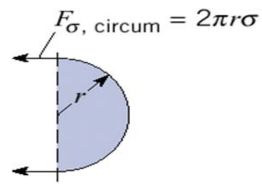
$$h = 14.9\,mm$$

Example 5

- **Find:** The formula for the gage pressure within a spherical droplet of water?
- **Solution:** Surface tension force is resisted by the force due to pressure on the cut section of the drop

$$p(\pi r^2) = 2\pi r\sigma$$

$$\boxed{p = \frac{2\sigma}{r}}$$



(a) Half of spherical droplet