FLUID PROPERTIES

1. VISCOSITY

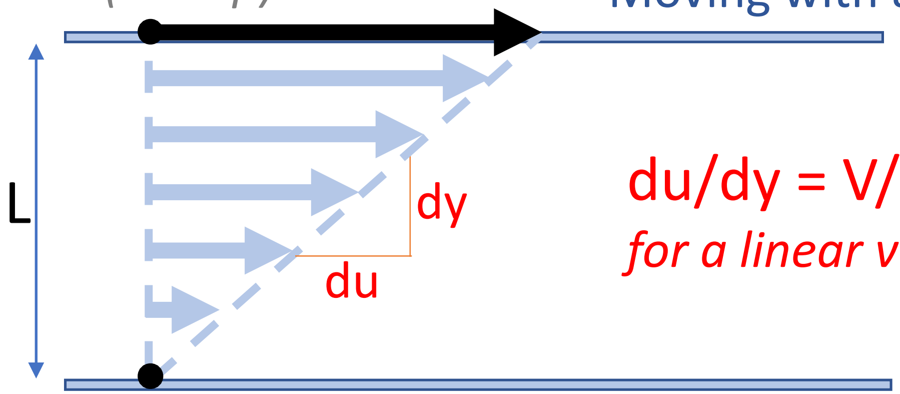
u(y) = **V**

(no slip)

Upper Plate:

Pulled with a force **F** ➔

Moving with a constant velocity **V** ➔



du/dy = V/L,

for a linear velocity profile

u(0) = 0

(no slip)

Lower Plate:

Stationary

NEWTON'S LAW OF VISCOCITY

Experimentally proven that,

$$F\ \alpha\ \frac{AV}{L} \qquad [\ \frac{F}{A} = \tau\ \ \&\ \ \frac{V}{L} = \frac{du}{dy}\ ]$$

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

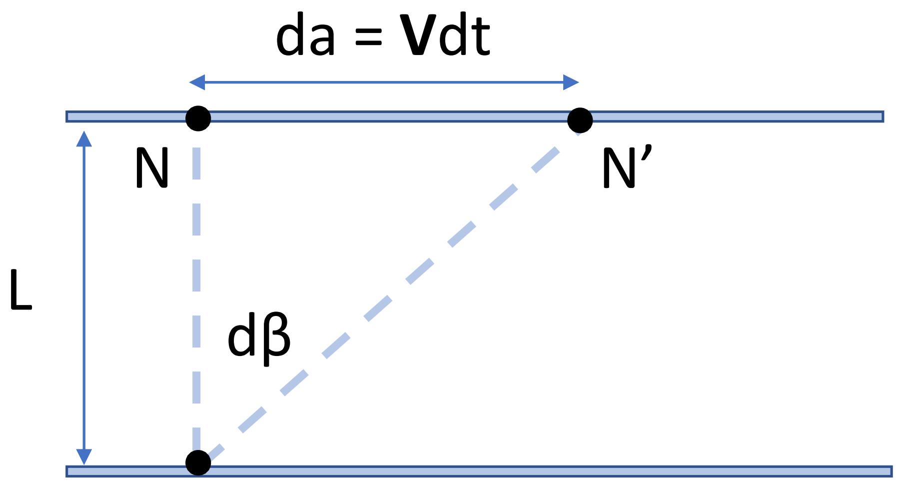
μ, coefficient of viscosity, [dynamic/absolute viscosity]

Unit:

Ns/m^2 or **Pa s** (SI), **Poise** (cgs)

[1 Poise = 0.1 Pa s, viscosity of water @ 20^{0}C is 1 centipoise]

For a small increment of time dt,

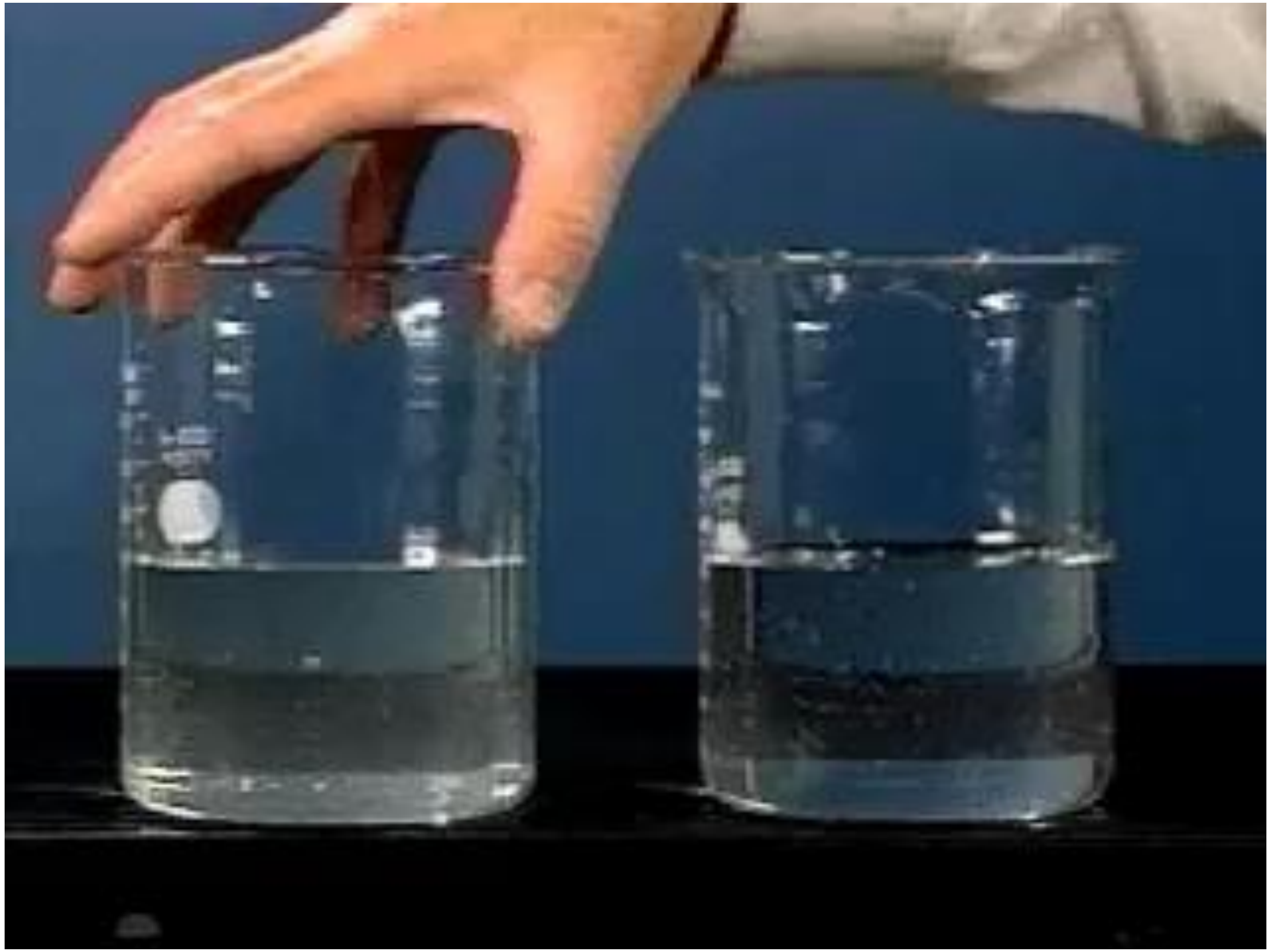


- tan dβ ~ dβ = $\frac{da}{L}$
- dβ = $\frac{\mathbf{V}dt}{L}$
- $\frac{d\beta}{dt} = \frac{V}{L} = \frac{du}{dy}$

$$\tau = \mu\frac{du}{dy} = \mu\frac{d\beta}{dt}$$

i.e., shear stress is proportional to ‘ rate of shear strain ($\frac{d\beta}{dt}$) ’ in fluids as opposed to just ‘ shear strain ($d\beta$) ’ in solids.

Water vs Silicon Oil



ρ_{water} = 1000 kg/m^3

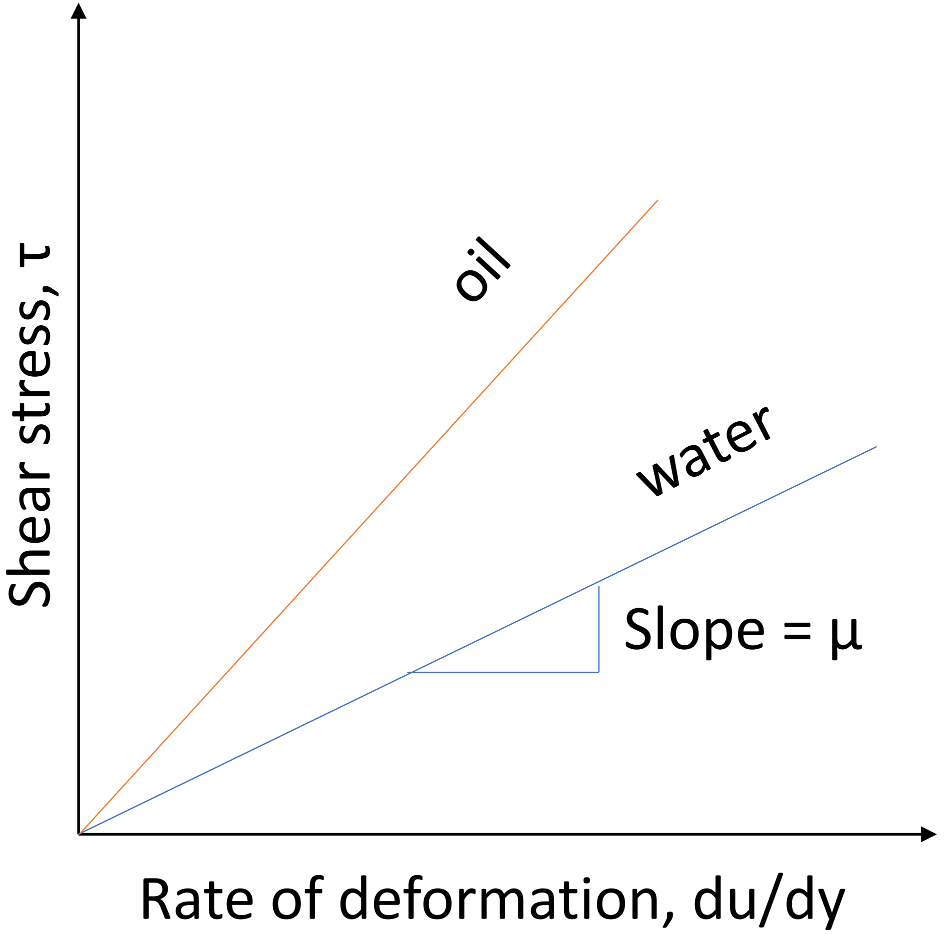
μ_{water} = 8.90 × 10^{-4} Pa. s

ρ_{oil} = 970 kg/m^3

μ_{oil} = 9 Pa. s

- Note that here the densities and appearance are similar.
- But Viscosity is several orders of magnitude different.
- It more difficult for a fluid to flow if its viscosity is higher
- Also it is more difficult to move an object in a higher viscosity fluid

Newtonian Fluids

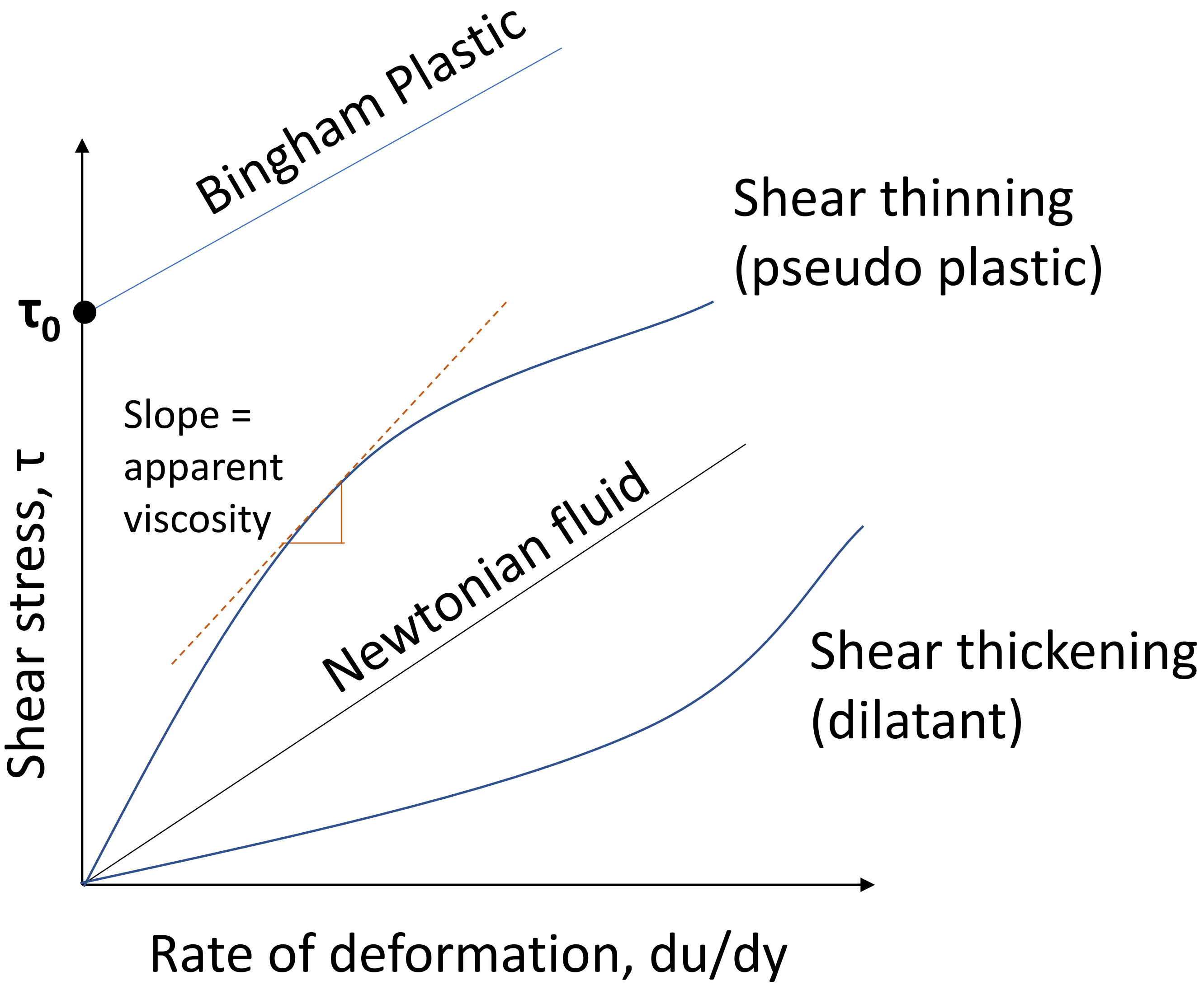


Viscosity is independent of rate of deformation for Newtonian Fluids.

Most common fluids such as water, air, gasoline, oils etc. are Newtonian Fluids.

In this course we discuss about Newtonian fluids alone.

Non- Newtonian Fluids



Shear thinning (pseudo plastic): larger the shear stress larger the rate of deformation [Becomes less viscous as sheared harder]

The viscosity of a fluid is to be measured by a viscometer constructed of two 40-cm-long concentric cylinders (Fig. 2–18). The outer diameter of the inner cylinder is 12 cm, and the gap between the two cylinders is 0.15 cm. The inner cylinder is rotated at 300 rpm, and the torque is measured to be 1.8 N · m. Determine the viscosity of the fluid.

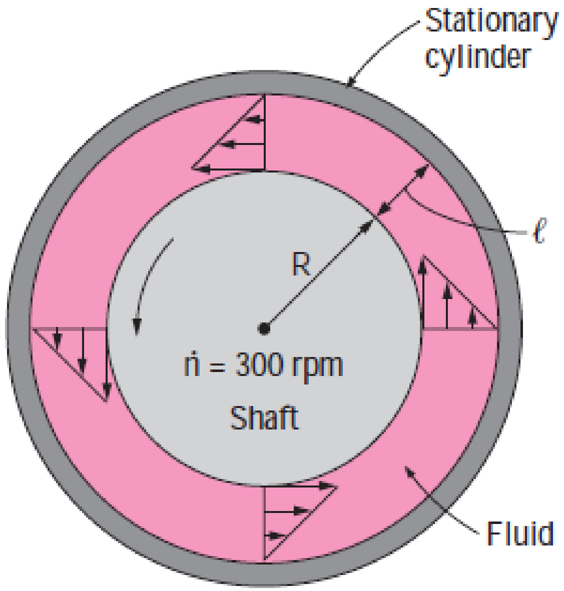
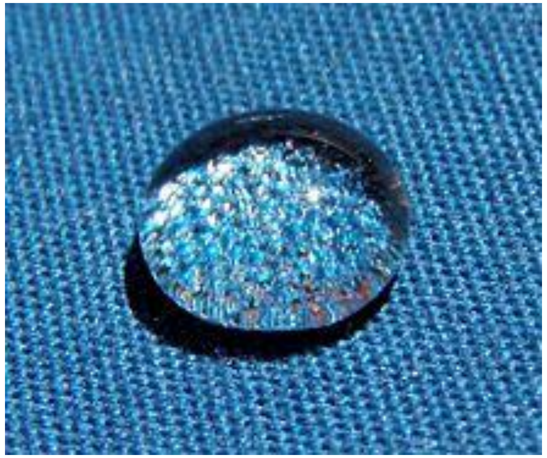
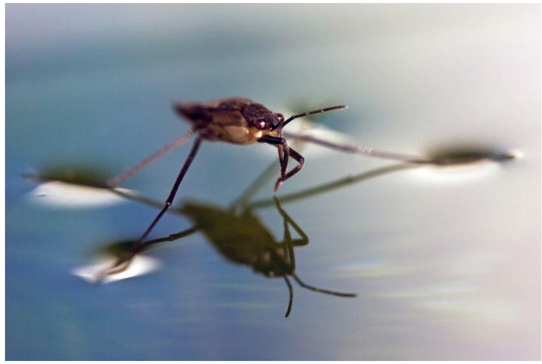


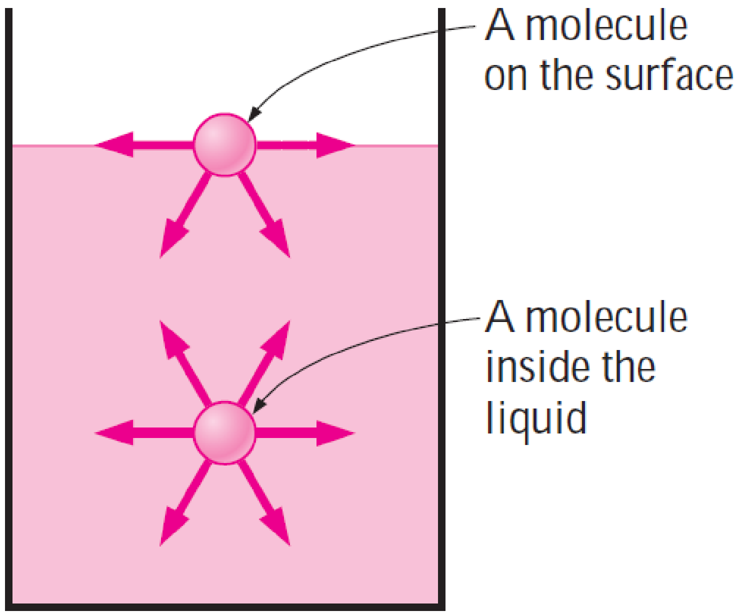
FIGURE 2–18

Surface Tension (σ)

- The interface between two immiscible liquids (or a liquid and a vapor) appears to be a membrane under tension.
- Molecules inside the liquid are pulled equally from all sides due to cohesive forces from other molecules.
- While there is a net downward pulling force on the molecules at the surface.
- This tends to pull the molecules towards the interior. This is balanced by the repulsive forces from the compressed particles







- The pulling force or tension, acting parallel to the surface, per unit length is called **Surface Tension (σ)**

- Unit: **N/m**

- The work required to increase the surface area of the liquid by a unit amount is called **Surface Energy (σ)**

- Unit: **J/m^2**

- Its also called *Coefficient of Surface Tension*

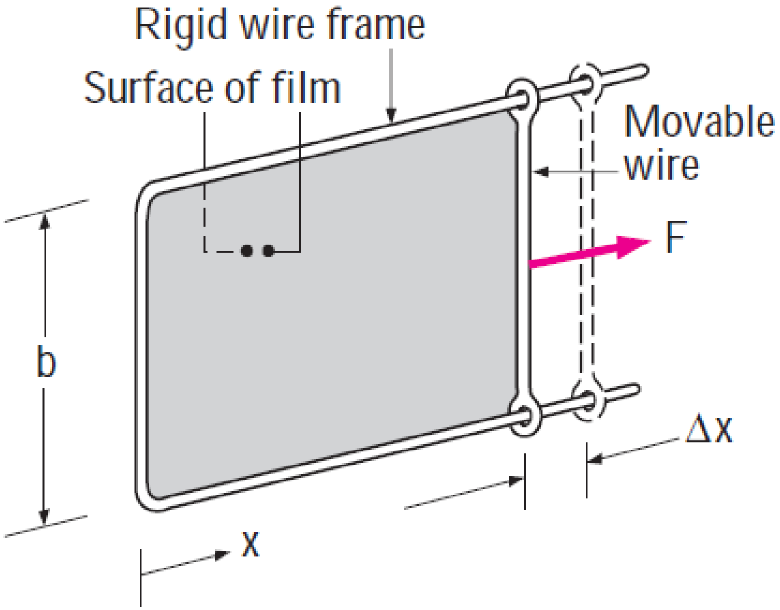
- Liquid film on a U-shaped rigid frame with a movable side.
- The movable wire gets pulled in unless balanced by a force **F.**

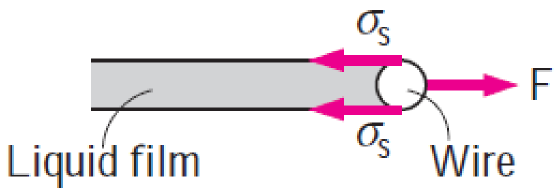
  $\mathbf{F=2b\sigma_s}$ (2b because σ acts along either side)

- Work required to pull it through a distance Δx,

  $$\mathbf{W} = F\Delta x = 2b\sigma_s\,\Delta x = \boldsymbol{\sigma_s}\,\Delta A$$

- Can be interpreted as surface energy
- Surface tension → a binary property





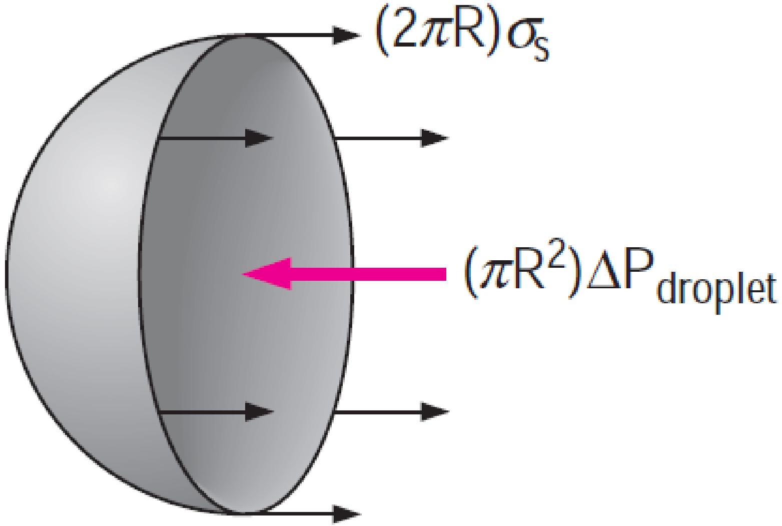
- $(\sigma_s)_{water+air} = 0.073$ N/m
- $(\sigma_s)_{Hg+air} = 0.44$ N/m ← HIGH, Forms nearly spherical droplets
- Decreases as *temperature* increases.
- Not a strong function of *pressure.*
- *Surfactants:* impurities used to decrease σ. Ex: Soap/detergent to water.
- For high the droplet size can also be high since the droplet can hold more mass before breaking

Droplet

$$(2\pi R)\sigma_s = (\pi R^2)\Delta P_{droplet} \rightarrow \Delta P_{droplet} = P_i - P_o = \frac{2\sigma_s}{R}$$

i → inside

o → outside (mostly atmospheric condition)



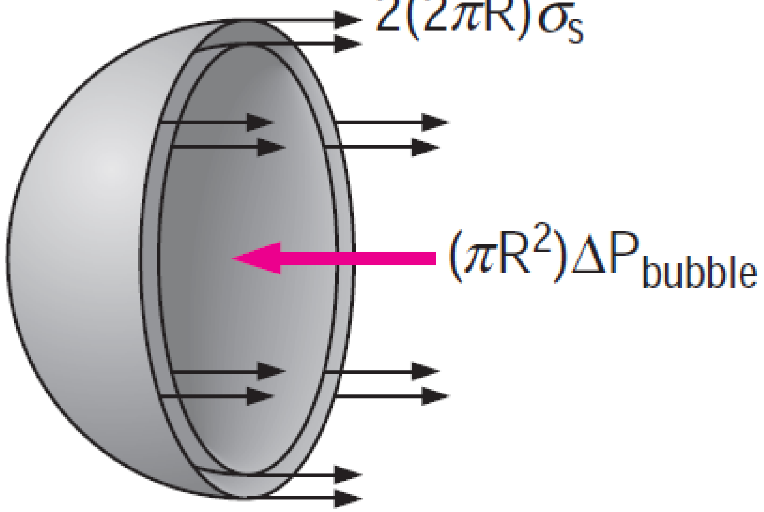
(a) Half a droplet

Bubble

$$2(2\pi R)\sigma_s = (\pi R^2)\Delta P_{bubble} \rightarrow \Delta P_{bubble} = P_i - P_o = \frac{4\sigma_s}{R}$$

$$\Delta P_{\text{Cylindrical Jet of liquid}} = \frac{\sigma_s}{R}$$

$$\Delta P_{\text{General Curved Surface}} = \sigma_s\left(\frac{1}{R_1} + \frac{1}{R_1}\right)$$



(b) Half a bubble