Ch1-3 Viscosity and Surface Tension

Objectives:

- Viscosity (Apply and Analyze)
- Surface tension (Identify and Explain)

Recall: "Big Idea"

$$\Sigma F = ma$$

pressure
gravity
viscous effect
surface tension

Acceleration
or
Inertia

Poll: Dimensions of μ ?

A) $F L^{-2} T^{-1}$

★ B) $F L^{-2} T$

C) $F^{-1} L^{2} T$

D) $F^{-1} L^{2} T^{-1}$

$$\mu = \frac{\tau}{\dot{\gamma}} \doteq \frac{F/L^2}{\frac{1}{T}} \doteq \frac{F}{L^2} \cdot T \doteq F L^{-2} T$$

Unit (SI): $\frac{N}{m^2} \cdot s \doteq Pa \cdot s$

Reading: 1.6, 1.9

For solid body,
$\tau = \gamma G$, $\tau \sim \gamma$

For a fluid, shear stress due to viscosity.

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

where $\dot{\gamma} = \frac{du}{dy}$ is shear strain rate or shear rate.
time rate of the change in shear strain!

Poll: Dimensions of $\dot{\gamma}$?

A) L/T

B) L^2/T

C) L/T^2

★ D) $1/T$

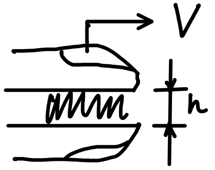
$$\dot{\gamma} = \frac{du}{dy} \doteq \frac{L/T}{L} \doteq \frac{1}{T}$$

$$\dot{\gamma} = \frac{\text{change in strain}}{\text{change in time}} \doteq \frac{1}{T}$$

The unit is "inverse second"
Not Hz.

Example: honey shear force.

Given Honey, b/t thumb and forefinger. Newtonian fluid.

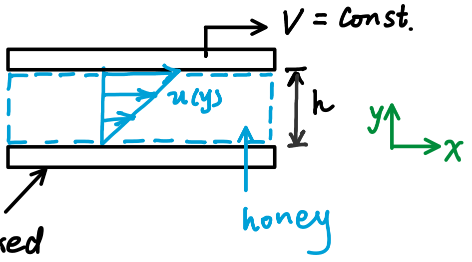


honey area: A

Find Estimate shear force

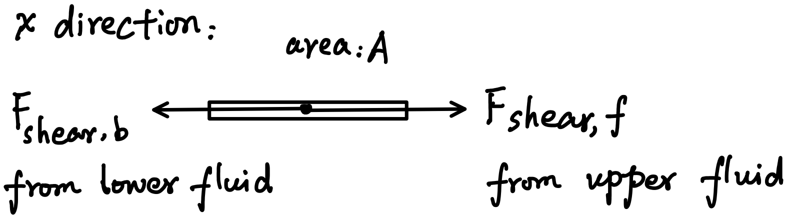
Solution

Model



FBD for a slice of honey:

x direction:



"Big Idea" $$\underset{\text{viscous effect}}{\underset{\uparrow}{\sum_i F}} = m \underset{0}{\underset{\uparrow}{a}}$$

Shear force:

$$F = \tau A$$
$$= (\mu \dot{\gamma}) A$$
$$= (\mu \frac{V}{h}) A$$

$$\dot{\gamma} = \frac{du}{dy} = \frac{V-0}{h-0} = \frac{V}{h}$$

So: $\boxed{F = \mu \frac{V}{h} A}$

* Sanity check. $\mu \frac{V}{h} A$

* Dimension check $\doteq (F L^{-2} T)\left(\frac{\frac{L}{T}}{L}\right) L^2$

* Unit check. $\doteq F L^{-2+1-1+2} T^{1-1} \doteq F L^0 T^0 \doteq F$

W/ numbers:

$\mu \approx 10 \text{ Pa} \cdot s$, $A \approx 1 cm^2$, $V \approx 2 \frac{cm}{s}$, $h \approx 0.1 mm$

$$F = \left(10 \frac{N}{m^2} \cdot s\right) \frac{(2 \cdot 10^{-2} \frac{m}{s})}{0.1 \cdot 10^{-3} m} 1 \cdot 10^{-4} m^2$$

$$= 0.2 N$$

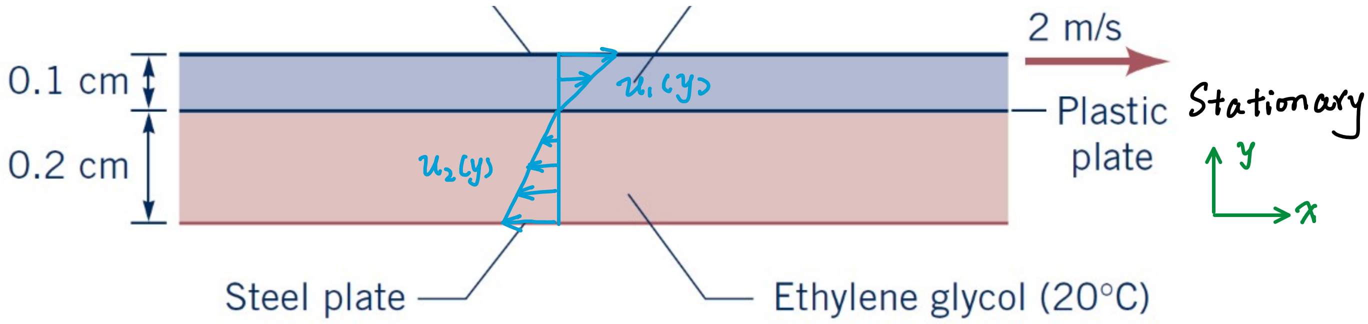
$1 N \approx 0.225 lb$ (lbf)

$0.2 N \approx 0.045 lb \nearrow$ (lbf)

Roughly the weight of two cherries.

Example: HW Problem 1.74

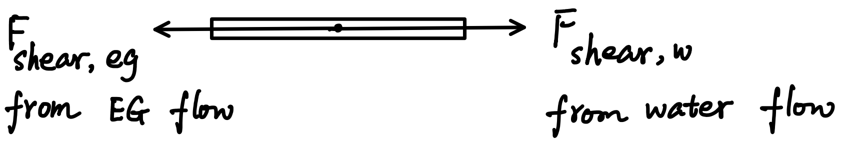
Three large plates are separated by thin layers of ethylene glycol and water, as shown in the figure below. The top plate moves to the right at 2 m/s. At what speed and in what direction must the bottom plate be moved to hold the center plate stationary?



Solution

x direction:

FBD for middle plate:



"Big Idea" $$\underset{\text{viscous effect}}{\sum F} = \underset{0}{ma}$$

Thus, $F_{shear,w} - F_{shear,eg} = 0$

$F_{shear,w} = F_{shear,eg}$

$F_{shear,w} = \tau_w A = (\mu_w \frac{du_1}{dy}) A$

$F_{shear,eg} = \tau_{eg} A = (\mu_{eg} \frac{du_2}{dy}) A$

Stop here. Students need to move ahead by themselves.

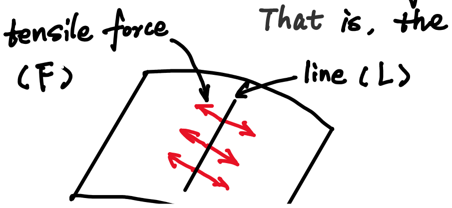
Surface Tension σ

What is surface tension? Show two youtube videos.

Key idea:

- "Surface": interface b/t two immiscible fluids, like air-and-water.
- "Tension": tensile force acting in the plane of surface along any line in the surface.

That is, the surface is like a stretched membrane.



"stretched membrane"

* Surface tension is the intensity of the molecular attraction per unit length along any line in the surface.

Poll: Dimensions of surface tension?

A> $F \cdot L$

B> $F \cdot L^2$

[✓ C> F/L]

D> F/L^2

So in other words, surface tension is the tensile force per unit length along any line in the surface (interface).