VAPOR PRESSURE AND VISCOSITY

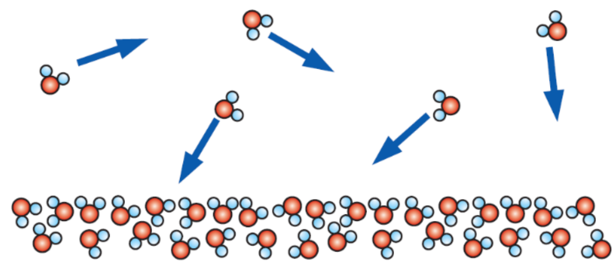
In this lesson, we will:

- Define **vapor pressure** and its significance
- Discuss **cavitation** and its consequences, and do an example problem
- Define **viscosity** and do some example problems that involve viscous forces

Vapor Pressure

$\{P_v\} = \{\frac{F}{L^2}\}$ $[P] = [kPa]$

Water molecules—vapor phase



Water molecules—liquid phase

- The ***vapor pressure P_v*** of a pure substance is the pressure exerted by its vapor molecules when the system is in phase equilibrium with its liquid molecules at a given temperature (as illustrated in the figure for water).
- ***Vapor pressure*** (preferred in fluid mechanics) is the same as ***saturation pressure P_{sat}*** (preferred in thermodynamics).
- When the pressure in a liquid drops below the vapor pressure, the liquid locally vaporizes or "boils" – a process called ***cavitation***.
- Cavitation involves the formation of tiny bubbles called ***cavitation bubbles***.

Example: Vapor Pressure and Cavitation

Given: Water at 20°C flows at high speed through the narrow gap in a valve. Some calculations indicate that the lowest pressure in the flow is 3220 Pa.

To do: Determine if cavitation is likely to occur in this valve.

Solution: Look up P_v (or P_{sat}) → @ 20°C, $P_v = 2.339$ kPa

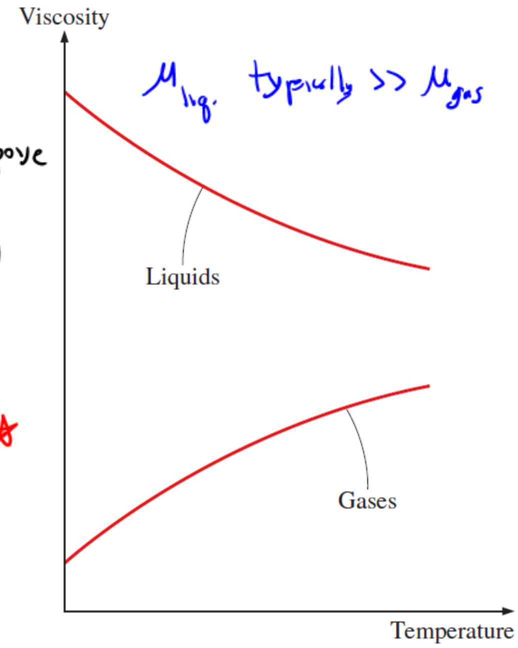
In our valve, lowest $P = 3220 \text{ Pa} \left(\frac{1 \text{ kPa}}{1000 \text{ Pa}}\right) = 3.220 \text{ kPa}$

$\boxed{\text{Since } P > P_v \text{ everywhere, we do not expect cavitation}}$

See my short YouTube video called "***Cool Consequences of Cavitation***" for more about cavitation and some of the interesting problems it causes.
https://youtu.be/2itqHHCj0dc

Cool Consequences of Cavitation

Viscosity



- ***Viscosity*** μ (some authors use η instead) is the fluid property that represents internal resistance of a fluid to motion.
- Viscosity μ is also called ***dynamic viscosity***.

  Poise Centipoise

  $\{\mu\} = \left\{\frac{m}{Lt}\right\}$ $[\mu] = \left[\frac{kg}{m\cdot s}\right]$ or $[P]$ or $[cP]$

- ***Kinematic viscosity*** ν is viscosity divided by density, since this combination of variables occurs frequently in fluid mechanics, $\boxed{\nu = \frac{\mu}{\rho}}$. $\{\nu\} = \left\{\frac{L^2}{t}\right\}$, $[\nu] = \left[\frac{m^2}{s}\right]$

  or $[St]$ Stokes

- The viscosity of gases increases with temperature, while the viscosity of liquids decreases with temperature, as illustrated in the figure.
- For water, μ and/or ν can be found in tables or online.

  Some empirical eq's are also available

- For air, μ and/or ν can be found in tables or online. In addition, we use ***Sutherland's Law*** for calculation of the viscosity of air at a given temperature,

$$\boxed{\mu \approx \mu_s \left(\frac{T}{T_{s,0}}\right)^{3/2} \frac{T_{s,0}+T_s}{T+T_s}}, \quad T_{s,0} = 298.15\ \text{K},\ T_s = 110.4\ \text{K},\ \mu_s = 1.849\times 10^{-5}\ \frac{\text{kg}}{\text{m}\cdot\text{s}}.$$

$\mu = \mu(T)$

ALWAYS USE ABSOLUTE T !!

Example: Viscosity of Air

Given: Air is at 50°C and 1.33 kPa.

To do: Calculate the dynamic viscosity and the kinematic viscosity of this air using Sutherland's Law and compare to the values listed in the Appendix at the given temperature.

Solution: $T = (50 + 273.15)\,\text{K} = 323.15\ \text{K}$

$$\mu = \left(1.849\times10^{-5}\ \frac{kg}{m\cdot s}\right)\left(\frac{323.15\ \cancel{K}}{298.15\ \cancel{K}}\right)^{3/2} \frac{(298.15 + 110.4)\cancel{K}}{(323.15 + 110.4)\cancel{K}} = 1.9661\times10^{-5}\ \frac{kg}{m\cdot s}$$

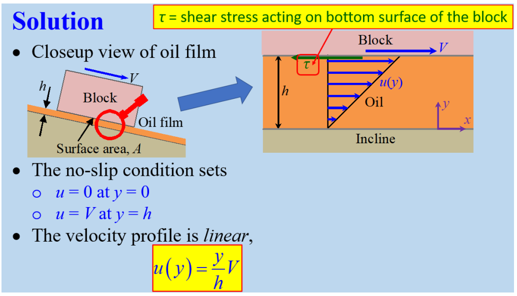
$$\boxed{\mu \approx 1.97\times10^{-5}\ \frac{kg}{m\cdot s}}$$

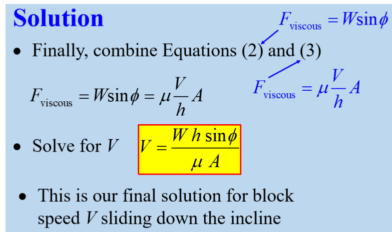
Appendix table @ 50°C, $\boxed{\mu = 1.963\times10^{-5}\ \frac{kg}{m\cdot s}}$

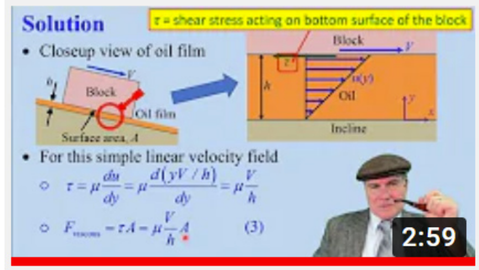
error is ≈ 0.2%

P not used → why? $\mu \approx \mu(T)$ only. (μ is a very weak fnc. of P)

See my short YouTube video called "***Block Sliding Down an Incline on an Oil Film***" for another example that applies viscosity.
https://youtu.be/8Ai59wQcyOk

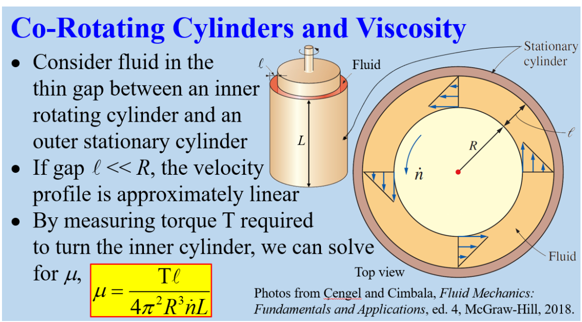


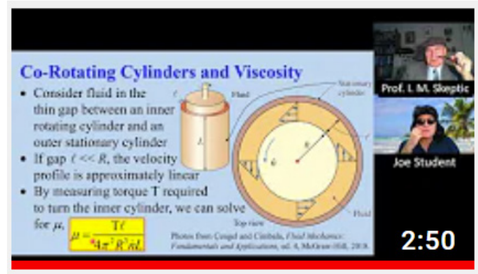




Block Sliding Down an Incline on an Oil Film

See my short YouTube video called "***TMFM: Fluid Viscosity and Its Bearing on Journal Bearings***" for another example that applies viscosity.
https://youtu.be/tLvvYGKI2xk





TMFM: Fluid Viscosity and Its Bearing on Journal Bearings

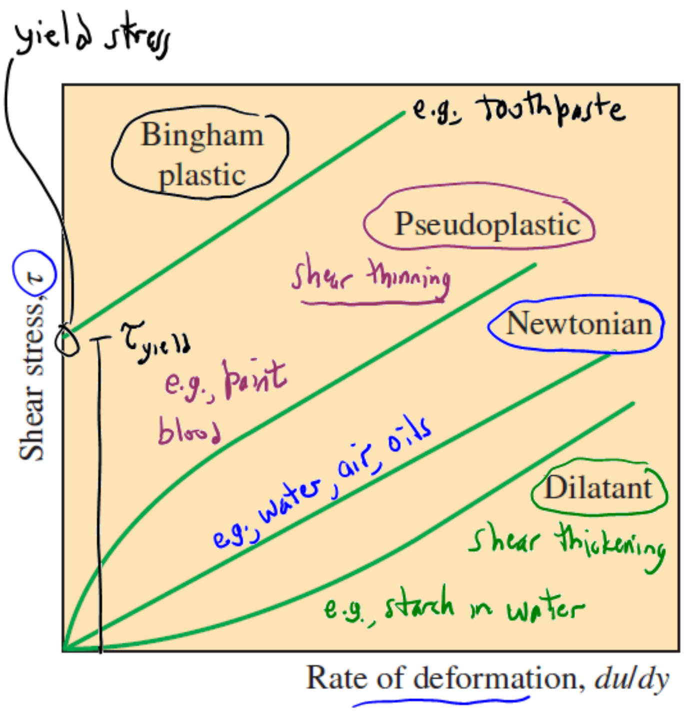
Newtonian vs. Non-Newtonian Fluids

- Newtonian — Rate of deformation is linearly proportional to shear stress τ

- For simple shear flows, $\boxed{\tau = \mu \frac{du}{dy}}$ *

  (as in the video examples)

- Non-Newtonian fluids — τ & rate of deformation are not linearly related



WE WILL ANALYZE NEWTONIAN FLUIDS ONLY