CE 319 F

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Elementary Mechanics of Fluids

Introduction &
Fluid Properties
(continued)

Table A.2

PHYSICAL PROPERTIES OF GASES AT STANDARD ATMOSPHERIC PRESSURE AND 15ºC (59ºF)

Gas	Density, kg/m^3 ($slugs/ft^3$)	Kinematic viscosity, m^2/s (ft^2/s)	R Gas constant, J/kg K (ft-lbf/slug-ºR)	c_p $\frac{J}{kg\ K}$ $\left(\frac{Btu}{lbm\text{-}°R}\right)$	$k = \frac{c_p}{c_v}$	S Sutherland's Constant K (ºR)
Air	1.22 (0.00237)	1.46×10^{-5} (1.58×10^{-4})	287 (1716)	1004 (0.240)	1.40	111 (199)
Carbon dioxide	1.85 (0.0036)	7.84×10^{-6} (8.48×10^{-5})	189 (1130)	841 (0.201)	1.30	222 (400)
Helium	0.169 (0.00033)	1.14×10^{-4} (1.22×10^{-3})	2077 (12,419)	5187 (1.24)	1.66	79.4 (143)
Hydrogen	0.0851 (0.00017)	1.01×10^{-4} (1.09×10^{-3})	4127 (24,677)	14,223 (3.40)	1.41	96.7 (174)
Methane (natural gas)	0.678 (0.0013)	1.59×10^{-5} (1.72×10^{-4})	518 (3098)	2208 (0.528)	1.31	198 (356)
Nitrogen	1.18 (0.0023)	1.45×10^{-5} (1.56×10^{-4})	297 (1776)	1041 (0.249)	1.40	107 (192)
Oxygen	1.35 (0.0026)	1.50×10^{-5} (1.61×10^{-4})	260 (1555)	916 (0.219)	1.40	

SOURCE: V. L. Streeter (ed.), *Handbook of Fluid Dynamics,* McGraw-Hill Book Company, New York, 1961; also R. E. Bolz and G. L. Tuve, *Handbook of Tables for Applied Engineering Science,* CRC Press, Inc. Cleveland, 1973; and *Handbook of Chemistry and Physics,* Chemical Rubber Company, 1951.

Example (2.4)

- Given: Natural gas
  - Time 1: T_1=10°C, p_1=100 kPa
  - Time 2: T_2=10°C, p_2=200 kPa
- Find: Ratio of mass at time 2 to that at time 1
  - Ideal gas law (p is absolute pressure)

$$M = \rho V = \frac{p}{RT} V \qquad \frac{M_1}{M_2} = \frac{\frac{p_1}{RT} V}{\frac{p_2}{RT} V} = \frac{p_1}{p_2}$$

$$\boxed{\frac{M_2}{M_1} = \frac{300\,kPa}{200\,kPa} = 1.5}$$

Example (2.8)

- Estimate the mass of 1 mi^3 of air in slugs and kgs
- Assume ρ_{air} = 0.00237 slugs/ft^3, the value at sea level for standard conditions

$$M = \rho_{air} V = 0.00237 * (5{,}280)^3$$

$$\boxed{M = 3.49x10^8 \ slugs}$$

$$M = 3.49x10^8 \ slugs * 14.59 \, kg / slugs$$

$$\boxed{M = 5.09x10^9 \ kg}$$

Elasticity (Compressibility)

- Deformation per unit of pressure change

$$E_v = -\frac{dp}{dV/V} = \frac{dp}{d\rho/\rho}$$

- For water $E_v = 2.2$ GPa,

  1 MPa pressure change = 0.05% volume change

  Water is relatively incompressible

Example (2.45)

- **Given:** Pressure of 2 MPa is applied to a mass of water that initially filled 1000-cm^3 volume.
- **Find:** Volume after the pressure is applied.
- **Solution:** $E = 2.2x10^9$ Pa (Table A.5)

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

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

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

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

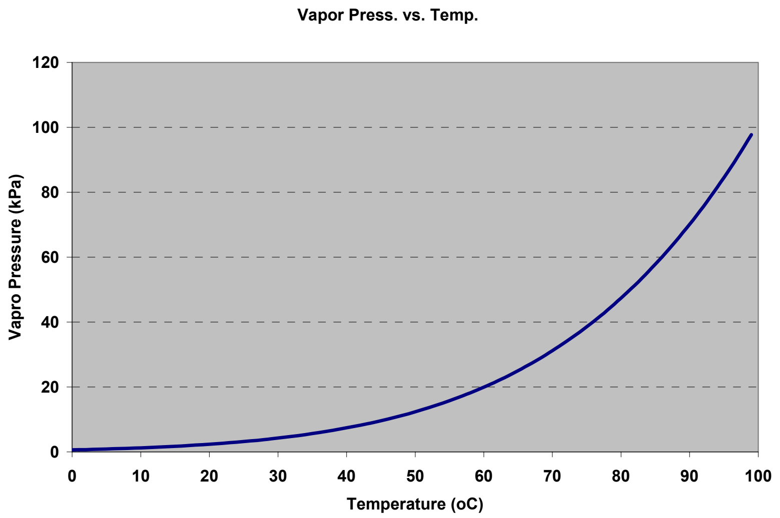
$$V_{final} = V + \Delta V$$

$$= 1000 - 0.909$$

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

Vapor Pressure

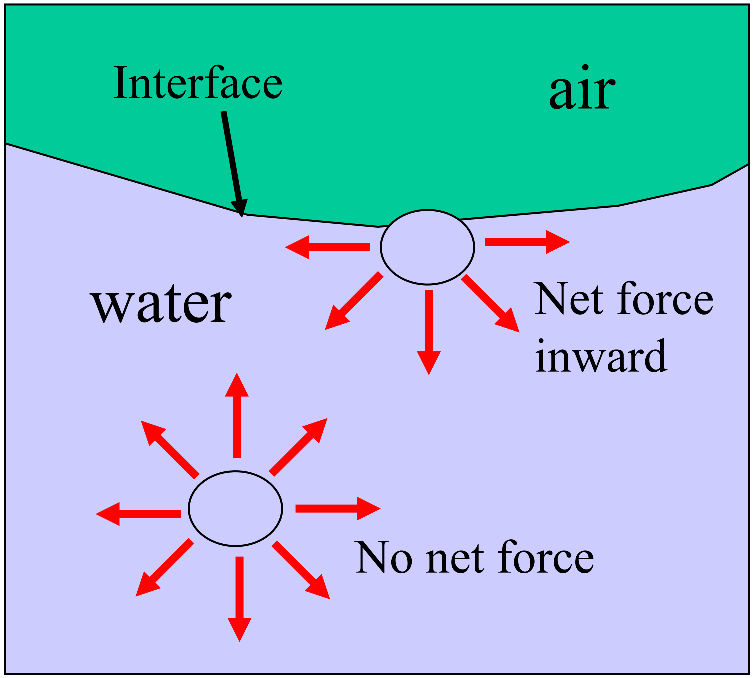
- Pressure at which a liquid will boil for given temp.
- Vapor pressure increases with temperature
  - Increasing temperature of water at sea level to 212 ^{o}F, increases the vapor pressure to 14.7 psia and boiling occurs
  - Boiling can occur below 212 ^{o}F if we lower the pressure in the water to the vapor pressure of that temperature



- At 50 ^{o}F, the vapor pressure is 0.178 psia
- If you reduce the pressure in water at this temperature, boiling will occur (cavitation)

Surface Tension

- Below surface, forces act equally in all directions
- At surface, some forces are missing, pulls molecules down and together, like membrane exerting *tension* on the *surface*
- If interface is curved, higher pressure will exist on concave side
- Pressure increase is balanced by surface tension, σ
- $\sigma = 0.073$ N/m (@ 20^{o}C)



Capillary Rise

- **Given:** Water @ 20°C,
  d = 1.6 mm
- **Find:** Height of water
- **Solution:** Sum forces in vertical

  Assume θ small, $\cos\theta \rightarrow 1$

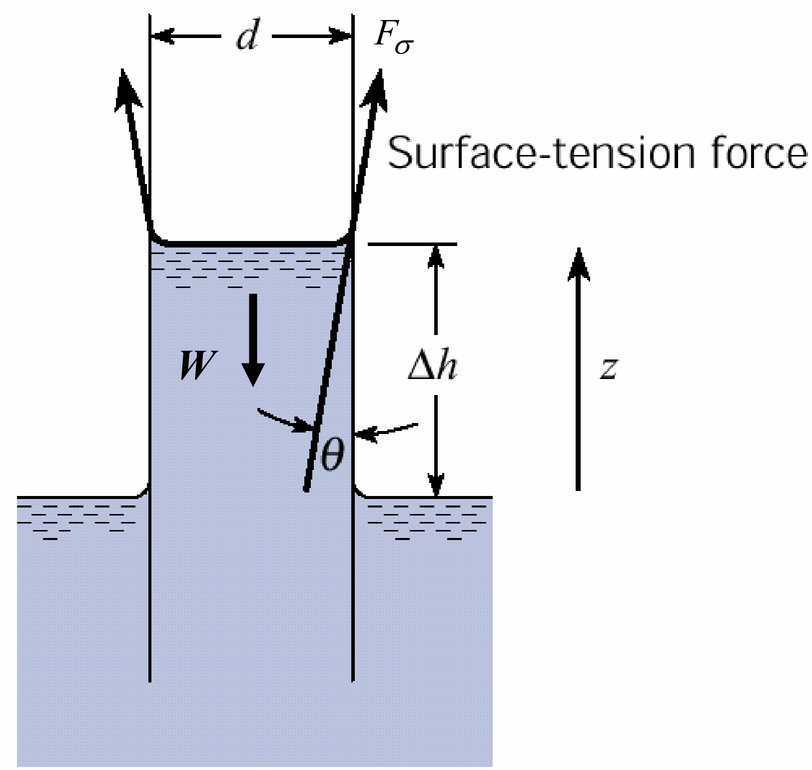
$$F_{\sigma,z} - W = 0$$

$$\sigma \pi d \cos\theta - \gamma(\Delta h)\left(\frac{\pi}{4} d^2\right) = 0$$

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

$$= \frac{4 * 0.073}{9790 * 1.6x10^{-3}}$$

$$\boxed{\Delta h = 18.6\, mm}$$



Example (2.51)

- **Find:** Capillary rise between two vertical glass plates 1 mm apart.

□ σ = 7.3x10^{-2} N/m

l is into the page

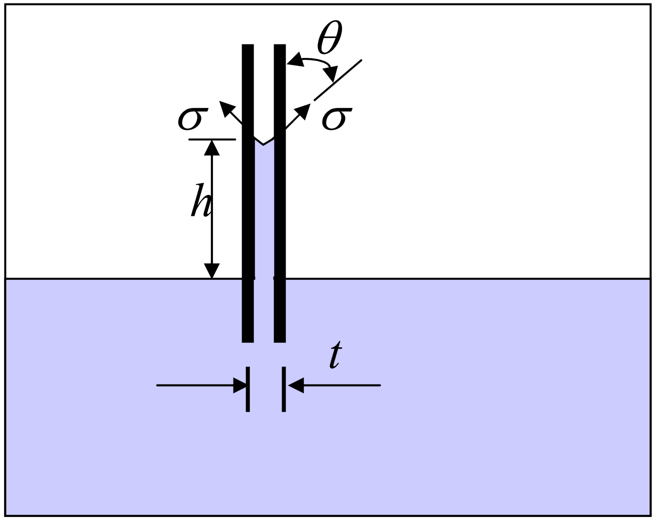
- **Solution:** $\sum F_{vertical} = 0$

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

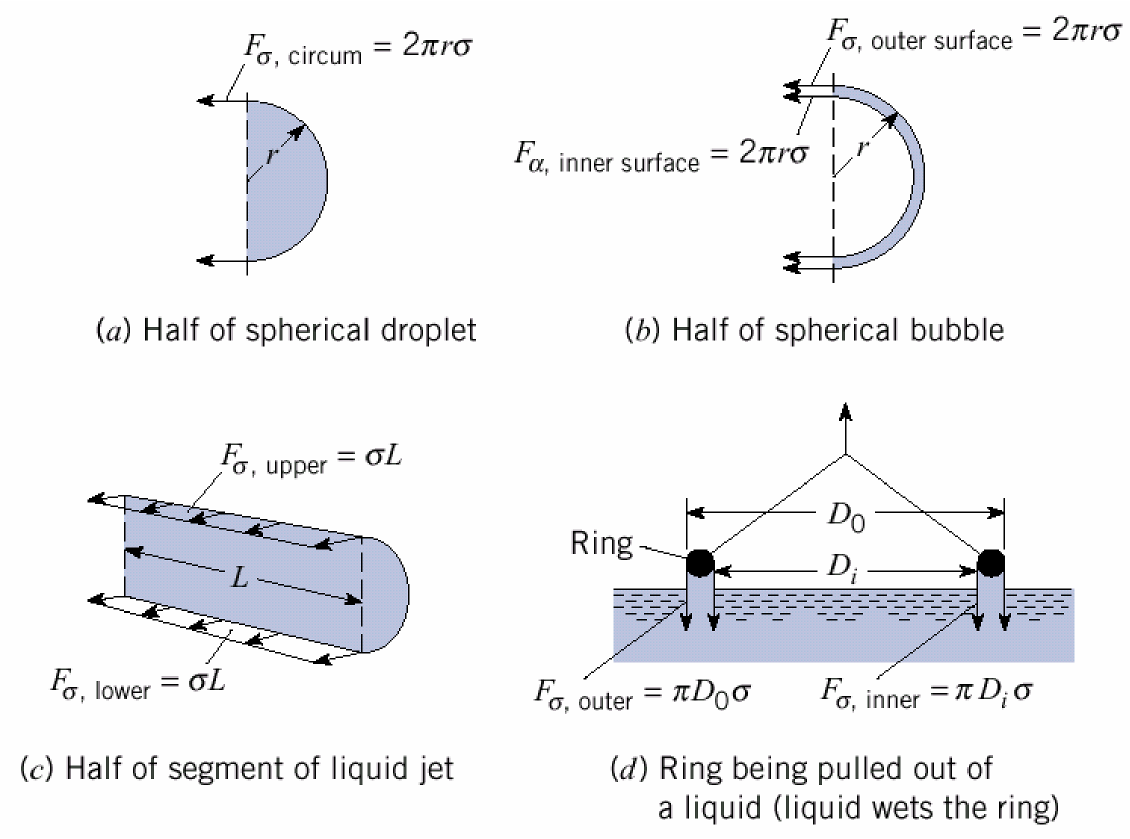
$$h = \frac{2\sigma}{t\gamma}$$

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

$$\boxed{\begin{aligned} h &= 0.0149\, m \\ h &= 14.9\, mm \end{aligned}}$$

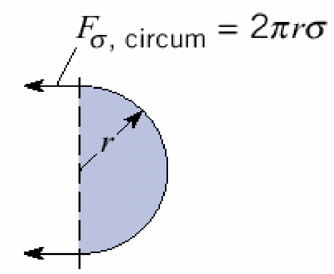


Examples of Surface Tension



Example (2.47)

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



(a) Half of spherical droplet

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

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

Example (2.48)

- **Given:** Sperical bubble, inside radius r, film thickness t, and surface tension σ.
- **Find:** Formula for pressure in the bubble relative to that outside.
- **Solution:**

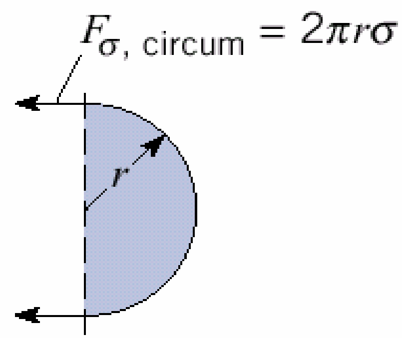
$$\sum F = 0$$

$$\Delta p \pi r^2 - 2(2\pi r\sigma) = 0$$

$$\boxed{\Delta p = \frac{4\sigma}{r}}$$

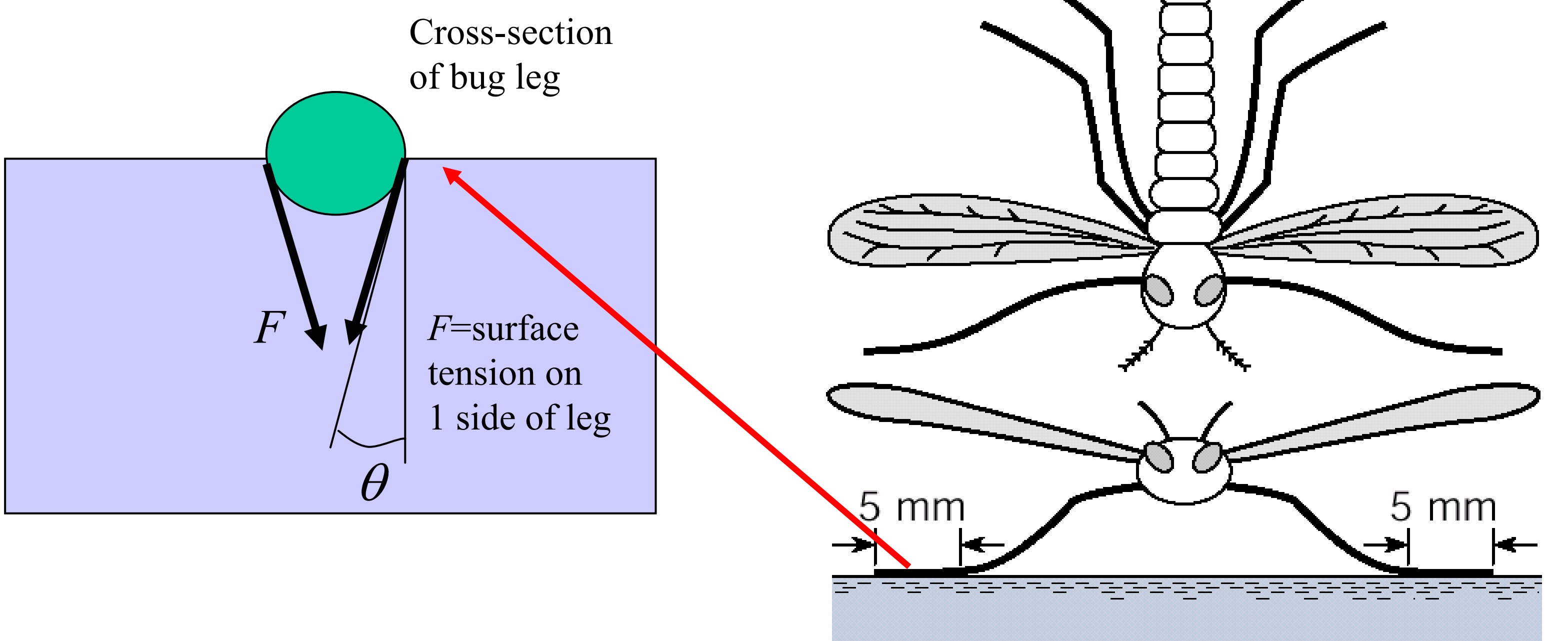
$$\Delta p = \frac{4 * 7.3x10^{-2}}{0.004}$$

$$\boxed{\Delta p = 73.0\, Pa}$$



(a) Half of spherical droplet

Bug Problem


Cross-section
of bug leg
F
F=surface
tension on
1 side of leg
θ
5 mm
5 mm