CE 319 F

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Elementary Mechanics of Fluids

Introduction &

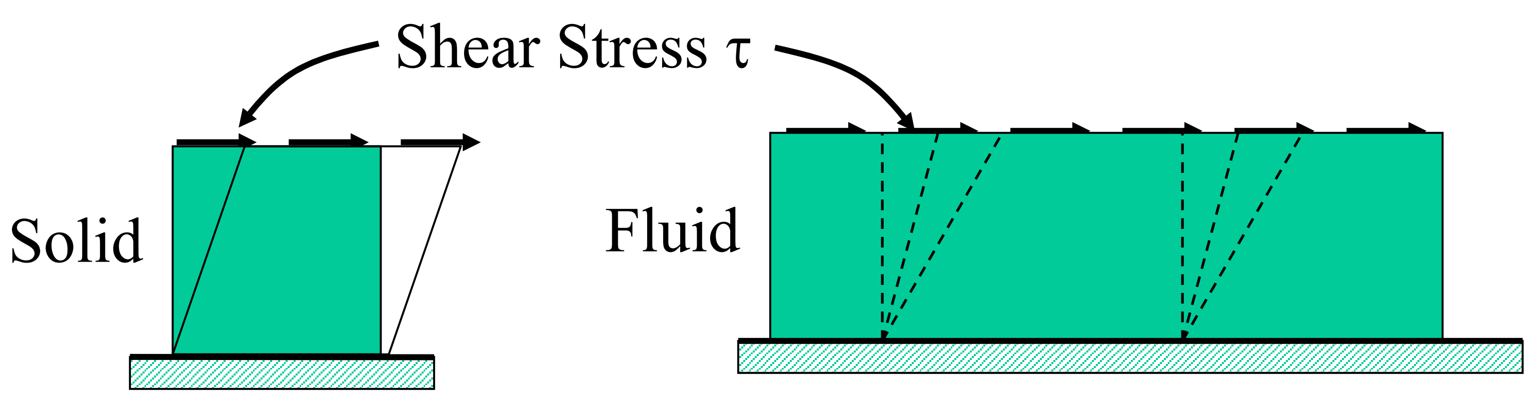
Fluid Properties

Fluid Mechanics

- Definition
  - The study of liquids and gasses at rest (statics) and in motion (dynamics)
- Engineering applications
  - Blood in capillaries
  - Oil in pipelines
  - Groundwater movement
  - Runoff in parking lots
  - Pumps, filters, rivers, etc.

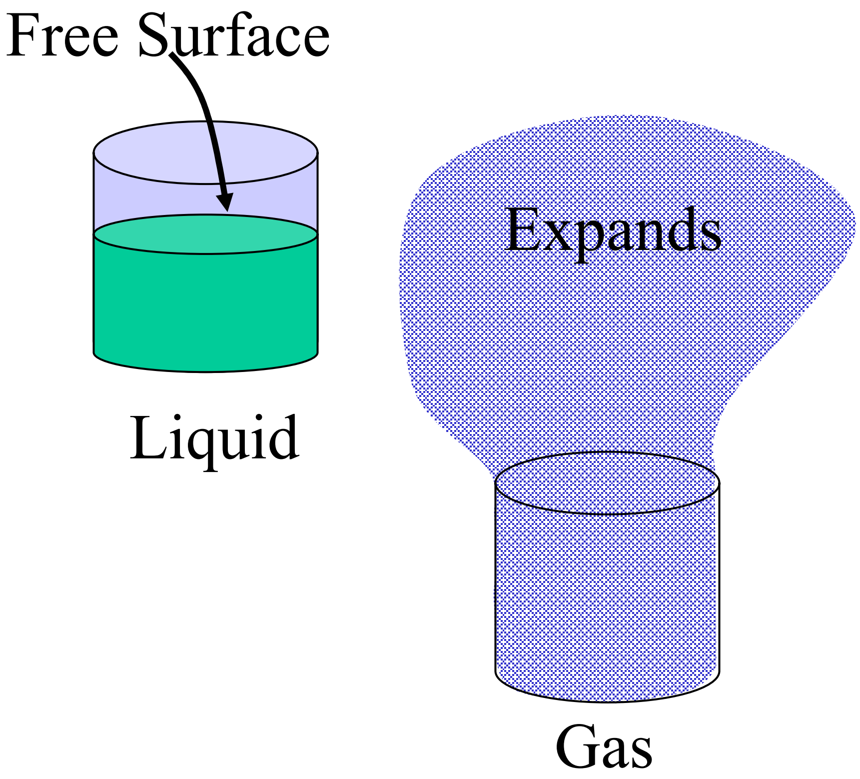
States of Matter

- Fluids (gasses and liquids) and solids
- What's the difference?
  - Fluid particles are free to move among themselves and give way (flow) under the slightest tangential (shear) force



Classes of Fluids

- Liquids and gasses – What's the difference?
  - **Liquids:** Close packed, strong cohesive forces, retains volume, has free surface
  - **Gasses:** Widely spaced, weak cohesive forces, free to expand



Common Fluids

- Liquids:
  - water, oil, mercury, gasoline, alcohol
- Gasses:
  - air, helium, hydrogen, steam
- Borderline:
  - jelly, asphalt, lead, toothpaste, paint, pitch

Primary Dimensions & Units

- **Dimension:** Generalization of "unit" telling us what kind of units are involved in a quantitative statement
  - Mass [M], length [L], time [T], temperature [θ]
- **Unit:** Particular dimension
  - kg, m, s, ^{o}K (Systeme International)
  - slug, ft, s, ^{o}R (British Gravitational)
  - lbm, ft, s, ^{o}R (something else)

What's a SLUG?!

- UC Santa Cruz Mascot
- Unit of mass in the BG system (~ 14.59 kg, ~32.17 lbm)
- 1 lbf will accelerate a slug 1ft/s^2
- 32.17 lb/14.59 kg = 2.2 lbm/kg

$$\vec{F} = m\vec{a}$$

Secondary Units

$$\left[\frac{ML}{T^2}\right] = [M]\left[\frac{L}{T^2}\right]$$

- Force

N	= kg-m/s^2	(Newton)
lbf	= slug-ft/s^2	(pound force)
	= 32.2 lbm-ft/s^2	

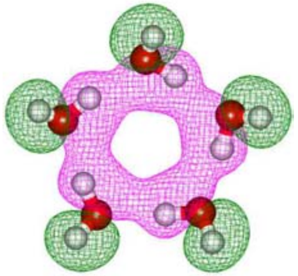
- Work (Force through a distance)

J	= N-m	(Joule)
ft-lbf		(foot pound)

- Energy (Work per time)

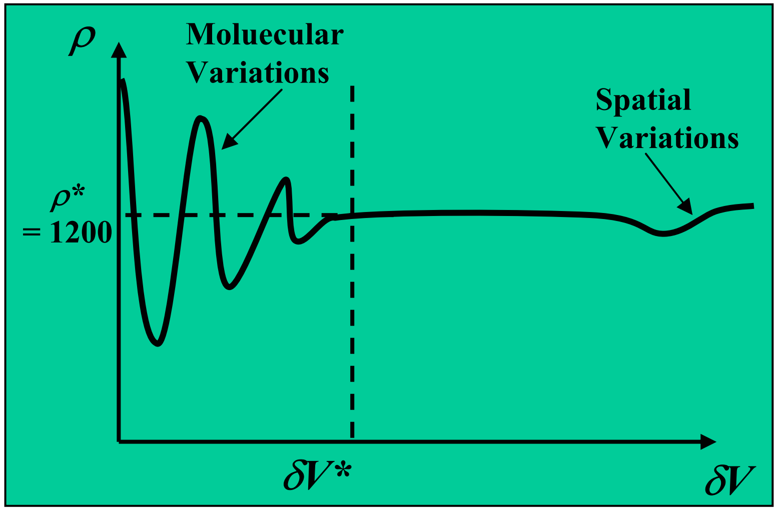
W	= J/s	(Watt)
ft-lbf/s		(foot pound per sec)
hp	550 ft-lb/s	(horsepower)

Fluid as a Continuum



- Fluids are aggregates of molecules
  - Widely spaced: gasses
  - Closely spaced: liquids
- Intermolecular distance is large compared to molecular diameter
- Molecules move freely
- Air at STP:

  $\delta V^{*}=10^{-9}$ mm^3 and contains $3\text{x}10^7$ molecules
- Continuum hypothesis



Fluid Properties

- Density: Mass per unit volume
  - How large is the volume?
    - Too small: # molecules changes continuously
    - Large: # molecules remains almost constant
  - At these scales, fluid properties (e.g., density) can be thought of as varying continuously in space.

$$\rho = \lim_{\delta V \to \delta V^*} \frac{\delta m}{\delta V}$$

Density

- Mass per unit volume (e.g., @ 20 ^{o}C, 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 gasses increase with pressure
- Densities of liquids are nearly constant (incompressible) for constant temperature
- Specific volume = 1/density

Specific Weight

$$\gamma = \rho g \qquad [N/m^3] \text{ or } [lbf/ft^3]$$

- Weight per unit volume (e.g., @ 20 ^oC, 1 atm)

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

$[= 62.4\ lbf/ft^3]$

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

$[= 0.0752\ lbf/ft^3]$

Specific Gravity

- Ratio of fluid density to density at STP

  (e.g., @ 20 ^{o}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 $SG_{air} = 1$

Table A.4

APPROXIMATE PHYSICAL PROPERTIES OF COMMON LIQUIDS AT ATMOSPHERIC PRESSURE

Liquid and temperature	Density kg/m^3 ($slugs/ft^3$)	Specific gravity (S) water at 4°C is ref.	Specific weight, N/m^3 (lbf/ft^3)	Dynamic viscosity, $N \cdot s/m^2$ ($lbf\text{-}s/ft^2$)	Kinematic viscosity, m^2/s (ft^2/s)	Surface tension, N/m* (lbf/ft)
Ethyl alcohol[3][1]	799	0.79	7,850	1.2×10^{-3}	1.5×10^{-6}	2.2×10^{-2}
20°C (68°F)	(1.55)		(50.0)	(2.5×10^{-5})	(1.6×10^{-5})	(1.5×10^{-3})
Carbon tetrachloride[3]	1,590	1.59	15,600	9.6×10^{-4}	6.0×10^{-7}	2.6×10^{-2}
20°C (68°F)	(3.09)		(99.5)	(2.0×10^{-5})	(6.5×10^{-6})	(1.8×10^{-3})
Glycerine[3]	1,260	1.26	12,300	6.2×10^{-1}	5.1×10^{-4}	6.3×10^{-2}
20°C (68°F)	(2.45)		(78.5)	(1.3×10^{-2})	(5.3×10^{-3})	(4.3×10^{-3})
Kerosene[2][1]	814	0.81	8,010	1.9×10^{-3}	2.37×10^{-6}	2.9×10^{-2}
20°C (68°F)	(1.58)		(51)	(4×10^{-5})	(2.55×10^{-5})	(2.0×10^{-3})
Mercury[3][1]	13,550	13.55	133,000	1.5×10^{-3}	1.2×10^{-7}	4.8×10^{-1}
20°C (68°F)	(26.3)		(847)	(3.2×10^{-5})	(1.3×10^{-6})	(3.3×10^{-2})
Sea water 10°C	1,026	1.03	10,070	1.4×10^{-3}	1.4×10^{-6}	
at 3.3% salinity	(1.99)		(64.1)	(3×10^{-5})	(1.5×10^{-5})	
Oils—38°C (100°F)						
SAE 10W[4]	870	0.87	8,530	3.6×10^{-2}	4.1×10^{-5}	
	(1.69)		(54.4)	(7.4×10^{-4})	(4.4×10^{-4})	
SAE 10W-30[4]	880	0.88	8,630	6.7×10^{-2}	7.6×10^{-5}	
	(1.71)		(55.1)	(1.4×10^{-3})	(8.2×10^{-4})	
SAE 30[4]	880	0.88	8,630	1.0×10^{-1}	1.1×10^{-4}	
	(1.71)		(55.1)	(2.0×10^{-3})	(1.2×10^{-3})	

*Liquid–air surface tension values.

SOURCES: (1) V.L. Streeter, *Handbook of Fluid Dynamics*, McGraw-Hill Book Company, New York, 1961; (2) V.L. Streeter, *Fluid Mechanics*, 4th ed., McGraw-Hill Book Company, New York, 1966; (3) J. Vennard, *Elementary Fluid Mechanics*, 4th ed., John Wiley & Sons, Inc., New York, 1961; (4) R. E. Bolz and G. L. Tuve, *Handbook of Tables for Applied Engineering Sciences*, CRC Press, Inc., Cleveland, 1973.

Ideal Gas Law

- Equation of state

$$pV = nR_nT \qquad\qquad p = \rho RT, \qquad R = R_n / M$$

R_n = universal gas constant

M = molecular weight of the gas