6. Fluid Properties

Some good fluid property references include:

a. Avallone, E.A. and Baumeister III, T., *Marks' Standard Handbook for Mechanical Engineers*, McGraw-Hill.
b. Kestin, J., and Wakeham, W.A., *Transport Properties of Fluids*, CINDAS Data Series on Material Properties, C.Y. Ho, ed., Hemisphere Publishing.

density, ρ {M/L^3}, [kg/m^3, slugs/ft^3, lb$_m$/ft^3]

- The density of a substance is a measure of how much mass there is of the substance per unit volume.
- $$\rho_{\mathrm{H_20@4^\circ C}} = 1000\ \mathrm{kg/m^3} = 1.94\ \mathrm{slugs/ft^3} = 62.4\ \mathrm{lb_m/ft^3}$$
  $$\rho_{\mathrm{air@15^\circ C,1\ atm}} = 1.23\ \mathrm{kg/m^3} = 2.38*10^{-3}\ \mathrm{slugs/ft^3} = 7.68*10^{-2}\ \mathrm{lb_m/ft^3}$$
- Density <u>does not</u> vary greatly with temperature for liquids, in general.
- Density <u>does</u> change considerably with temperature and pressure for gases.
- A substance where the <u>density remains constant</u> for all conditions is considered <u>incompressible</u>.
  - A good engineering rule of thumb is that if there are no significant temperature changes and for fluid velocities less than approximately 1/3 the speed of sound in the fluid, the fluid can be approximated as incompressible (the proof of this is examined when discussing compressible fluid flow).
    - In air, the speed of sound at standard conditions (p = 1 atm, T = 59 °F = 15 °C), is approximately 1100 ft/s (340 m/s).
    - The speed of sound in water is approximately 4800 ft/s (1500 m/s).
    - The speed of sound in steel is approximately 16400 ft/s (5000 m/s).
    - In most instances, liquids and gases flowing at low speeds can be approximated as incompressible.

- <u>specific gravity, *SG*</u> {no units – dimensionless}
  - The specific gravity of a liquid is the ratio of the liquid's density to the density of water at some specified condition, typically at 4 °C.

    $$SG_{\mathrm{liquid}} \equiv \frac{\rho_{\mathrm{liquid}}}{\rho_{\mathrm{H_2O@4^oC}}}$$

    For example, the density of mercury (Hg) at 20 °C is 13.6*10^3 kg/m^3. Hence, SG_{Hg} = 13.6.

- <u>specific weight, γ</u> {F/L^3} [N/m^3, lb$_f$/ft^3]
  - The specific weight of a substance is the weight of the substance per unit volume.

    $$\gamma \equiv \frac{W}{V} = \frac{mg}{V} = \frac{\rho V g}{V}$$
    $$\therefore \gamma = \rho g$$

    For example, the specific weight of water at 4 °C is 9.81*10^3 N/m^3 = 62.4 lb$_f$/ft^3.

- <u>specific volume, *v*</u> {L^3/M} [m^3/kg, ft^3/slug, ft^3/lb$_m$]
  - The specific volume of a substance is how much volume the substance occupies per unit mass.
  - The specific volume is simply the inverse of the density,

    $$v = \frac{1}{\rho}$$

  - In thermodynamics, the specific volume is commonly used in place of density.

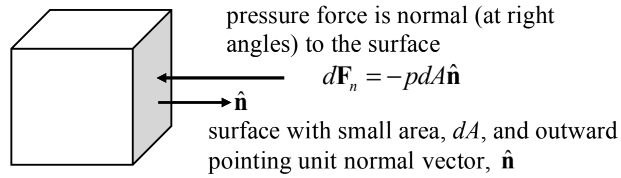
Be Sure To:

1. Be careful when using the incompressible flow assumption. Make sure that the assumption is reasonable for your flow situation. For liquids, the assumption is usually reasonable. For gases, you need to check the flow velocities and temperatures.

pressure, p $\{F/L^2\}$ [Pa = N/m^2, psf=lb$_f$/ft^2, psi=lb$_f$/in^2, torr, atm, bar]

- Pressure is the inward acting force per unit area acting normal to a surface.

$$\underbrace{d\mathbf{F}_n}_{\text{small normal force acting on surface}} = \underbrace{-}_{\text{negative sign since pressure acts inward on surface}} \underbrace{p}_{\text{pressure acting on surface}} * \underbrace{dA}_{\text{area of surface}} * \underbrace{\hat{\mathbf{n}}}_{\text{outward pointing unit normal vector for the surface}}$$



- Pressure is a scalar quantity. It has no direction (it's a number – just like temperature). The surface orientation is what gives the pressure force its direction.

Proof: Consider the pressure forces acting on a small triangular wedge of fluid at rest. Assume the wedge extends a depth of 1 (unit depth) into the page. Also assume that the pressure depends on direction.

$$\sum F_x = m\ddot{x}$$

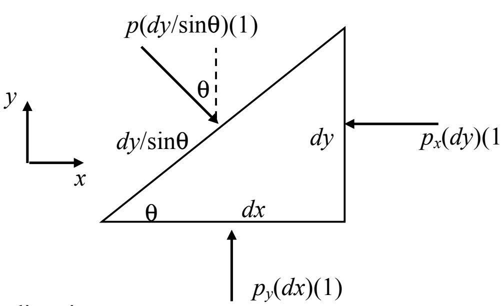
$$p\left(\frac{dy}{\sin\theta}\right)(1)\sin\theta - p_x(dy)(1) = \rho\left(\tfrac{1}{2}dxdy\right)(1)\ddot{x}$$

$$(p - p_x)dy = \rho\left(\tfrac{1}{2}dxdy\right)\ddot{x}$$

As $dx, dy \to 0$, $p = p_x$

A similar approach can be taken in the y-direction to find $p = p_y$.

Thus, we observe that the pressure is the same in every direction.



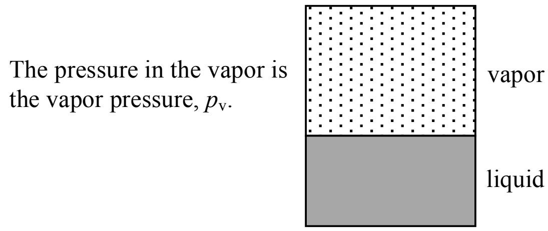
- Pressure is the result of molecules colliding against (a real or imaginary) surface. Every time a particle bounces off a surface, its momentum, $m\mathbf{u}$, changes ($\mathbf{u}$ changes direction). From Newton's 2nd Law, $\mathbf{F}=d/dt(m\mathbf{u})$, so there must be a force exerted on the molecule by the wall (and conversely, on the wall by the molecule) in order to cause the change in the molecule's momentum. These collisions result in what we call pressure.

- Absolute pressure [psia] is referenced to zero pressure (a perfect vacuum has $p_{\text{vacuum,abs}} = 0$).
  - There are no molecules in a perfect vacuum thus there is no pressure (due to molecular collisions).
  - Atmospheric pressure at standard conditions:
    $p_{\text{atm, abs}}$ = 14.696 psia = 101.33*10^3 Pa (abs) = 1 atm = 1.0133 bar = 760 torr

  - Gage pressure [psig] is referenced to atmospheric pressure: $p_{\text{gage}} = p_{\text{abs}} - p_{\text{atm}}$
    - Atmospheric pressure at standard conditions: p_{atm} = 0 psig.
    - A perfect vacuum has p_{vacuum} = -14.7 psig (referencing to standard atmospheric conditions).

  - An important equation of state for an ideal gas is the ideal gas law:
    $p = \rho RT$
    Note that p and T are absolute quantities, e.g., [p] = psia or Pa (abs), [T] = °R or K

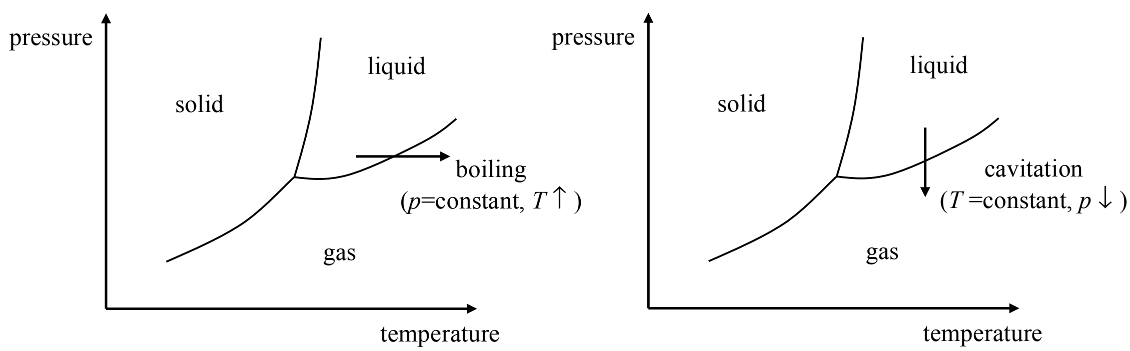
- The vapor pressure, p_v of a liquid is the pressure at which the liquid is in equilibrium with its own vapor.



A closed container with the liquid and vapor in equilibrium.

  - The vapor pressure for a liquid will increase with increasing temperature.

  - If the pressure in the liquid falls below the vapor pressure, then the liquid will turn to vapor. This can occur via boiling or cavitation.
    - Boiling occurs when the temperature of the liquid increases so that the vapor pressure equals the surrounding atmospheric pressure. For example, the vapor pressure of water at 20 °C is 0.023 atm while the vapor pressure at 100 °C is 1 atm. Hence, one method of turning liquid water to vapor is to bring the water temperature to 100 °C while holding the surrounding pressure at 1 atm. This is known as boiling and is shown schematically in the phase plot shown below on the left-hand side.
    - Cavitation occurs when the surrounding pressure drops below the vapor pressure. Using the previous example, we can also turn liquid water to water vapor by dropping the surrounding pressure to 0.023 atm at 20 °C. This is shown schematically in the phase plot shown below on the right-hand side.



    - Cavitation can cause considerable damage to surfaces. When cavitation occurs in a liquid, pockets of vapor form (either as bubbles or large "voids"). As the vapor pockets travel into a region where the surrounding pressure is greater than the vapor pressure, the vapor region rapidly collapses. This collapse can be so rapid that shock waves and high speed water jets propagate from the collapsing region and impact on nearby surfaces causing small bits of the surface to erode away. Hence, cavitation is typically avoided when designing pumps, pipe bends, and underwater propellers.

Be Sure To:
1. Use an absolute pressure, and not a gage pressure, in the ideal gas law.
2. Be careful not to mix gage and absolute pressures when evaluating pressure forces.
3. Use the correct area when calculating a pressure force.
4. Integrate to find a pressure force when the pressure is not uniform over the area over which the pressure acts.
5. Check for cavitation in low pressure flows of liquids.