The University of Jordan
Faculty of Engineering & Technology
Chemical Engineering Department

Chemical Engineering Principles (0905211)

Processes and Process Variables

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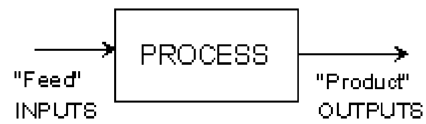
- Temperature

Introduction

- A Process is any operation or series of operation which cause physical or chemical changes in a substance or a mixture of substances.



- A Process usually consists of multiple steps, each of which is carried out in a process unit.
- A Process unit is an apparatus, equipment in which one of the operations that constitute a process is carried out.
- Each process unit has associated with it a set of input and output "process streams", which consists of materials that enter and leave the unit.
- Process Streams: A process stream is a line that represents the movement of material to form process unit .
- They are labeled with information regarding the amounts compositions , temperatures ,pressures of the components.

- Process Flow sheet: is a sequence of process units connected by process streams. It shows the flow of materials and energy through the units.

A chemical engineer task is to design or operate a process

Design

includes formulation of a process flowsheet (layout)

specification of individual process units (such as reactors, separation equipment, heat exchangers)

specification of operating variables,

operation involves the day-to-day running of the process.

To design or analyze a process,
we need to know the **amounts**, **compositions**, and **condition** of materials entering, leaving, and within the process.

Process variables are quantities used to describe a process. These must be measured or computed.

Density, Mass & Volume

- Density(ρ) = mass (m) per unit volume (V) of substance(kg/m^3, g/cm^3, lbm/ft^3)
- Can be used as a conversion factor to relate the mass and volume of a substance
- Densities of pure solids and liquids are essentially independent of pressure and vary slightly with temperature

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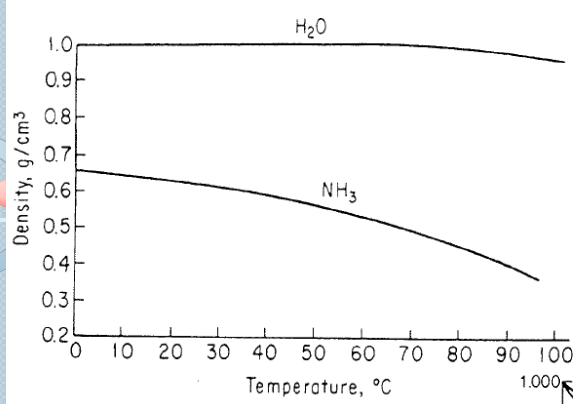
For most compounds, density decreases with temperature (volume expansion). Water is an exception:

Density (H_2O (liquid)) **= 0.999868 g/cm^3 at 0°C**
= 1.00000 g/cm^3 at 4°C
= 0.95828 g/cm^3 at 100°C

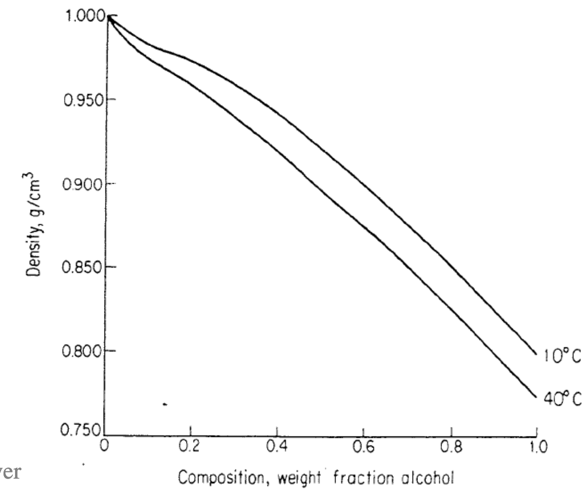
- Assumptions:
- Solids and liquids are *incompressible* Ł density constant with pressure but changes slightly with temperature
- Gases (vapors) are *compressible* Ł density changes with pressure

Gas/vapor densities depend heavily on Pressure and Temperature.

You must almost always treat them as direct functions of P, T, or both



Density of ammonia and water as a function of temperature



Density of a mixture of ethanol and water as a function of composition

$$\frac{1}{\bar{\rho}} = \sum_{i=1}^{n} \frac{x_i}{\rho_i}$$

Specific volume ($1/\rho$) = volume occupied by a unit mass of a substance; units length^3/mass (reciprocal of density)

Specific gravity (SG) = ratio of the density (ρ) of a substance to the density (ρ_{ref}) of a reference substance at a specific condition; dimensionless

$$SG = \frac{\rho}{\rho_{ref}} = \frac{density\ of\ substance}{density\ of\ reference\ substance} = [\ ]\ dimensionless$$

The reference commonly used for solids and liquids is water at 4°C, which has the following density:

$$\rho_{ref} = \rho_{H_2O}\Big|_{@4^0C} = 1.000\,g/cm^3 = 1000\,kg/m^3 = 62.43\,lbm/ft^3$$

The following notation signifies that the specific gravity of a substance at 20°C with reference to water at 4°C is 0.6.

$$SG = 0.6\frac{20°}{4°}$$

Or simply: SG = 0.6

If $sg = 0.6$

$$\rho = (0.6)\left(1000\,\mathrm{kg/m^3}\right) = 600\,\mathrm{kg/m^3}$$

Remember that

$$\rho_{H_2O(l)}(4^\circ C) = 1.000\ \mathrm{g/cm^3} = 1000.\ \mathrm{kg/m^3} = 62.43\ \mathrm{lb_m/ft^3}$$

$$\left(\rho = 62.4\,\mathrm{lb_m/ft^3} = 1000\,\mathrm{kg/m^3}\right)$$

EXAMPLE

Mass, Volume, and Density

Calculate the density of mercury in lb_m/ft^3 from a tabulated specific gravity, and calculate the volume in ft^3 occupied by 215 kg of mercury.

EXAMPLE

You have a drum containing 8.00 liters of toluene. What is the mass of the liquid?

Effect of Temperature on Liquid Density

the effect of temperature on liquid density is measurable.

mercury in a thermometer rises or falls with changing temperature

Coefficient of linear and cubic (volume) expansion of selected liquids and solids are available, in Perry‘s Chemcial engineer‘s Handbook, as empirical polynomial functions

For mercury $V(T) = V_0\left(1 + 0.18182 \times 10^{-3}T + 0.0078 \times 10^{-6}T^2\right)$

$V(T)$ is the volume of a given mass of mercury at temperature T(°C)

V_0 is the volume of the same mass of mercury at 0°C.

EXAMPLE

215 kg of mercury was found to occupy 0.560 ft^3 at 20°C.

Find volume at 100°C

Suppose the mercury is contained in a cylinder having a diameter of 0.25 in. What change in height would be observed as the mercury is heated from 20°C to 100°C

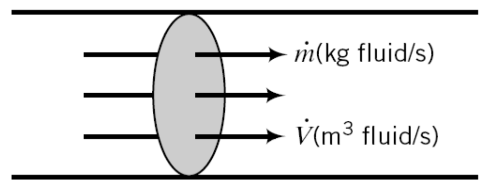
Flow Rate

Flow Rate : the rate at which a material is transported through a process line

$$\text{Mass flow rate} = \dot{m} = \frac{\text{mass}}{\text{time}}$$

$$\text{Volume flow rate} = \dot{V} = \frac{\text{volume}}{\text{time}}$$

where, the “dot” above the m and V refers to a flow rate i. e relatively to time



the mass m and the volume V of a fluid are related through the fluid density, ρ:

$$\rho = m/V = \dot{m}/\dot{V}$$

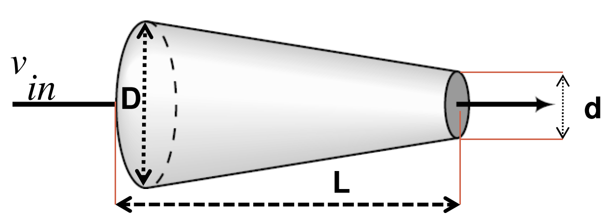
$$\Rightarrow \quad \dot{m} = \rho \dot{V}$$

The volumetric flow rate is then calculated from the velocity and the cross-sectional area of the pipe:

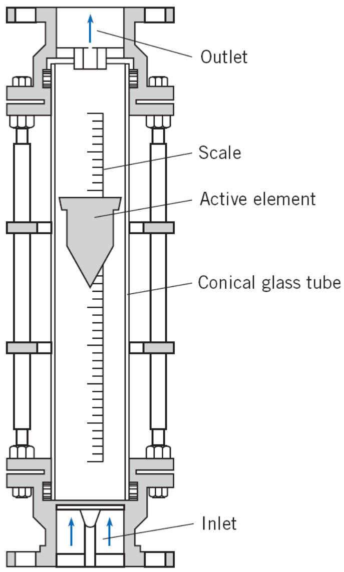
$$\dot{V} = A\,v$$

Task:

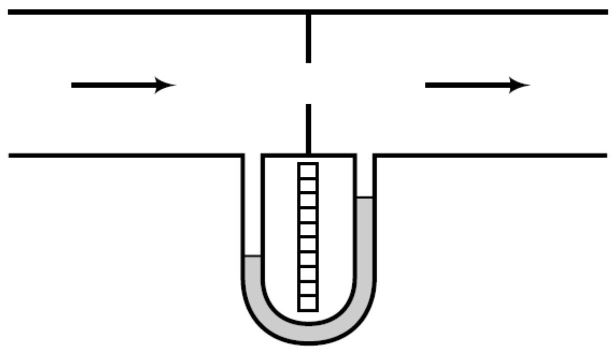
Find the relation between the volumetric flow rate and the diameter for a flow a conical shape pipe



Flow Rate Measurement (Flowmeters)



Rotameter



Orifice meter

Task: Problem 3.13 (p. 67)

Chemical composition (Concentration)

The physical properties of a mixture depend strongly on the mixture composition.

Moles and Molecular Weight

Atomic Weight : the mass of an atom of an element

Mole : the amount of a species whose mass in grams is numerically equal to its molecular weight.

$$1 mole - - - -- > 6.02 \times 10^{23} \text{ (Avogadro's number) molecules}$$

Molecular Weight : the sum of the atomic weights of the atoms that constitute a molecule of the compound (same as molar mass)(kg/kmol, g/mol or lbm/lb-mole)

$$M = n(moles) \times mass$$

Carbon Dioxide has a molecular weight of 44,

→ Mol of CO_2 contains 44 grams

If the molecular weight of a substance is M, then there are M grams per gram-mole. Or

$$M \text{ kg/kmol}, \; M \text{ g/mol}, \; and$$

$$M \text{ lb}_m\text{/lb-mole } \textit{of this substance.}$$

→ You can use the molecular weight as a conversion factor for going from mass to moles.

EXAMPLE

34 kg of ammonia (NH_3: $M = 17$) is equivalent to

$$\frac{34 \text{ kg } NH_3 \;\Big|\; 1 \text{ kmol } NH_3}{\;\Big|\; 17 \text{ kg } NH_3} = 2.0 \text{ kmol } NH_3$$

4.0 lb-moles of ammonia

$$\frac{4.0 \text{ lb-moles } NH_3 \;\Big|\; 17 \text{ lb}_m \text{ } NH_3}{\;\Big|\; 1 \text{ lb-mole } NH_3} = 68 \text{ lb}_m \text{ } NH_3$$

$$454 \text{ g/lb}_m = 454 \text{ mol/lb-mole}$$

EXAMPLE

How many moles in 72 pounds of ammonium nitrate?

The molecular weight is used to convert from mass to moles,

→ It is used to convert between mass and molar rates:

$$\dot{M} = \frac{\dot{m}}{\text{MW}}$$

Conversion Between Mass and Moles

How many of each of the following are contained in 100.0 g of CO_2 ($M = 44.01$)?

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Mass and Mole Fractions

- Process streams occasionally contain one substance, but more often they consist of mixtures of liquids or gases, or solutions of one or more solutes in a liquid solvent.
- The following terms may be used to define the composition of a mixture of substances, including a species A:

$$\text{Mass Fraction}: \; x_A = \frac{\text{mass of } A}{\text{total mass}}\left(\frac{kg\ A}{kg\ total} \text{ or } \frac{g\ A}{g\ total} \text{ or } \frac{lb_m\ A}{lb_m\ total}\right)$$

$$\text{Mole Fraction}: \; y_A = \frac{\text{moles of } A}{\text{total moles}}\left(\frac{kmol\ A}{kmol} \text{ or } \frac{mol\ A}{mol} \text{ or } \frac{lb\text{-}moles\ A}{lb\text{-}mole}\right)$$

→ Unitless

The *mass percent* of A is $100x_A$, and the *mole percent* of A is $100\ y_A$.

Mass fractions can be converted to mole fractions or vice versa by assuming a basis of calculation

EXAMPLE

Conversions Using Mass and Mole Fractions

A solution contains 15% A by mass ($x_A = 0.15$) and 20 mole% B ($y_B = 0.20$).

1. Calculate the mass of A in 175 kg of the solution.

2. Calculate the mass flow rate of A in a stream of solution flowing at a rate of 53 lb_m/h.

3. Calculate the molar flow rate of B in a stream flowing at a rate of 1000 mol/min.

4. Calculate the total solution flow rate that corresponds to a molar flow rate of 28 kmol B/s.

5. Calculate the mass of the solution that contains 300 lb_m of A.

EXAMPLE ***Conversion from a Composition by Mass to a Molar Composition***

A mixture of gases has the following composition by mass:

O_2	16%
CO	4.0%
CO_2	17%
N_2	63%

What is the molar composition?

Basis: 100 g of the mixture.

Component i	Mass Fraction x_i $(g\ i/g)$	Mass (g) $m_i = x_i m_{total}$	Molecular Weight M_i (g/mol)	Moles $n_i = m_i/M_i$	Mole Fraction $y_i = n_i/n_{total}$
O_2	0.16	16	32	0.500	0.150
CO	0.04	4	28	0.143	0.044
CO_2	0.17	17	44	0.386	0.120
N_2	0.63	63	28	2.250	0.690
Total	1.00	100		3.279	1.000

The Average Molecular Weight of a mixture $\overline{M}$ (kg/kmol, lb_m/lb-mole, etc.)

$$\overline{M} = y_1 M_1 + y_2 M_2 + \cdots = \sum_{\text{all components}} y_i M_i$$

y_i is the mole fraction of the ith component

M_i is the molecular weight of this component.

If x_i is the mass fraction of the ith component, then

$$\frac{1}{\overline{M}} = \frac{x_1}{M_1} + \frac{x_2}{M_2} + \cdots = \sum_{\text{all components}} \frac{x_i}{M_i}$$

EXAMPLE

Calculation of an Average Molecular Weight

Calculate the average molecular weight of air (1) from its approximate molar composition of 79% N_2, 21% O_2 and (2) from its approximate composition by mass of 76.7% N_2, 23.3% O_2.

Concentration

Concentration: quantity of a component per unit volume of the mixture.

Mass Concentration : mass of a component per unit volume of the mixture (g/cm^3, lb$_m$/ft^3, kg/in^3,…)

Molar Concentration : number of moles of the component per unit volume of the mixture (kmol/m^3, lb-moles/ft^3)

Trace species (species present in minute amounts) in mixtures of gases or liquids are typically expressed in units of parts per million (ppm) or parts per billion (ppb).

If y_i is the fraction of component *i*, then

$$ppm_i = y_i \times 10^6$$

$$ppb_i = y_i \times 10^9$$

Task: Problem 3.24 (p. 69)

EXAMPLE

If I dissolve 1 g of salt in 1000 liters of water, what is the concentration of the mixture?

EXAMPLE

A 0.50-molar aqueous solution of sulfuric acid flows into a process unit at a rate of 1.25 m^3/min The specific gravity of the solution is 1.03. Calculate

(1) the mass concentration of H_2SO_4 in kg/m^3.

(2) the mass flow rate of H_2SO_4 in kg/s,

(3) the mass fraction of H_2SO_4.

Task: Problem 3.11 (p. 66) and 3.20 (p. 68)

Pressure

Pressure : ratio of a *normal* force to the area on which the force acts

Units:

- SI Unit $\frac{N}{m^2} (or \ \ Pa)$
- CGS Unit $\frac{dynes}{cm^2}$
- American Engineering Unit $\frac{lb_f}{in^2} (or \ \ Psi)$

Hydrostatic pressure

How does the pressure in a fluid at rest vary from point to point?

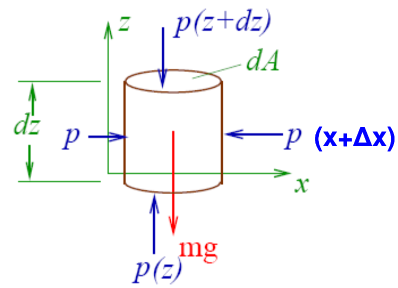
$\sum \delta \mathbf{F} = \delta m\, \mathbf{a}$ For a fluid at rest a = 0.0

$$mg - p(z)dA + p(z+dz)dA = 0$$

$$(\rho dz dA)g - p(z)dA + p(z+dz)dA = 0$$

$$(\rho dz)g - p(z) + p(z+dz) = 0$$

$$\gamma dz - p(z) + p(z+dz) = 0$$



$$\gamma = \rho g$$

$$\frac{dP}{dz} = \lim_{\Delta z \to 0} \frac{(P)_z - (P)_{z+\Delta z}}{\Delta z} = -\rho g = -\gamma$$

$$\frac{\partial p}{\partial z} = -\gamma$$

In the same manner

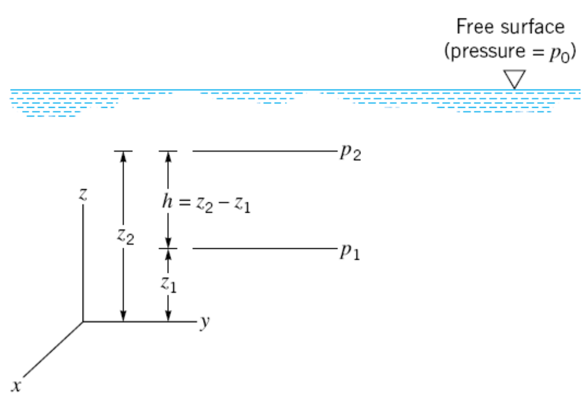
$$\frac{\partial p}{\partial x} = 0 \qquad \frac{\partial p}{\partial y} = 0$$

$$\frac{dp}{dz} = -\gamma$$

$$\int_{p_1}^{p_2} dp = -\gamma \int_{z_1}^{z_2} dz$$

$$p_2 - p_1 = -\gamma(z_2 - z_1)$$

$$p_1 - p_2 = \gamma(z_2 - z_1)$$



$$\Delta P = P_2 - P_1 = \rho g\, \Delta z = \gamma_s\, \Delta z$$

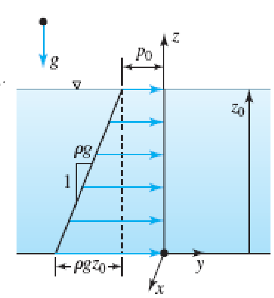
Where the subscripts 1 and 2 refer two different vertical levels as in the schematic.

As in the schematic, noting the definition of h = $z_2 - z_1$

$$p_1 - p_2 = \gamma h$$

$$p_1 = \gamma h + p_2$$

Linear Variation with Depth



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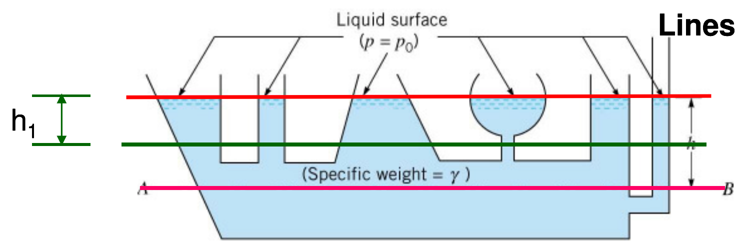
The equation for the pressure head is the following:

$$h = \frac{p_1 - p_2}{\gamma}$$

Physically, it is the height of the column of fluid of a specific weight, needed to give the pressure difference $p_1 - p_2$.

The Pressure in a homogenous, incompressible fluid at rest depends on the depth of the fluid relative to some reference and is not influenced by the shape of the container.

Lines of constant Pressure



For p_2 = $p = \gamma h + p_o$
For p_1 = $p = \gamma h_1 + p_o$

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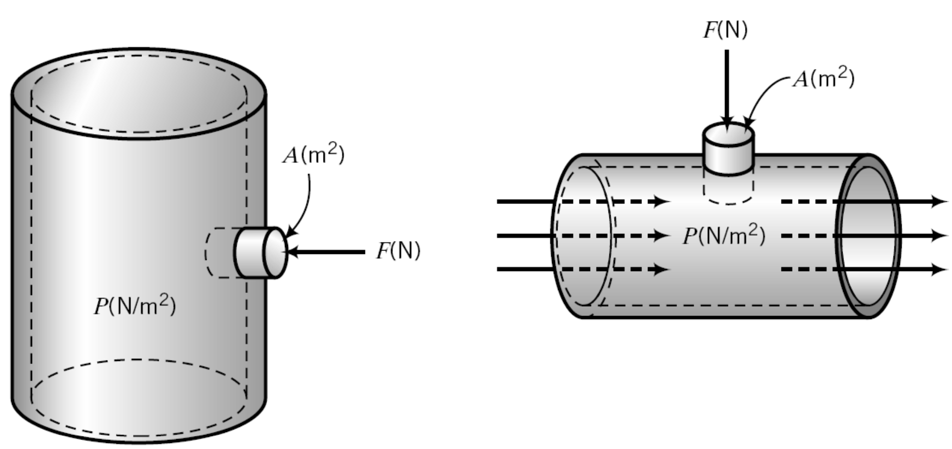

If a fluid is flowing through a horizontal pipe and a leak develops. A force must applied over the area of the hole that causes the leak.

This pressure is called fluid pressure (the force must be applied divided by the area of the hole

The **fluid pressure** is the ratio F/A, where F is the minimum force that would have to be exerted on a frictionless plug in the hole to keep the fluid from emerging.

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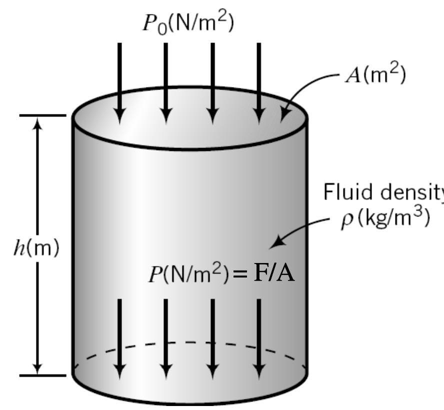
If the vertical container contains a fluid , the mass of it will exert a force on the base on the container.

This pressure is called the hydrostatic pressure. It is the pressure caused by the mass of a fluid



$$P = \frac{F_{base}}{A} = \frac{1}{A}(F_o + W) = \frac{1}{A}\left(F_o + \frac{mg}{g_c}\right) = \frac{F_0}{A} + \frac{\rho hg}{g_c} = P_0 + \frac{\rho hg}{g_c}$$

$$\boxed{P = P_0 + \rho gh}$$

where, P_o is the pressure exerted on the top of the column and g is the acceleration of gravity.

Atmospheric Pressure

Is the hydrostatic pressure exerts on the surface by the air above the earth

$$1 \text{ atm} = 14.696 \text{ psi} = 760 \text{ mm Hg} = 101.325 \text{ kPa}$$

It is useful to have a fixed reference value for atmospheric pressure. The sea-level value is used.

EXAMPLE

What is the hydrostatic pressure exerted by the water in a 6.00 ft diameter cylindrical tank which contains 90.0 gal?

Types of pressure

- Atmospheric pressure P_{atm} is the pressure caused by the weight of the earth's atmosphere. (Barometric Pressure)
- Absolute pressure ,P_{abs} is total pressure and relative to a perfect vacuum (P = 0).
- Gauge pressure ,P_{gauge} is the pressure of the fluid relative to atmospheric pressure. A gauge pressure of 0 indicates that the absolute pressure of the fluid is equal to atmospheric pressure. A relationship for converting between absolute and gauge pressure is:

$$P_{absolute} = P_{gauge} + P_{atmospheric}$$

- Vacuum pressure P_{vac} is a gauge pressure that is a pressure below atmospheric pressure. It is used so that the positive number can be reported.

The standard atmosphere is defined as the pressure equivalent to 760mm of hg at sea level and at 0°C. The unit for it is the atmosphere, atm. Pressure equivalents to the standard atmosphere are:

$$1\,\text{atm} = 760\text{ mm Hg} = 76\text{ cm Hg}$$
$$= 1.013\times10^5 \frac{\text{N}}{\text{m}^2}(or\ \text{Pa}) = 101.3\text{kPa} = 1.013\text{bars}$$
$$= 14.696\text{ psi}(\text{or}\ \frac{\text{lb}_f}{\text{in}^2}) = 29.92\text{ in Hg} = 33.91\text{ ft H}_2O$$

Psia	absolute
Psig	gauge

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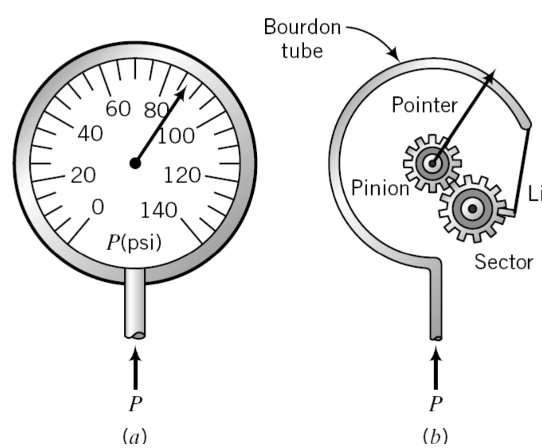
Pressure measuring devices

Bourdon gauge



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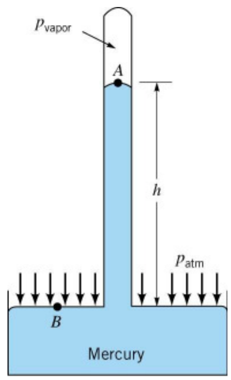
Barometer

Evangelista Torricelli (1608-1647)

The atmospheric pressure at a location is the weight of the air above that location per unit surface area. Therefore, it changes not only with elevation but also with weather conditions.

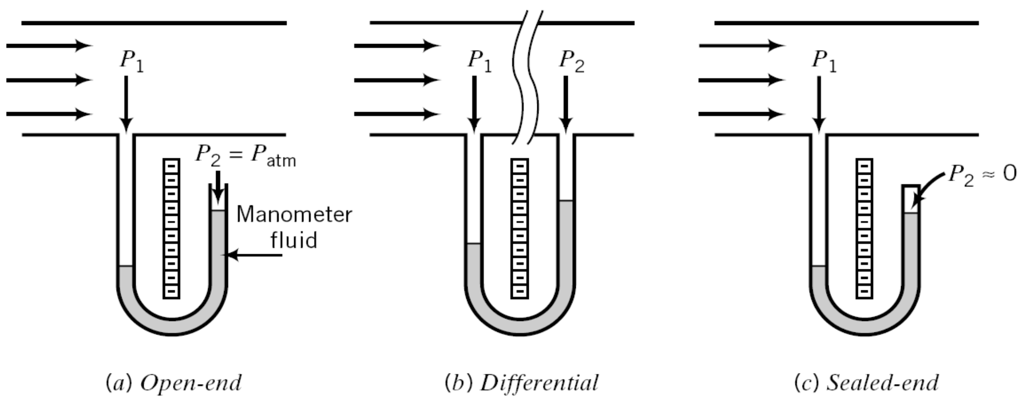


$$p_{atm} = \gamma h + p_{vapor}$$

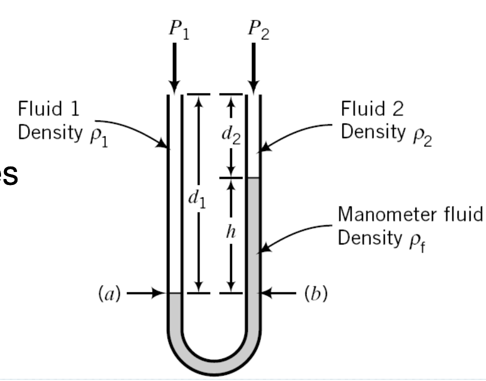
Note, often p_{vapor} is very small, 0.0000231 psia at 68° F, and p_{atm} is 14.7 psi, thus:

$$p_{atm} \approx \gamma h$$

Manometers



Manometers variables



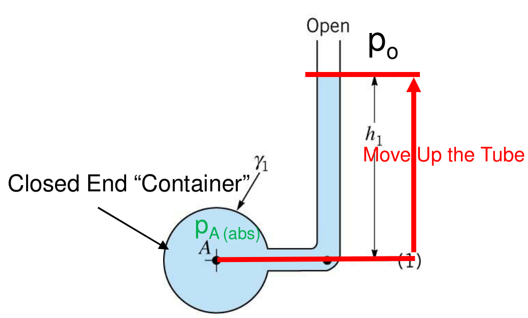
Types of manometers:
1) The Piezometer Tube
2) The U-Tube Manometer
3) The Inclined Tube Manometer

The fundamental equation for manometers since they involve columns of fluid at rest is the following:

$$p = \gamma h + p_0$$

h is positive moving downward, and negative moving upward, that is pressure in columns of fluid decrease with gains in height, and increase with gain in depth.

Piezometer Tube



Disadvantages:
1. The pressure in the container has to be greater than atmospheric pressure.
2. Pressure must be relatively small to maintain a small column of fluid.
3. The measurement of pressure must be of a liquid.

Note: $p_A = p_1$ because they are at the same level

Moving from left to right: $p_{A(abs)} - g_1 h_1 = p_o$

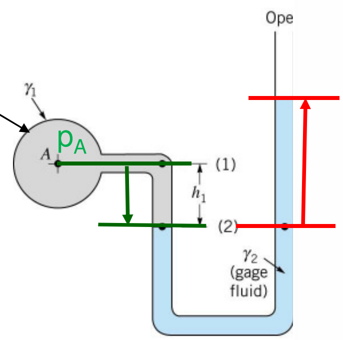
Rearranging: $p_A - p_o = \gamma_1 h_1$

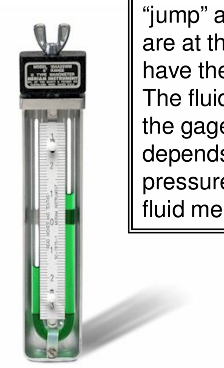
Gage Pressure

Then in terms of gage pressure, the equation for a Piezometer Tube:

$$p_A = \gamma_1 h_1$$

U-Tube Manometer





Note: in the same fluid we can "jump" across from 2 to 3 as they are at the sam level, and thus must have the same pressure.
The fluid in the U-tube is known as the gage fluid. The gage fluid type depends on the application, i.e. pressures attained, and whether the fluid measured is a gas or liquid.

Since, one end is open we can work entirely in gage pressure:

Moving from left to right: $p_A + g_1h_1 - g_2h_2 = 0$

Then the equation for the pressure in the container is the following:

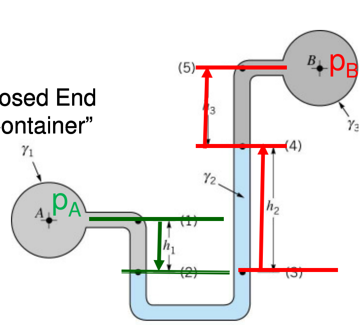
$$p_A = \gamma_2 h_2 - \gamma_1 h_1$$

If the fluid in the container is a gas, then the fluid 1 terms can be ignored:

$$p_A = \gamma_2 h_2$$

U-Tube Manometer

Measuring a Pressure Differential *between* two containers



Final notes:

1. Common gage fluids are Hg and Water, some oils, and must be immiscible.
2. Temp. must be considered in very accurate measurements, as the gage fluid properties can change.
3. Capillarity can play a role, but in many cases each meniscus will cancel.

Meniscus: The curved free surface of a liquid in a capillary tube

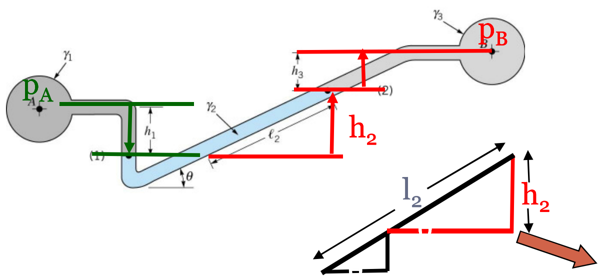
Moving from left to right: $p_A + g_1h_1 - g_2h_2 - g_3h_3 = p_B$

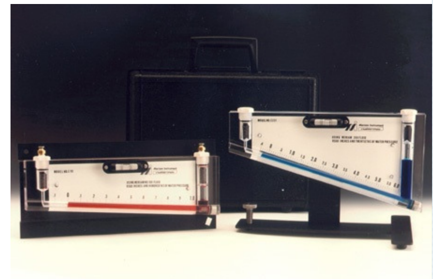
Then the equation for the pressure difference in the container is the following:

$$p_A - p_B = \gamma_2 h_2 + \gamma_3 h_3 - \gamma_1 h_1$$

Inclined-Tube Manometer

This type of manometer is used to measure small pressure changes.





$$\sin\theta = \frac{h_2}{l_2} \Rightarrow h_2 = l_2 \sin\theta$$

Moving from left to right: $p_A + g_1 h_1 - g_2 h_2 - g_3 h_3 = p_B$

Substituting for h_2: $p_A + \gamma_1 h_1 - \gamma_2 \ell_2 \sin\theta - \gamma_3 h_3 = p_B$

Rearranging to Obtain the Difference: $p_A - p_B = \gamma_2 \ell_2 \sin\theta + \gamma_3 h_3 - \gamma_1 h_1$

If the pressure difference is between gases: $p_A - p_B = \gamma_2 \ell_2 \sin\theta$

$$\ell_2 = \frac{p_A - p_B}{\gamma_2 \sin\theta}$$

Thus, for the length of the tube we can measure a greater pressure differential.

Task: Problem 3.34 (p. 73) and 3.42 (p. 74)

Temperature

Temperature is defined as the degree of hotness or coldness of a substance measured on some definite scale

Hotness (and coldness) result from molecular activity
As molecules take up energy, they start to move faster, and the temperature of the substance increase

Temperature is a measure of the average kinetic energy of the molecules of a substance.

Can not be measured directly

Measured indirectly by

Electrical resistance of a conductor	**resistance thermometer**
Voltage at the junction of two dissimilar metal	**thermocouple**
Spectral of emitted radiation	**pyrometer**
Volume of a fixed mass of fluid	**thermometer**

Temperature Scales

Can be defined in terms of any property or physical phenomena, that takes place at fixed temperature, freezing or boiling.

The two most common temperature scales are the Fahrenheit scale and the Celsius scale.
They are defined using T_f and T_b of water at 1 atm at sea level

Celsius (or centigrade) scale:

T_f is assigned a value of (0 degrees C,) and T_b a value (100 degrees C)

Absolute zero (theoretically the lowest temperature attainable in nature) on this scale falls at −273.15°C.

Fahrenheit scale:

T_f is assigned a value of 32°F, and T_b is assigned a value of 212°F. Absolute zero falls at −459.67°F.

Relation between temperature scales

$$T(\text{K}) = T(^\circ\text{C}) + 273.15$$
$$T(^\circ\text{R}) = T(^\circ\text{F}) + 459.67$$
$$T(^\circ\text{R}) = 1.8T(\text{K})$$
$$T(^\circ\text{F}) = 1.8T(^\circ\text{C}) + 32$$

$$y = ax + b$$

$$T(^\circ\text{F}) = aT(^\circ\text{C}) + b$$

Example

$T_1 = 0^\circ\text{C}\ (32^\circ\text{F})$ and $T_2 = 100^\circ\text{C}\ (212^\circ\text{F})$.

$$32 = (a)(0) + b \Longrightarrow b = 32$$
$$212 = (a)(100) + 32 \Longrightarrow a = 1.8$$

Conversion between temperature scales

$$\frac{212^\circ F - 32^\circ F}{100^\circ C - 0^\circ C} = \frac{180F^\circ}{100C^\circ} = 1.8\frac{F\text{ degrees}}{C\text{ degrees}}$$

$$\frac{1.8^\circ\text{F}}{1^\circ\text{C}}, \frac{1.8^\circ\text{R}}{1\text{ K}}, \frac{1^\circ\text{F}}{1^\circ\text{R}}, \frac{1^\circ\text{C}}{1\text{ K}}$$

$T(^\circ\text{C}) \rightarrow$	0	1	2	3	4	5
$T(\text{K}) \rightarrow$	273	274	275	276	277	278

$T(^\circ\text{F}) \rightarrow$	32	33	34	35	36	37	38	39	40	41
$T(^\circ\text{R}) \rightarrow$	492	493	494	495	496	497	498	499	500	501

Note: keep in mind that these conversion factors refer to temperature interval and not temperatures

i.e. when converting an interval, you don't need to compensate for the zero shift

Example

You have a mixture at 50 degrees F and increase its temperature by 30°C degrees. What is the final temperature?

Example

the number of Celsius degrees between 32°F and 212°F

Example

Consider the interval from 20°F to 80°F.

1. Calculate the equivalent temperatures in °C and the interval between them.

2. Calculate directly the interval in °C between the temperatures.

Example ***Temperature Conversion and Dimensional Homogeneity***

For Ammonia (NH_3) $$C_p\left(\frac{\text{Btu}}{\text{lb}_m\cdot{}^\circ\text{F}}\right) = 0.487 + 2.29 \times 10^{-4}T({}^\circ\text{F})$$

Determine the expression for C_p in $\text{J}/(\text{g}\cdot{}^\circ\text{C})$ in terms of $T({}^\circ\text{C})$.

2. Convert to the desired temperature interval unit