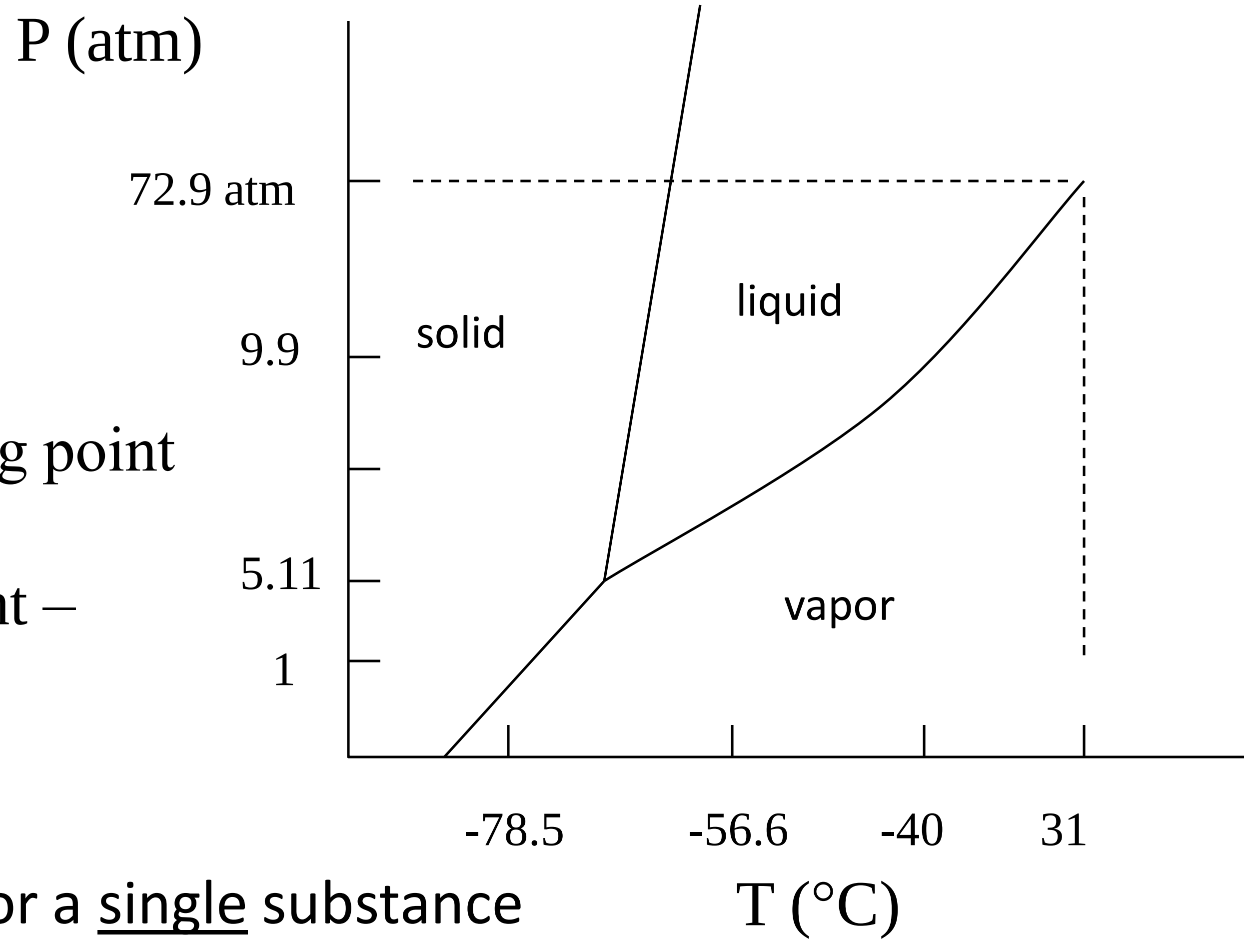
ABE 201
Biological Thermodynamics 1

Module 7:
Ideal and Non-Ideal Gas "Laws"

Review

- Equations of state are mathematical expressions describing the relationship between state properties.
- Ideal gas law is simplest equation of state.
- Ideal gas law is a good approximation for dilute (low pressure) gasses far from the critical point.
- Non-ideal gas equations use various approaches to account for deviation from ideality.

Phases of Mater



1. Critical point –
2. Boiling point –
   "Normal" Boiling point
3. Melting point –
4. Sublimation point –
5. Triple point –

This is a diagram for a <u>single</u> substance at <u>equilibrium.</u>

Ideal Gas Law

Given: A fire extinguisher holds 10.0 lb of CO_2 in a 20.0 ft^3 tank at 30.0°C. Using the ideal gas law holds, estimate the gauge pressure on the tank.

$P V = n R T$

10 lbm CO2 (1 lbmol/ 44.01 lb) = 0.23 lbmol

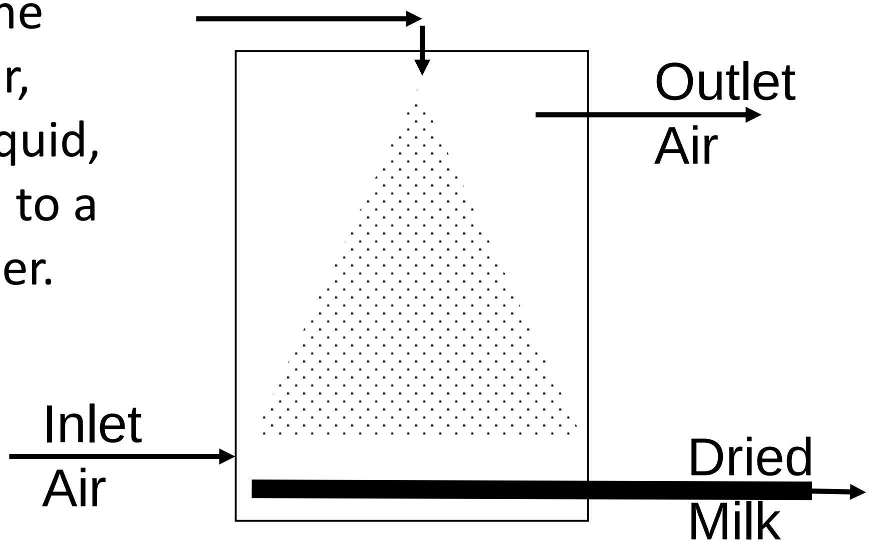
30C = 86F = (86 + 459.69) R = 546 R

$P = (nRT)/V = (0.23 \text{ lbmol})(10.73 \text{ ft}^3\text{-psia}/(\text{lbmol R}))(546 \text{ R})/20\text{ft}^3$

P = 67.4 psia = (67.4 - 14.696)psig = 52.7 psig

Spray Dried Milk

Spray drying is a process in which a liquid containing suspended or dissolved solids is injected into a chamber through a spray nozzle or centrifugal disk atomizer. The resulting mist is contacted with hot air, which evaporates most or all of the liquid, leaving the dried solids powder to fall to a conveyor at the bottom of the chamber.

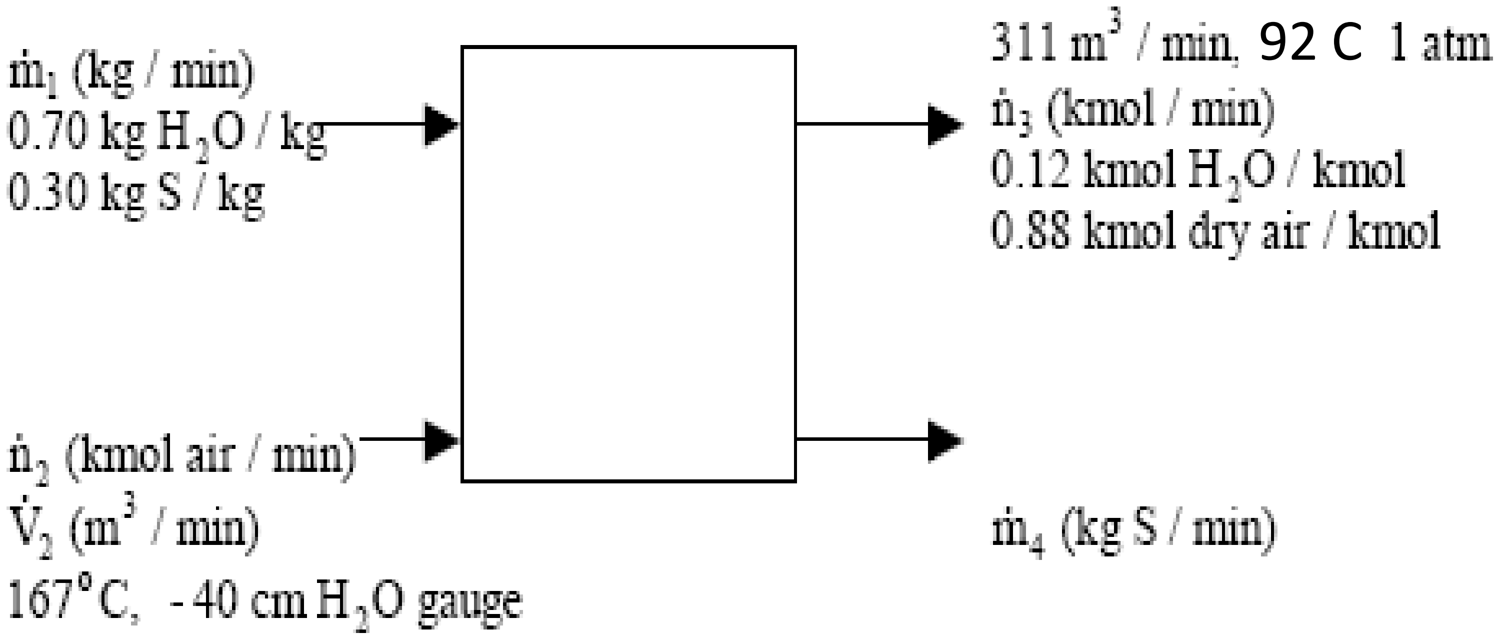


Spray Dried Milk

Powdered milk is produced in a cylindrical spray dryer 6 m in diameter by 6 m high. Air enters at 167°C and -40 cm H_2O (gauge). The milk feed contains 70% water by mass, all of which evaporates. The outlet air contains 12 mol% water and leaves the chamber at 92°C and 1 atm (absolute) at a rate of 311 m^3/min.

a) Calculate the production rate of dried milk and the volumetric flow rate of inlet air.
b) Estimate the average upward velocity of the air (m/s) at the bottom of the dryer.
c) What problem(s) would you predict if the velocity is too high?

5 sis: Given flow rates of outlet gas. Assume ideal gas behavior



a. $$\dot{n}_3 = \frac{1\ \text{atm}}{365.2\text{K}} \left| \frac{311\ \text{m}^3}{\text{min}} \right| \frac{\text{kmol}\cdot\text{K}}{0.08206\ \text{m}^3\cdot\text{atm}} = 10.38\ \text{kmol/min}$$

$$\underline{\text{H}_2\text{O balance}}\text{:}\quad 0.70\ \text{m}_1 = \frac{10.38\ \text{kmol}}{\text{min}} \left| \frac{0.12\ \text{kmol H}_2\text{O}}{\text{kmol}} \right| \frac{18.02\ \text{kg}}{\text{kmol}}$$

$$\Rightarrow \dot{m}_1 = 32.2\ \text{kg/min milk}$$

$$\underline{\text{S(olids) balance}}\text{:}\quad 0.30(32.2\ \text{kg/min}) = \dot{m}_4 \Rightarrow \underline{\underline{\dot{m}_4 = 9.6\ \text{kg S/min}}}$$

$$\underline{\text{Dry air balance}}\text{:}\quad \dot{n}_2 = 0.88(10.38\ \text{kmol/min}) \Rightarrow \dot{n}_2 = 9.13\ \text{kmol/min air}$$

$$\dot{V}_2 = \frac{9.13\ \text{kmol}}{\text{min}} \left| \frac{0.08206\ \text{m}^3\cdot\text{atm}}{\text{kmol}\cdot\text{K}} \right| \frac{440\text{K}}{(1033-40)\text{cm H}_2\text{O}} \left| \frac{1033\ \text{cm H}_2\text{O}}{1\ \text{atm}} \right.$$

$$= \underline{\underline{343\ \text{m}^3\ \text{air/min}}}$$

b. $$u_{\text{air}}(\text{m/min}) = \frac{\dot{V}_{\text{air}}\ (\text{m}^3/\text{s})}{\text{A}\ (\text{m}^2)} = \frac{343\ \text{m}^3}{\text{min}} \left| \frac{1\ \text{min}}{60\ \text{s}} \right| \frac{}{\frac{\pi}{4}\cdot(6\ \text{m})^2} = \underline{\underline{0.20\ \text{m/s}}}$$

c. If the velocity of the air is too high, the powdered milk would be blown out of the reactor by the air instead of falling to the conveyor belt.

Using Standard Volumes

- Oxygen flows into a reactor at 30 SCM per minute. Sensors at the inlet read 35^{o}C and 1500 kPa(a). What is the actual volumetric flow rate?

$PV=nRT$

$n = PV/(RT)$

$= (1.013 \text{ x } 10^5 \text{ Pa})(30 \text{ m}^3)/(8.314 \text{ m}^3\text{-Pa/(mol-K)})/(273 \text{ K})$

$= 1340 \text{ mol } O_2\text{/min}$

$V = nRT/P = (1340)(8.314)(35+273)/1500e3 = 2.3 \text{ m}^3\text{/min}$

Using the Virial Equation

Estimate the pressure in bars for carbon dioxide at 380 K and 0.311 L/mol using the virial equation. Compare this to the estimate from the ideal gas equation.

$$\frac{P\hat{V}}{RT} = 1 + \frac{B}{\hat{V}}$$

Needed Information:

$$B = \frac{RT_c}{P_c}(B_0 + \omega B_1)$$

$$B_0 = 0.083 - \frac{0.422}{T_r^{1.6}}$$

$$\mathbf{T_r = T/T_c}$$

$$\mathbf{P_r = P/P_c}$$

Tc = 304.2 K

Pc = 72.9 atm

Accentric factor = 0.225

$$B_1 = 0.139 - \frac{0.172}{T_r^{4.2}}$$

$$T_r > 0.686 + 0.439P_r$$

$T_c = 304.2$ K, $P_c = 72.9$ atm

$T_r = 380/304.2 = 1.25$, $P_r = P/72.9$
$w = 0.225$

$PV/RT = 1 + B/V$

$B = RT_c(B0 + wB1)/P_c$

$B0 = 0.083 – 0.422/T_r^{1.6} = 0.083 – 0.422/(1.25)^{1.6} = -0.212$

$B1 = 0.139 – 0.172/T_r^{4.2} = 0.139 - 0.172/(1.25)^{4.2} = 0.072$

$B = 0.08206(304.2)(-0.212 + (0.225)*0.072)/(72.9) = -0.0670$

$P(0.311)/(0.08206)(380) = 1 – 0.0670/(0.311)$
$P = 78.7$ atm

$P\hat{V} = RT$

$P = RT/\hat{V} = (0.08206)(380)/0.311 = 100$ atm

Error = (Pideal – P) / P = (100 – 78.7) / 78.7 = 27% error

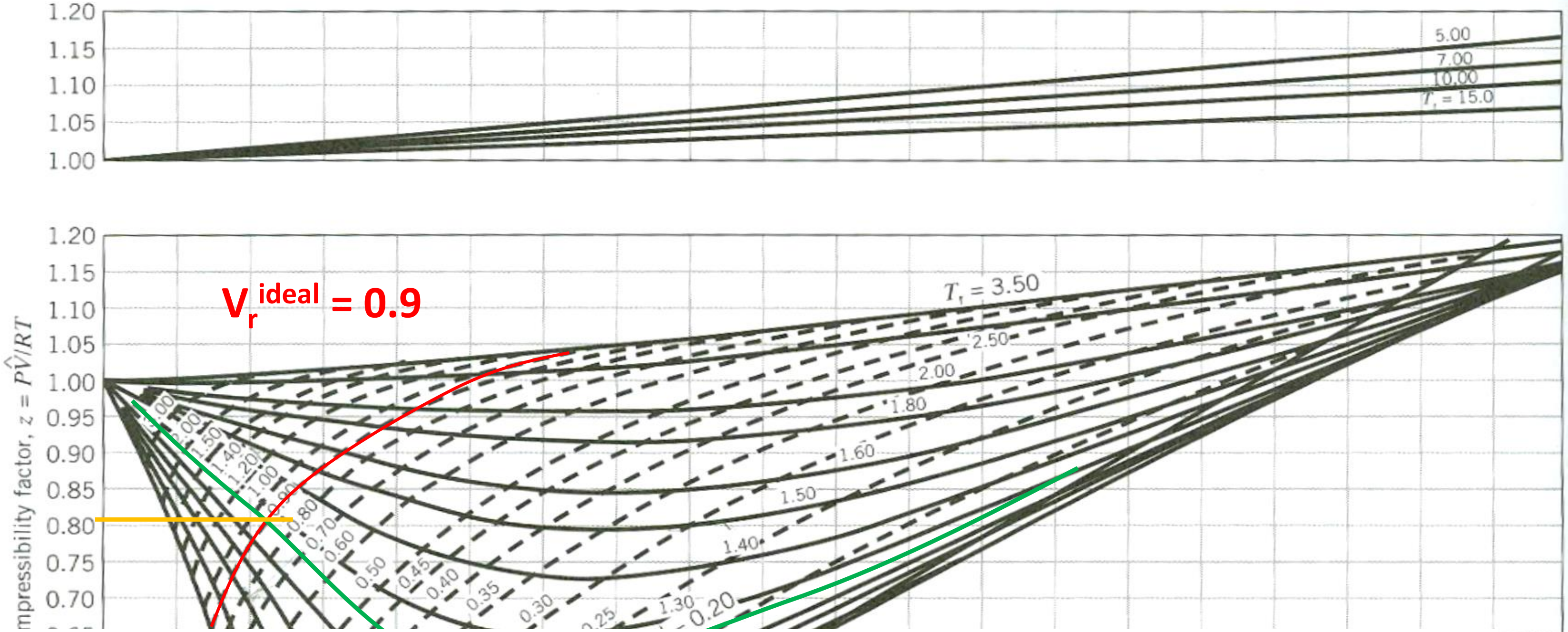
Example:

- Estimate the pressure in atm for carbon dioxide at 380 K and 0.311 L/mol using the compressibility charts.

T_c = 304.2 K, P_c = 72.9 atm

T_r = 380K/304.2K = 1.25

$$\hat{V}_r^{ideal} = \hat{V}P_c/RT_c$$
$$= (0.311\text{L/mol})\left(72.9\text{atm}\right)/(0.08206\text{atm*L/mol*K})\left(304.2\text{K}\right)$$
$$= 0.908$$



$$P\hat{V} / RT = z$$

$$P = zRT / \hat{V}$$

$$= 0.80(0.08206 atm*L / mol*K)\left(380K\right) / 0.311L / mol$$

$$= 80.2 atm$$