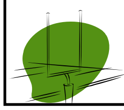
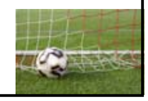
Business

- This is lecture #19 out of 36
  - More than half way!
- Exam next week
  - 3 hrs
  - Take home
  - Practice exam posted on Learning Suite
- Quiz

Goals

- Review: Vapor Pressure, Raoult's Law
- Definitions for 1 liquid species, 2+ gas species
  - Dew Point
  - Boiling Point
  - Relative and Absolute Humidity
  - Degrees Superheat
- Examples





Raoult's Law

$$y_i P = x_i P_i^*$$

Pure Component (1 species)	1 liquid species 2+ gas species	2+ liquid species 2+ gas species
Yesterday	Today	Friday
	Example: Air-water	

What is Saturation?

- Think of a sponge

- The maximum amount of water absorbed by the sponge is called saturation
- Any extra water after saturation runs off the sponge

Saturated Air

- What happens when air becomes saturated with water vapor?
  - Any additional water starts to condense and form liquid water droplets
  - Point at which the first drop condenses is called the **dew point**
  - Saturation point (and hence dew point) is a function of temperature (related to vapor pressure)
    - Higher temperature air can hold more water vapor

Dew Point Equations

- Dew point is when first drop condenses
  - Saturated Air
  - Occurs when $y_i P_{tot} = P_i^*$ $(x_i = 1)$
    - So air is saturated when $P_i = P_i^*$
    - P_i^* is sometimes called P_i^{sat}

- Examples:
  - If you know y_i and P_{tot}, you can calculate P_i^* and then calculate the corresponding temperature (T_{dp}), or
  - If you know that you are at the dew point temperature, you can calculate y_{H2O} from P_i^* and P_{tot}

What if you are not at the dew point?

- How do you quantify the amount of moisture in the air?
  - Mole or mass fraction of H_2O
  - **Relative Humidity** = $\frac{P_i}{P_i^*} = \frac{P_{H2O}}{P_{H2O}^*}$
    - Like the percent of saturation
    - 50% humidity = 50% of the moisture that the air can hold at that temperature
    - P_{H2O}^* is a function of temperature
    - Saturation is 100% relative humidity
  - **Absolute Humidity** = $\frac{mass\ of\ vapor}{mass\ of\ dry\ gas}$
    - Kind of like a weird mass fraction

More Definitions
(1 liquid species, 2+ gas species)

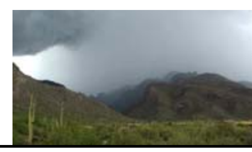
- **Boiling Point**
  - First bubble of vapor appears in liquid
  - Essentially, $x_i = y_i = 1$ at interface
  - $P_{H2O}^* = P_{tot}$ (same as for 1 gas species)
- **Degrees Superheat**
  - Measure of how far you have to cool the gas to condense the first drop of liquid
  - Degrees superheat = $T - T_{dp}$

More Definitions
(1 liquid species, 2+ gas species)

- **What if $P_i > P_i^*$**
  - Supersaturated (relative humidity > 100%)
  - Not at equilibrium
  - Liquid will condense out of the gas phase
  - Conditions will change back to the saturation point where $P_i = P_i^*$

Examples

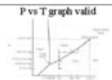
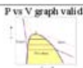
1. BYU Heating Plant
2. Boiling point in Provo
3. Relative humidity in Virginia
   1. P_{H2O}
   2. y_{H2O}
   3. Degrees superheat
4. *Rain in mountains (if time)*



Raoult's Law

$y_i P_{tot} = x_i P_i^*$

$y_i \hat{\phi} P = x_i \gamma_i \phi_i^s P_i^s \exp\left[\int_{P_i^s}^{P} \frac{V_i^L}{RT} dP\right]$

Single Component	Liquid = 1 component Gas = 2+ components (n_g)	Liquid = 2+ components (n_L) Gas = 2+ components (n_g)
DF = 2 + 1 − 2 = 1	DF = 2 + n_{spec} − 2 = n_{spec}	DF = 2 + n_{spec} − 2 = n_{spec}
$y_i = 1.0$ $x_i = 1.0$	$y_i \neq 1.0$ $x_i = 1.0$	$y_i \neq 1.0$ $x_i \neq 1.0$
At vapor-liquid equilibrium, $P_i^* = P_{tot}$	At vapor-liquid equilibrium, $y_i P_{tot} = P_i^*$	At vapor-liquid equilibrium, $y_i P_{tot} = x_i P_i^*$
boiling T = condensing T	dew point occurs at T_{dp} i.e., when first liquid condenses - saturated vapor ($P_i = P_i^*$)	1st drop of liquid = dew point (saturated vapor)
	boiling when $P_{tot} = P_i^*$ (like single component, saturated liquid)	1st bubble of gas = bubble point (saturated liquid)
	Relative humidity = $y_i P_{tot}/P_i^*$ (or P_i/P_i^*) - saturated when R.H. = 100%	No boiling point defined - temperature changes as lighter component evaporates
P vs T graph valid 	Absolute humidity = $m_{steam}/m_{dry\ gas}$ $= \left(\frac{P_i MW_i}{RT}\right) / \left(\frac{(P_{tot} - P_i) MW_{dry}}{RT}\right)$ $= P_i MW_i / ((P_{tot} - P_i) MW_{dry})$	
P vs V graph valid 	Degrees superheat = $T - T_{dp}$	

6.16 in 4[th] Edition

6.17. Air containing 20.0 mole% water vapor at an initial pressure of 1 atm absolute is cooled in a 1-liter sealed vessel from 200°C to 15°C.

(a) What is the pressure in the vessel at the end of the process? (*Hint:* The partial pressure of air in the system can be determined from the expression $p_{air} = n_{air}RT/V$ and $P = p_{air} + p_{H_2O}$. You may neglect the volume of the liquid water condensed, but you must show that condensation occurs.)

(b) What is the mole fraction of water in the gas phase at the end of the process?

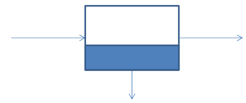
(c) How much water (grams) condenses?

Upcoming HW problems

6.27. On a hot summer day the temperature is 35°C, barometric pressure is 103 kPa, and the relative humidity is 90%. An air conditioner draws in outside air, cools it to 20°C, and delivers it at a rate of 12,500 L/h. Calculate the rate of moisture condensation (kg/h) and the volumetric flow rate of the air drawn from the outside.

6.28 in 4th Edition

T=35°C
P=103 kPa
RH = 90%
$\dot{V}_{in}$ = ?

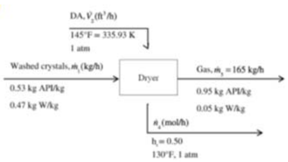


T=20°C
P=103 kPa
RH = ?
$\dot{V}_{out}$ = 12,500 L/h

H_2O

Strategy:
1. Find P* for inlet, then $y_{H2O,in}$
2. Recognize that outlet air is saturated with water (RH = 100%), so find P* for outlet and $y_{H2O,out}$
3. From outlet volumetric flow rate, find $n_{gas,out}$, then $n_{H2O,out}$
4. $n_{air,in} = n_{air,out}$, so find $n_{H2O,in}$
5. $n_{H2O,liq}$ by difference

6.35 in 4th Edition

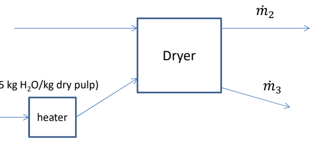


Strategy:
1. Find $\dot{m}_{API,3}$
2. API balance to find $\dot{m}_1$
3. Water balance to find $\dot{m}_{H2O,4}$
4. Use RH_{H2O} to find $y_{H2O,4}$
5. Find $\dot{n}_4$ and $\dot{n}_{air,4}$
6. Ideal gas law to find $\dot{V}_2$

6.33. A hot-air dryer is used to reduce the moisture content of 1500 kg/min of wet wood pulp from 0.75 kg H_2O/kg dry pulp to 0.15 wt% H_2O. Air is drawn from the atmosphere at 28°C, 760 mm Hg, and 50% relative humidity, sent through a blower-heater, and then fed to the dryer. The air leaves the dryer at 80°C and 10 mm Hg (gauge). A sample of the exit air is drawn into a chamber containing a mirror and cooled slowly, keeping the gauge pressure at 10 mm Hg. A mist is observed to form on the mirror at a temperature of 40.0°C. Calculate the mass of water removed from the pulp (kg/min) and the volumetric flow rate of air entering the system (m³/min).

6.34* in 4th Edition

wet wood pulp
1500 kg/min
x_w = 0.4286
(using info of 0.75 kg H_2O/kg dry pulp)



$\dot{m}_2$
Dry pulp
x_w = 0.0015

$\dot{m}_3$
air
80°C
10 mm Hg gauge
(770 mm Hg)
P*=?

$\dot{m}_1$
air
28°C = 301 K
760 mm Hg
50% RH

Strategy:
1. P^*_{out} at 40°C is dew point (from table) = P_{H2O}
2. Get $y_{w,out}$ from P_{H2O}/P_{tot}
3. Get $y_{H2O,in}$ from RH_{in}
4. Balances on
   1. dry pulp
   2. water
   3. dry air

6.25. An adult takes roughly 12 breaths each minute, inhaling approximately 500 mL with each breath. Oxygen and carbon dioxide are exchanged in the lungs. The amount of nitrogen exhaled equals the amount inhaled, and the mole fraction of nitrogen in the exhaled air is 0.75. The exhaled air is saturated with water vapor at body temperature, 37°C. Estimate the increase in the rate of water loss (g/day) when a person breathing air at 23°C and a relative humidity of 50% enters an airplane in which the temperature is also 23°C but the relative humidity is 10%.

6.26 in 4th Edition

12 breaths/min
500 mL/breath
$n_{N2,in}$
$n_{O2,in}$
23°C, 1 atm
(a) RH = 50%
(b) RH = 10%

$n_{N2,out}$
$y_{N2,out}$ = 0.75
37°C, 1 atm
RH = 100% (why?)

$n_{N2,out} = n_{N2,in}$
$y_{N2,in}$ = 0.79 on a dry basis

Find Δm_{H2O} for both inlet RH's

Strategy:
1. From P^*_{in} and P^*_{out} and RH's find $y_{H2O,in}$ and $y_{H2O,out}$
2. Find $y_{N2,in,wet\ basis}$
3. Find $n_{total,in}$
4. Balance on N_2, then get n_{total} out
5. $\Delta\ n_{H2O}$ using n_{total} and inlet and outlet y_{H2O}'s
6. Convert to Δm_{H2O}