Lecture 1: 1-9-18

Slide 21 Looking at this problem

Chapter 2 & 3: $^{gal}/_{min} \rightarrow ^{mol}/_{s}$ (Liquid)

Chapter 4: Material Balances
General Solution Procedure

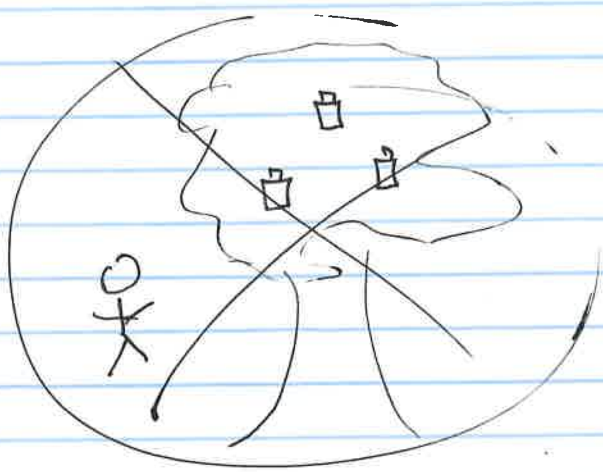
Chapter 5: $P\dot{V} = \dot{n}RT$ (Equations of state)

Chapter 6: Gas - Liquid Systems
% Humidity
Finding vapor pressure p_i^*
Saturation & Raoult's Law

Chapter 7: Energy Balances

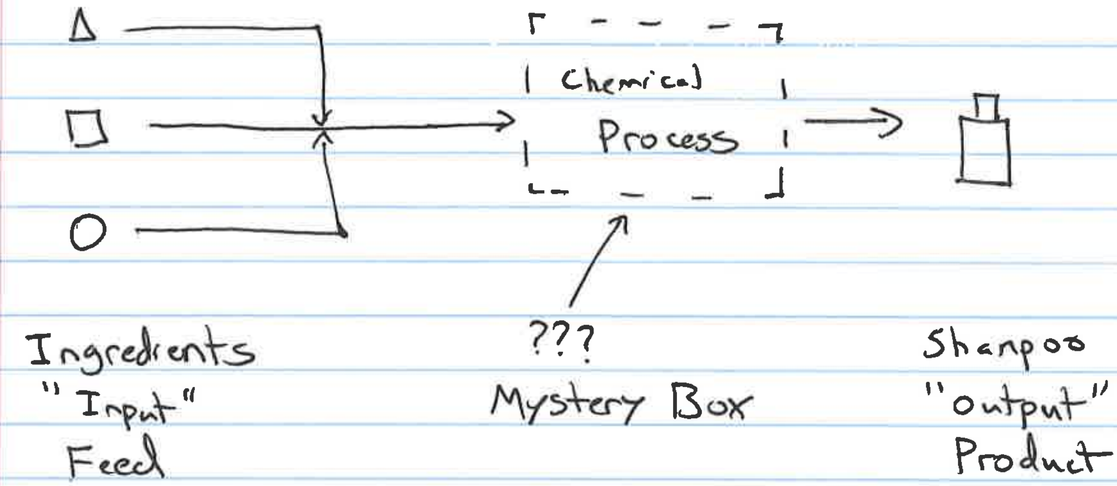
Chapter 8: Calculating/determining Enthalpy Changes

Slide 27



No sunscreen trees

sunscreen is made up of different ingredients



Slide 33

Addition & Subtraction

$3\ cm^2 + 5\ cm^2 = 8\ cm^2$ (Homogeneous)

$3x^2 + 5x^2 = 8x^2$

$3\ cm + 5\ cm^2 = ?$ (Non - Homogeneous)

$3x + 5x^2 = ?$

Multiplication & Division

$3\ cm \cdot 5\ cm^2 = 15\ cm^3$

$3x \cdot 5x^2 = 15x^3$

OR

$\frac{15\ cm^2}{5\ cm} = 3\ cm$

Different units can also be multiplied / divided

$3x \cdot 5y = 15xy$

$3\ kg \cdot 5\ \frac{m}{s^2} = 15\ kg\ m/s^2 \rightarrow 1\ N$

"Force"

$m \cdot a = F \qquad 15\ N$

Slide 34 Conversion Factors

Simple conversions — multiple unit

$$1\,m \left(\frac{100\,cm}{1\,m}\right) = 100\,cm$$

Base units $\quad 1\,m = 100\,cm$

OR: convert 26 N to Dynes $\left(g \cdot \frac{cm}{s^2}\right)$

$$N\ [=]\ kg\,\frac{m}{s^2}$$

cm

g

$$26\,kg\,\frac{m}{s^2}\underbrace{\left(\frac{1000\,g}{1\,kg}\right)}_{\text{conversion}}\underbrace{\left(\frac{100\,cm}{1\,m}\right)}_{\text{conversion}} = 26 \times 10^5\ \text{Dynes}$$

write out your conversions!

$1\,N = 10^5$ Dynes $\Rightarrow$ New conversion

$$26\,N\left(\frac{10^5\ \text{Dynes}}{1\,N}\right) = 26 \times 10^5\ \text{Dynes}$$

Slide 35 Table 2.3-1 gives SI and CGS units

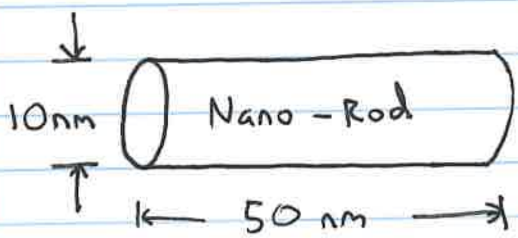
Lecture 2: 1-11-18

Slide 3 Because lb_m and lb_F

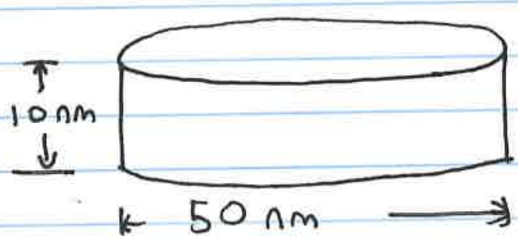
$$1\ lb_F = 32.174\ lb_m \cdot \frac{ft}{s^2}$$

$$1\ N = 1\ kg \cdot \frac{m}{s^2}$$

Slide 4 Aspect Ratio $\frac{L}{D} = \frac{\text{Length}}{\text{Diameter}}$



$$AR = \frac{L}{D} = \frac{50\ nm}{10\ nm} = 5$$



$$AR = \frac{L}{D} = \frac{10nm}{50nm} = 0.2$$

What can be said about an object with an AR of 10?
with an AR of 0.5?

In fluids (CHE 231) the Reynold's number is important

$$Re = \frac{D u \rho}{\mu}$$

D: pipe diameter
u: fluid velocity
ρ: density
μ: viscosity

If $Re < 2000$ Laminar Flow
$2000 < Re < 4000$ Transition
$Re > 4000$ Turbulent Flow

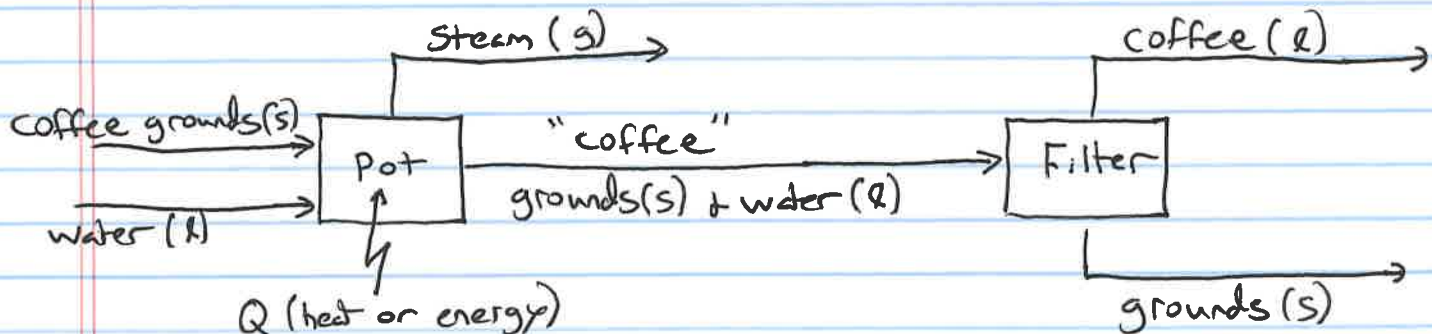
If Re is dimensionless, what are units of μ (SI)?

$$Re = \frac{D u \rho}{\mu} = \frac{m \left(\frac{m}{s}\right)\left(\frac{kg}{m^3}\right)}{\mu}$$

$$Re = \frac{m^2}{s}\left(\frac{kg}{m^3}\right) = \frac{\frac{kg}{s \cdot m}}{\mu}$$

units of viscosity (dynamic) $\Rightarrow \frac{kg}{s \cdot m}$ $\left(1 \text{ poise} = 0.1 \frac{kg}{s \cdot m}\right)$

Slide 8 Chapter 3



Picture ~~is~~ is called Flow Chart
made up of arrows (streams)
boxes (units)

What factors will affect the desired product (coffee)
(Hint: Think about the taste)

<u>Factors</u>: How much we add: More/less coffee
More/less water
(strength of coffee)

How long do we brew: More/less time
(strength of coffee)

~~Ho~~ Kind of coffee we use : Light/dark roast
" " water " " : Minerals in H_2O

Temperature of pot : coffee burned/weak

These factors (and more) will affect how our product turns out and how much we produce

Making coffee is a relatively simple "chemical process"

More complex processes $\Rightarrow$ More factors to consider
↳ slide

Slide 11 Density : use conversion factors to change units
(like everything else)

ρ of H_2O : 1 g/cm^3 @ 4 °C

ρ of H_2O in kg/m^3 ?

$$1\ g/cm^3 \left(\frac{1\,kg}{1000\,g}\right)\left(\frac{100\,cm}{1\,m}\right)^3$$

$$1\ \frac{g}{cm^3}\left(\frac{1\,kg}{1000\,g}\right)\left(\frac{100^3\,cm^3}{1^3\,m^3}\right) = 1000\ kg/m^3$$

can also use ρ as a conversion factor that relates the mass + volume of a substance

The ρ of carbon Tetrachloride is 1.595 g/cm^3
what is the m of 20.0 cm^3 of CCl_4?

$$20.0\ cm^3\left(\frac{1.595\,g}{1\,cm^3}\right) = \boxed{31.9\ g}$$

Slide 13 * Table 3.1-2 (Important)

reference value ⇒ $\rho_{H_2O(l)}(4°C) = 1.000 \ g/cm^3$
$1000 \ kg/m^3$
$62.43 \ lb_m/ft^3$

If $SG = 10$ $SG = \rho_A / \rho_{ref}$

$$\rho_A = 10 \left(1 \frac{g}{cm^3}\right) = 10 \ g/cm^3$$
$$= 10 \left(1000 \ kg/m^3\right) = 10{,}000 \ kg/m^3$$
$$= 10 \left(62.43 \ lb_m/ft^3\right) = 624.3 \ lb_m/ft^3$$

one value represents all densities

Slide 14 Many resources exist that give physical properties of compounds

- Perry's Chemical Engineering Handbook
  (AKA Perry's → One of the most widely known)

- For this class we will use Appendix B (pg 628)
  → Tab it → use it (alternative sources may be different)

From Appendix B.1

$$SG_{Hg} = 13.546 \ \frac{20°}{4°}$$ $\frac{\text{Temp of compound}}{\text{Temp of reference}}$

As engineers we will often need to make assumptions in order to solve problems

ALWAYS state assumptions!

This problem doesn't specify the temp but we will assume Hg is 20°C (in order to use reference)

Assuming Hg @ 20°C

$\rho_{Hg} = (13.546)(62.43\ lb_m/ft^3) = 845.7\ lb_m/ft^3$

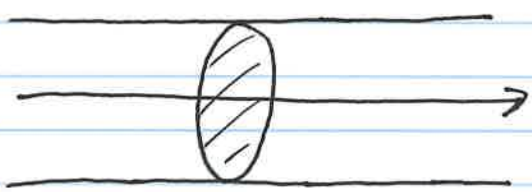
From B.1   Table 3.1-2

$215\ kg \left(\frac{1\ lb_m}{0.454\ kg}\right)\left(\frac{1\ ft^3}{845.7\ lb_m}\right) = \boxed{0.560\ ft^3}$

Slide 15   Alternate way to ask same question

↳ Less direction

Slide 16   Flow Rate



$\dot{m}$: For every 1 second some amount of mass passes through the cross-section

Convert $\dot{V} \rightarrow \dot{m}$

$\frac{m^3}{s} \rightarrow \frac{kg}{s}$ (SI)

How do we convert volume to mass?

$\rho = \frac{m}{V}$

$\frac{m^3}{s}\left(\frac{kg}{m^3}\right) = \frac{kg}{s}$

$$\dot{V}\rho = \dot{m} \quad \text{OR} \quad \boxed{\rho = \frac{\dot{m}}{\dot{V}}} \Rightarrow \rho = \frac{m}{V}$$

Time dimension cancels out

$\dot{m} \to \dot{n}$ (discussed later)

Lecture 3

slide 7 MW of O_2 is 32

Actually g-mol

1 mol O_2 = 32 g O_2
1 k-mol O_2 = 32 kg O_2
1 lb-mol O_2 = 32 lb_m O_2

use these as conversion factors

How many k-mol in 34 kg of O_2

$$34\ kg \left(\frac{1\ k\text{-}mol}{32\ kg}\right) = 1.1\ k\text{-}mol$$

slide 8 Example 3.3-1

1) mol CO_2 $\Rightarrow$ C: 12.01, O: 16 x 2

MW CO_2 = 44.01

$$100\ g\ CO_2 \left(\frac{1\ mol\ CO_2}{44.01\ g\ CO_2}\right) = \boxed{2.273\ mol\ CO_2}$$

2) lb-mol CO_2?

$$2.273\ mol\ CO_2 \left(\frac{1\ lb_m}{453.6 g}\right) = \boxed{5.011 \times 10^{-3}\ lb_m\text{-}mol\ CO_2}$$

remember this is actually g-mol

4) mol O?

$$2.273 \text{ mol } CO_2 \left(\frac{2 \text{ mol O}}{1 \text{ mol } CO_2}\right) = \boxed{4.546 \text{ mol O}}$$

6) g O?

$$4.546 \text{ mol O} \left(\frac{16 \text{ g O}}{1 \text{ mol O}}\right) = \boxed{72.7 \text{ g O}}$$

Slide 9

mass Fraction - Fraction of a particular compound by mass in a mixture

1 kg H_2O + 0.5 kg NaCl = 1.5 kg mixture

$$X_{H_2O} = \frac{1 \text{ kg } H_2O}{1.5 \text{ kg}} = 0.67 \text{ kg } H_2O/\text{kg}$$

$$X_{NaCl} = \frac{0.5 \text{ kg NaCl}}{1.5 \text{ kg}} = 0.33 \text{ kg NaCl}/\text{kg}$$

multiple by 100 for % mass

For binary mixture $\quad X_A + X_B = 1.0$

↳ 2 compounds

For n components $\quad \sum_{i=1}^{n} X_i = 1.0$

mole Fractions - Fractions of a particular compound based on # of moles in mixture

Do mass fractions = mole fractions?

$$1 \text{ kg } H_2O \left(\frac{1 \text{ k-mol}}{18 \text{ kg}}\right) = 0.056 \text{ kmol} \left(\frac{1000 \text{ mol}}{1 \text{ kmol}}\right) = 56 \text{ mol } H_2O$$

$$0.5 \text{ kg NaCl} \left(\frac{1 \text{ k-mol}}{58.5 \text{ kg}}\right) = 0.0085 \text{ kmol} \Rightarrow 8.5 \text{ mol NaCl}$$

$$56 \text{ mol } H_2O + 8.5 \text{ mol NaCl} = 64.5 \text{ mol mixture}$$

$$y_{H_2O} = \frac{56}{64.5} = 0.87 \text{ mol } H_2O/\text{mol}$$

$$y_{NaCl} = \frac{8.5}{64.5} = 0.13 \text{ mol NaCl}/\text{mol}$$

$y_A + y_B = 1.0$

$\boxed{\text{mass fractions} \neq \text{mole fractions}}$

make sure to convert!

Slide 10 Before we were told mass of components

Now, composition of mixture by mass:

H_2O 67 %
NaCl 33 %

what is the mole fraction?

⇓

Can still make conversion ⇒ Basis of calculation

Assume a 100 g basis of calculation (pick something easy)

$$100\text{ g}\left(\frac{0.67\text{ g } H_2O}{1\text{ g}}\right)\left(\frac{1 \text{ mol } H_2O}{18 \text{ g } H_2O}\right) = 3.7 \text{ mols } H_2O$$

Don't erase

$$100\text{ g}\left(\frac{0.33\text{ g NaCl}}{1\text{ g}}\right)\left(\frac{1 \text{ mol NaCl}}{58.5 \text{ g NaCl}}\right) = 0.56 \text{ mol NaCl}$$

Basis of calculation

4.26 mols total

mole fractions:

$$\frac{3.7 \text{ mols } H_2O}{4.26 \text{ mols}} = 0.87 \frac{\text{mol } H_2O}{\text{mol}} \qquad \frac{0.56}{4.26} = 0.13 \frac{\text{mol NaCl}}{\text{mol}}$$

Answers from before check out

Example 3.3-3 (pg 54) gives another good example

Slide 11 $\boxed{\text{mass fractions} \xleftrightarrow[MW]{} \text{mole fractions}}$ *very important

Slide 12 can use 3.3-7 to find $\bar{M}$ for our $H_2O/NaCl$ mixture

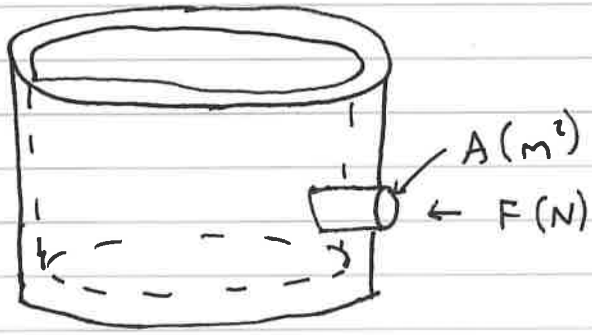
$$y_{H_2O} = 0.87 \qquad MW_{H_2O} = 18$$
$$y_{NaCl} = 0.13 \qquad MW_{NaCl} = 58.5$$

$$\bar{M} = 0.87(18) + 0.13(58.5) = 23$$

using 3.3-8 would also work

Slide 17 Pressure

consider a fluid in a tank



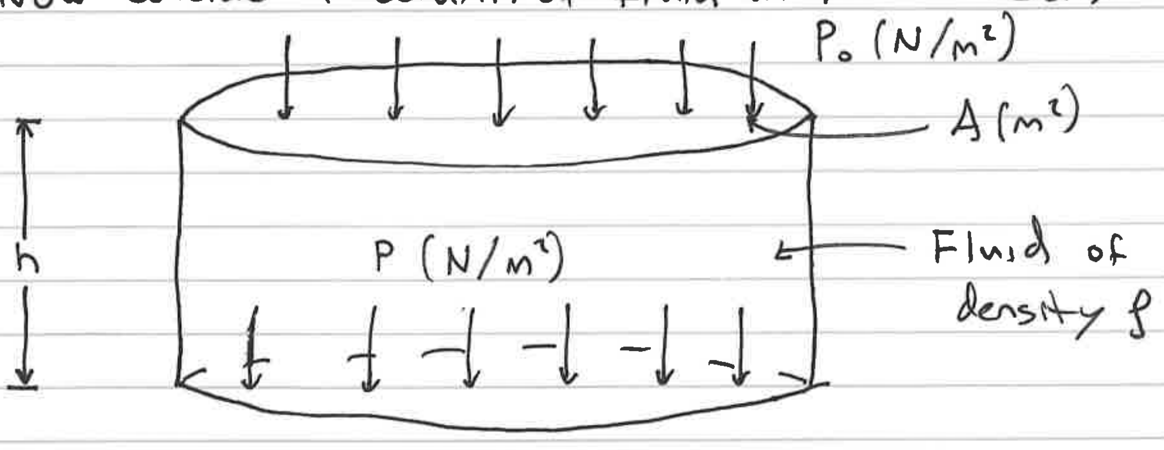
Fluid Pressure is the minimum force we would have to apply to hold a frictionless plug (A) in place

Figure 3.4-1

Lecture 4 - 1/17/18

Slide 3 Now consider a column of fluid with known density (ρ)

Fig 3.4-2



we have a pressure (P_0) at the top of the column and a different pressure (P) at the bottom

Why are the pressures @ top & bottom different?

$W = mg$ weight is a force

we know that the Force is acting on A

$$P = P_0 + \frac{W}{A} = P_0 + \frac{mg}{A}$$

$$\rho = \frac{m}{V} \Rightarrow m = \rho V$$

$$P = P_0 + \frac{\rho V g}{A}$$

$V = ?$ how does h relate to volume?

$$V = A \cdot h$$

$$P = P_0 + \frac{\rho \cancel{A} h g}{\cancel{A}} \Rightarrow \boxed{P = P_0 + \rho g h}$$

Fluid not moving

"hydro"static" pressure

Check units

$$\left(\frac{N}{m^2}\right) \quad \frac{kg}{m^2\,\cancel{m^3}}\left(\frac{m}{s^2}\right)\cancel{(m)} \quad kg\left(\frac{m}{s^2}\right) \Rightarrow N \quad \frac{N}{m^2} = Pa$$

so consider our column of fluid again

we've shown: $P = P_0 + \rho g h$ constant

how do increase P?

$\boxed{h \text{ \& } P \text{ are directly related}}$

Slide 4 Hydrostatic Head (Pressure Head)

more height ⇒ more fluid ⇒ more weight ⇒ more pressure

$$\boxed{P = \rho_{fluid}\, g\, P_h}$$ — "Pressure" head of fluid (height units)

Slide 5 What is the pressure due to 760 mmHg?

$$P = \rho_{fluid}\, g\, P_h \qquad \text{(solve in Pa)}$$

ρ_{Hg} ⇒ SG of Hg : 13.546 Table B.1 ↴
Assume Hg @ 20°C

$$\frac{\rho_{Hg} \text{ @ } 20°C}{\rho_{H_2O} \text{ @ } 4°C} = SG_{Hg} \Rightarrow \rho_{Hg} = 13546 \ \frac{kg}{m^3}$$

1000 kg/m³ (3.1-2)

$$g = 9.8 \ m/s^2$$
$$P_h = 760 \ mm \left(\frac{1 \ m}{1000 \ mm}\right) = 0.760 \ m$$

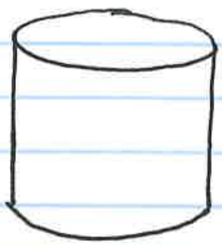
$$P = 13546 \ kg/m^3 \ (9.8 \ \tfrac{m}{s^2})(0.760 \ m)$$
$$\boxed{P = 100890 \ Pa \approx 1.00 \times 10^5 \ Pa}$$

Slide 6 1.00×10^5 Pa = 1 atm
↳ An alternative unit of pressure

conversions for pressure

$1 \text{ atm} = 1 \times 10^5 \text{ Pa}$
760 mm Hg
$29.92 \text{ inches of Hg}$

Slide 7 Absolute & Gauge (when measuring pressure)



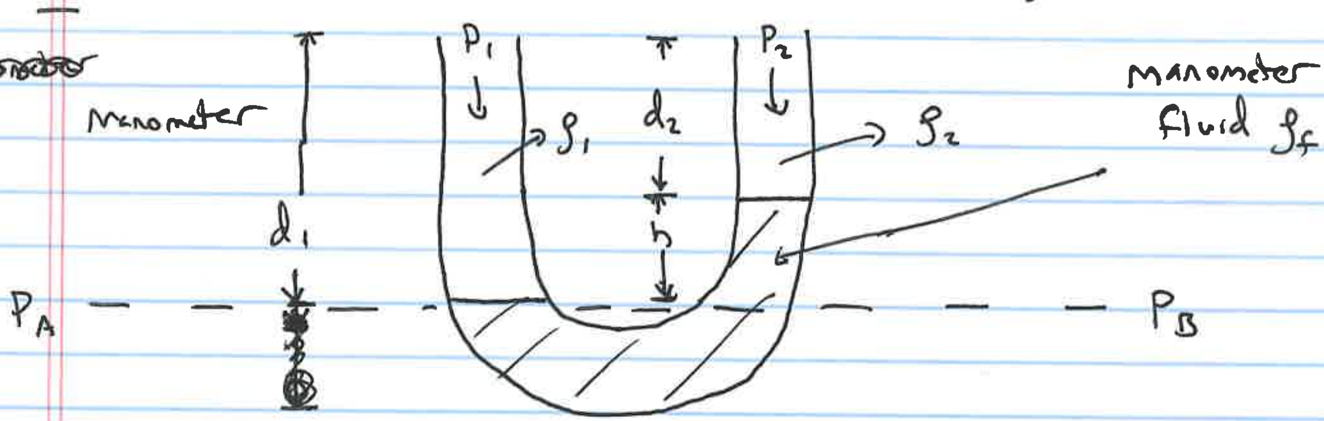
P_o = open to atmosphere $\therefore$ $P_o = P_{atmosphere}$

$P = P_o + \rho g h$

Gauge: $P_{atm} = 0$
$P_{gauge} = \rho g h$

Absolute: $P_{absolute} = P_{atmosphere} + P_{gauge}$

Slide 9



we can imagine that as P_1 increases h will increase $\therefore$ $P_1 > P_2$

As h increases the column of manometer fluid gets higher $\Rightarrow$ more fluid $\Rightarrow$ more weight $\Rightarrow$ more force

Deriving the general manometer equation is just a force balance

$$P_A = P_B \quad \text{(Equilibrium Hydrostatic)}$$

$$P_A = P_1 + d_1 \rho_1 g$$
$$P_B = P_2 + d_2 \rho_2 g + h \rho_f g$$

$$\boxed{P_1 + d_1 \rho_1 g = P_2 + d_2 \rho_2 g + h \rho_f g}$$

General manometer equation → slide 10

Slide 11

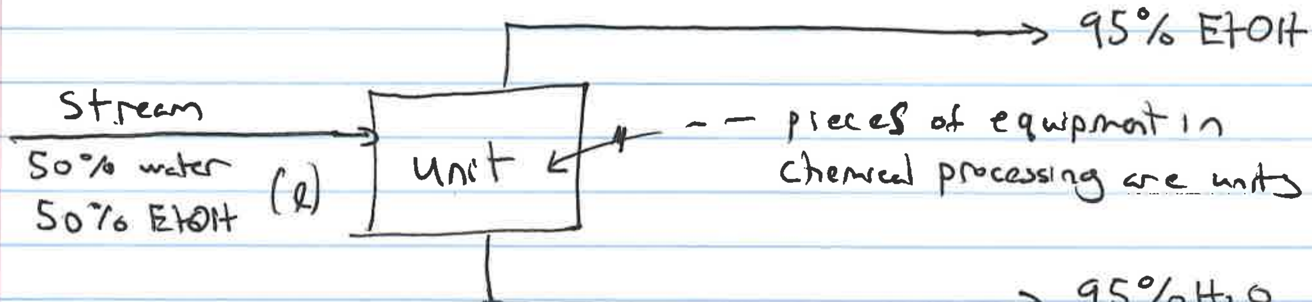
Temperature

$$T(K) = T(°C) + 273.15$$
$$T(°R) = T(°F) + 459.67$$

$$T(°R) = 1.8\,T(K)$$
$$T(°F) = 1.8\,T(°C) + 32$$

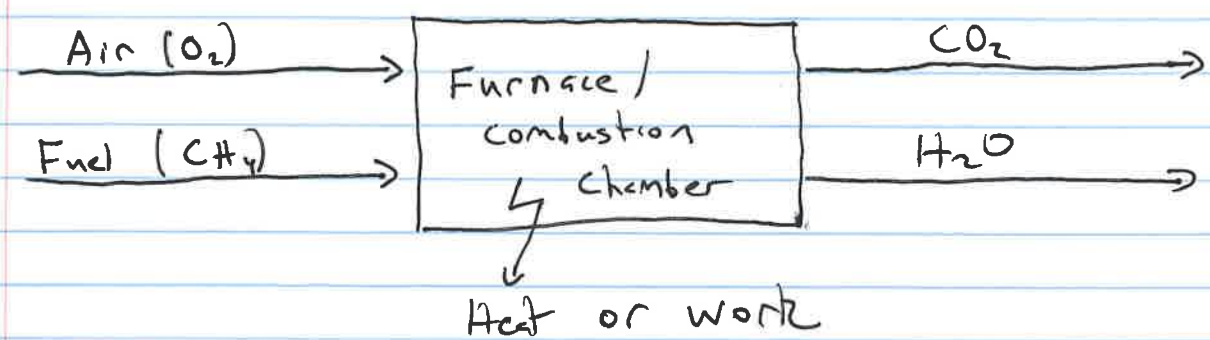
Slide 13

Non-Reactive (Physical Process):



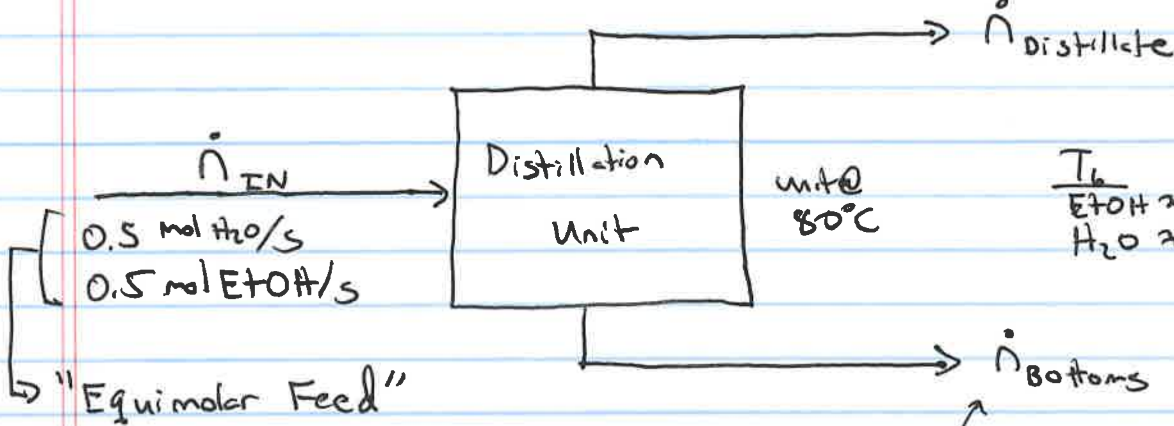
No chemical reactions, just a separation of components

Reactive Process:



A chemical reaction → Input different from output

Slide 14 Continuous Process: Let's look @ EtOH & H_2O Example



T_b
EtOH ≈ 78°C
H_2O ≈ 100°C

continuous processes use flow rates $\left(\frac{\text{material}}{\text{time}}\right)$

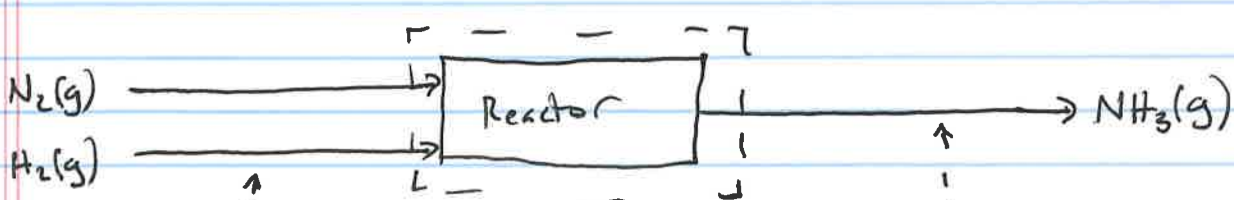
Tells us what's happening @ a particular "instant" in time (snapshot)

* most common process we work with

Batch Process
Make Ammonia (NH_3) using Hydrogen & Nitrogen

$$N_2 + 3H_2 \rightarrow 2H_3$$

↳ For reactive processes always start with balanced eqn.



Initially loaded

Removed @ end (after period of time)

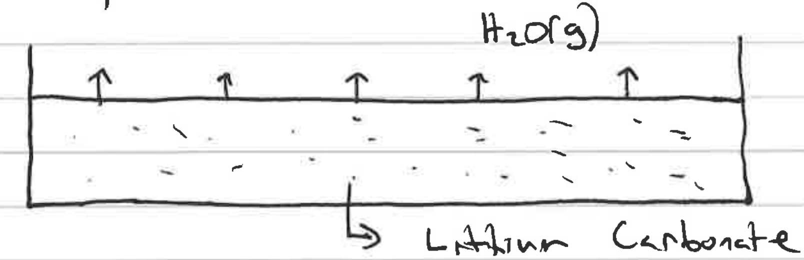
Batch processes use set amounts of material in & out (amount of material out depends on time)

Picture of what happens between two points in time

Lecture 5

Slide 3 Semi - continuous process

Evaporation Pond



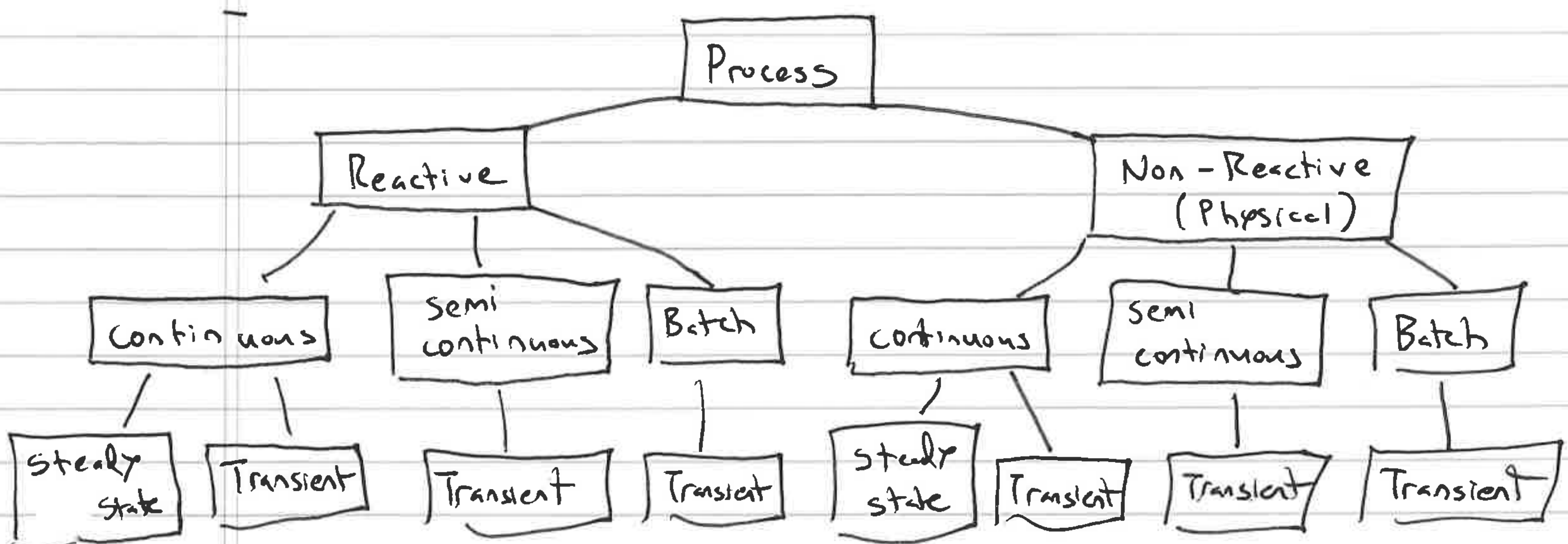
water evaporation → "continuous"
limited amount of material → " batch"
(water runs out)

Slide 6 So what form do the Xs take?

Slide 7 Differential Balances ⟷ Integral Balances
calculus

Focus of this course

Discussed in Ch 10 & future courses



All of these processes will have an associated form of the <u>Material Balance Eqn.</u>

Slide 9

Steady State Process

$$X_{IN} - X_{OUT} + X_{GEN} - X_{CON} = X_{ACC}$$

Always start with the general balance eqn!

For S.S. what goes in comes out

$X_{ACC} = 0$ (cancel out above)

$$\boxed{X_{IN} + X_{GEN} = X_{OUT} + X_{CON}}$$

(Material Balance for S.S.)

Non-Reactive S.S. Process

$$X_{IN} - X_{OUT} + \cancelto{\text{Non-reactive}}{X_{GEN}} - \cancelto{\text{Non-reactive}}{X_{CON}} = \cancelto{\text{S.S}}{X_{ACC}}$$

$$\boxed{X_{IN} = X_{OUT}}$$

Non-Reactive Transient Processes

$$X_{IN} - X_{OUT} + \cancelto{\text{No Rxn}}{X_{GEN}} - \cancelto{\text{No Rxn}}{X_{CON}} = X_{ACC}$$

$$\boxed{X_{IN} - X_{OUT} = X_{ACC}}$$

Batch Process

No material crosses the system boundary for Batch Processes

$$\cancelto{0}{X_{IN}} - \cancelto{0}{X_{OUT}} + X_{GEN} - X_{CON} = X_{ACC}$$

$$X_{GEN} - X_{CON} = X_{ACC} \quad (1)$$

unique to batch systems we know that accumulation in the unit is the difference between what was initially fed & what was finally removed

$$(1) \quad X_{ACC} = X_{(Final)\,output} - X_{(Initial)\,Input}$$

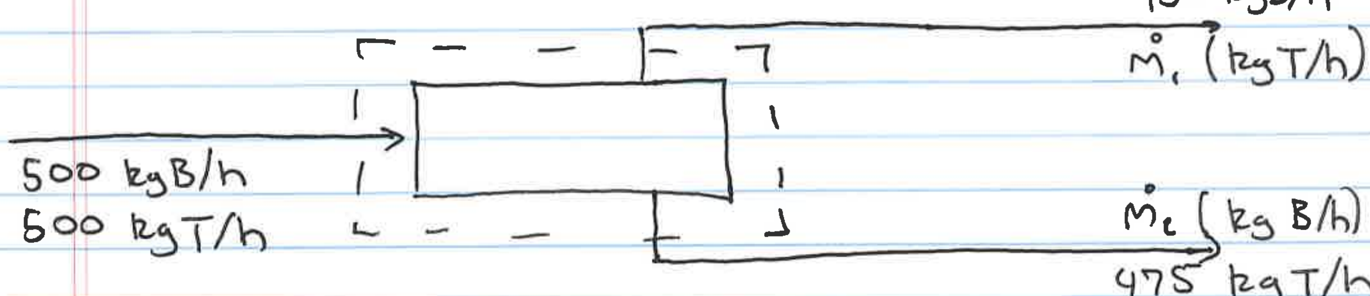
$$\boxed{X_{(Initial)\,IN} + X_{GEN} = X_{(Final)\,OUT} + X_{CON}}$$

Same as S.S. process except IN & OUT represent different things

S.S - material flowing in and out

Batch - initial & final amounts

Slide 10 Example 4.2-2



we will learn how to draw and label flowcharts in the near future

Material Balances

Physical Process S.S.

$$X_{IN} - X_{OUT} + \cancel{X_{GEN}} - \cancel{X_{CON}} = \cancel{X_{ACC}}$$

$$\boxed{X_{IN} = X_{OUT}}$$

<u>Benzene Balance</u> (what goes in, what goes out?)

$$500 \text{ kg B/h} = 450 \text{ kg B/h} + \dot{m}_2$$

$$\boxed{\dot{m}_2 = 50 \text{ kg B/h}}$$

<u>Toluene Balance</u>

$$500 \text{ kg T/h} = \dot{m}_1 + 475 \text{ kg T/h}$$

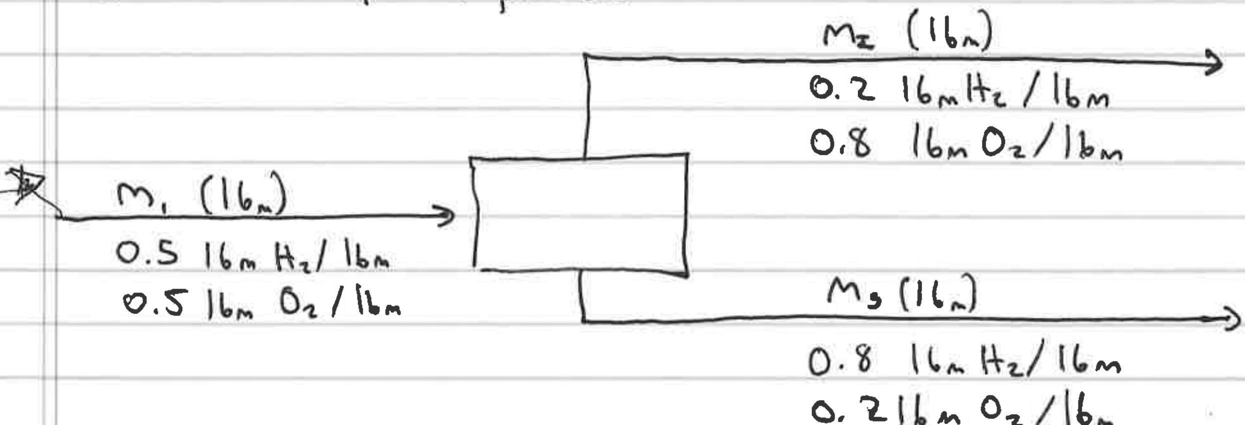
$$\boxed{\dot{m}_1 = 25 \text{ kg T/h}}$$

<u>Total mass Balance</u>

$$500 \text{ kg/h} + 500 \text{ kg/h} = 450 \text{ kg/h} + 50 \text{ kg/h} + 475 \text{ kg/h} + 25 \text{ kg/h}$$

(Checks out)

Slide 20 Non-reactive, batch process



Find the Feed In and Product Out Amounts (m_1 m_2 m_3)

To solve this problem it is necessary to choose a basis of calculation

Again pick something easy:

$m_1 = 100 \; lb_m$

Overall mass Balance

$$\overset{\text{Batch}}{\cancel{M_{IN}}} - \overset{\text{Batch}}{\cancel{M_{OUT}}} + \overset{\text{No Rxn}}{\cancel{M_{GEN}}} - \overset{\text{No Rxn}}{\cancel{M_{CON}}} = M_{Acc}$$

$$M_{Acc} = M_{(Final)\,out} - M_{(Initial)\,In}$$

$$\boxed{M_{IN} = M_{OUT}}$$

<u>Total Balance</u>

$$M_1 = M_2 + M_3$$

① $$100\ lb_m = M_2 + M_3$$

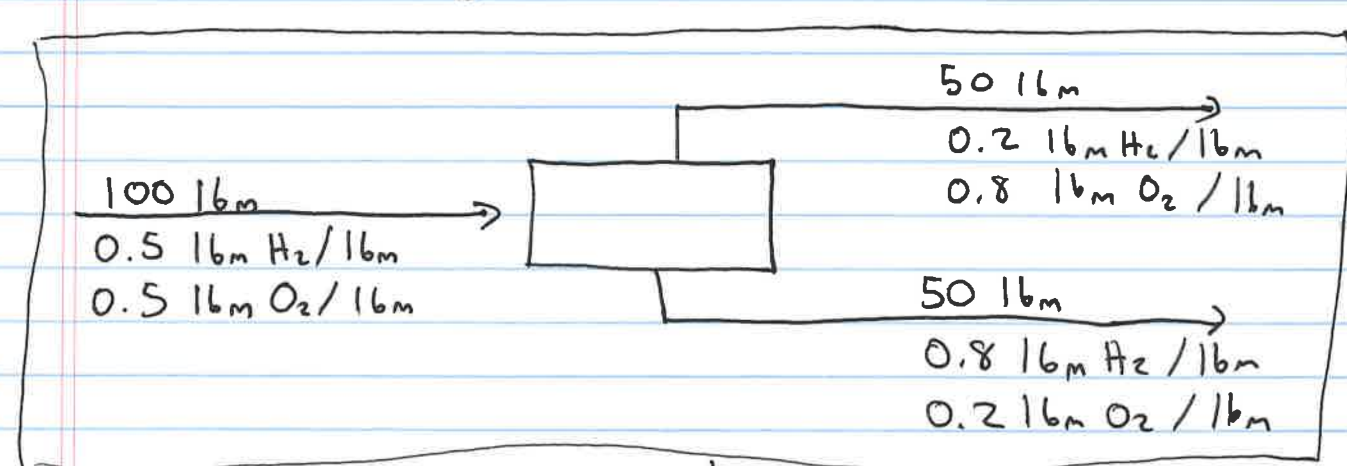
<u>Hydroge Balance</u>

$$100\ lb_m \left(\frac{0.5\ lb_m H_2}{lb_m} \right) = M_2 \left(\frac{0.2\ lb_m H_2}{lb_m} \right) + M_3 \left(\frac{0.8\ lb_m H_2}{lb_m} \right)$$

② $$50\ lb_m H_2 = 0.2\ M_2 \left(\frac{lb_m H_2}{lb_m} \right) + 0.8\ M_3 \left(\frac{lb_m H_2}{lb_m} \right)$$

Two equations two unknowns

$$M_2 = 50\ lb_m$$
$$M_3 = 50\ lb_m$$

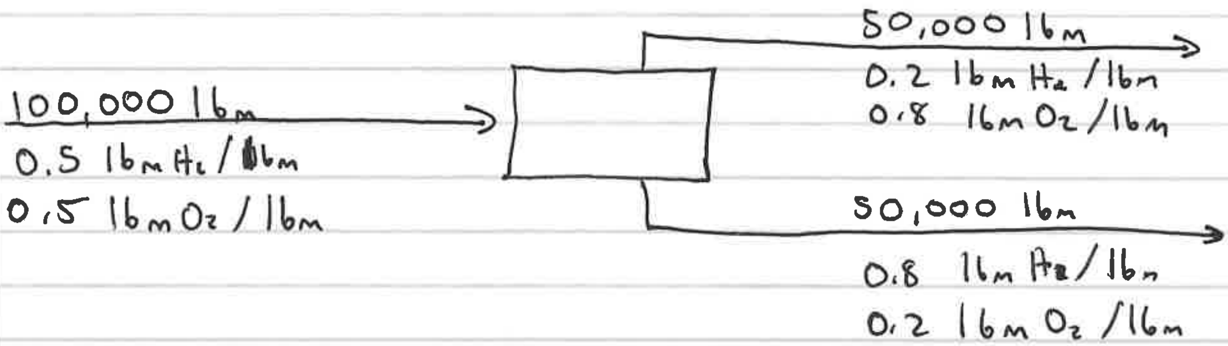


Balanced

slide 21

Scaling

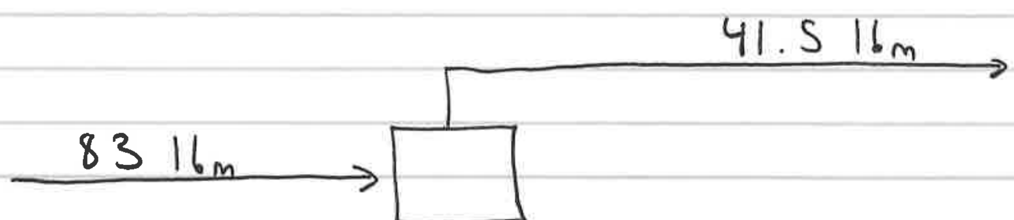
Because this process is balanced it can be scaled → If we want to increase production by 1000, we increase mass input by 1000



* Chemical composition won't change from scaling

we only have 83 lb_m of input mixture left

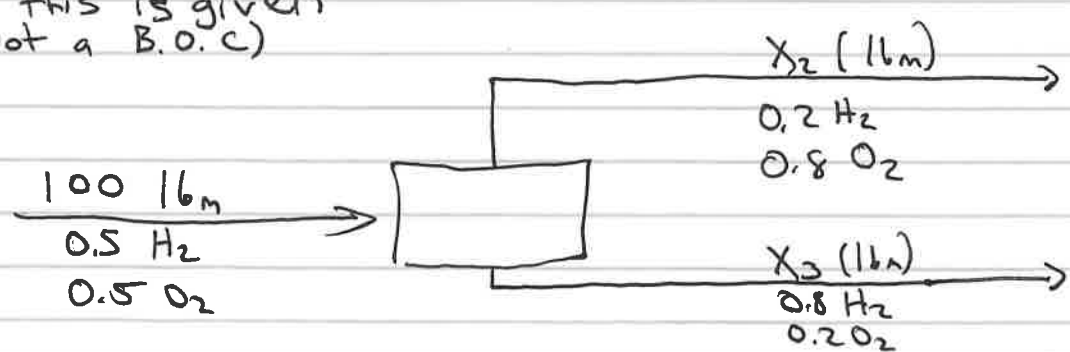
multipy streams by $\frac{83}{100} = 0.83$ $\left(\frac{\text{desired amount}}{\text{original amount}}\right)$



Lecture 6

Slide 5 Use step 9 if

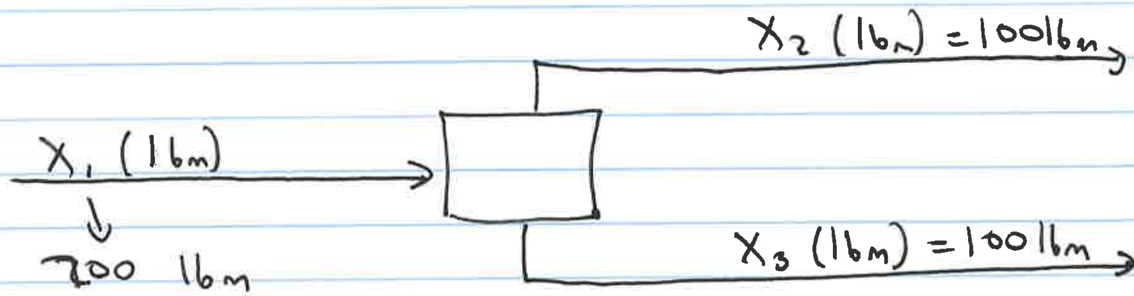
Say this is given (Not a B.O.C)



You decide to use a basis of calculation for X_3 instead of the given 100 lb_m

You assume $X_3 = 100\ lb_m$ (Doing this is silly)

This is no longer known



To convert back to given values

$n_{given} = 100\ lb_m$

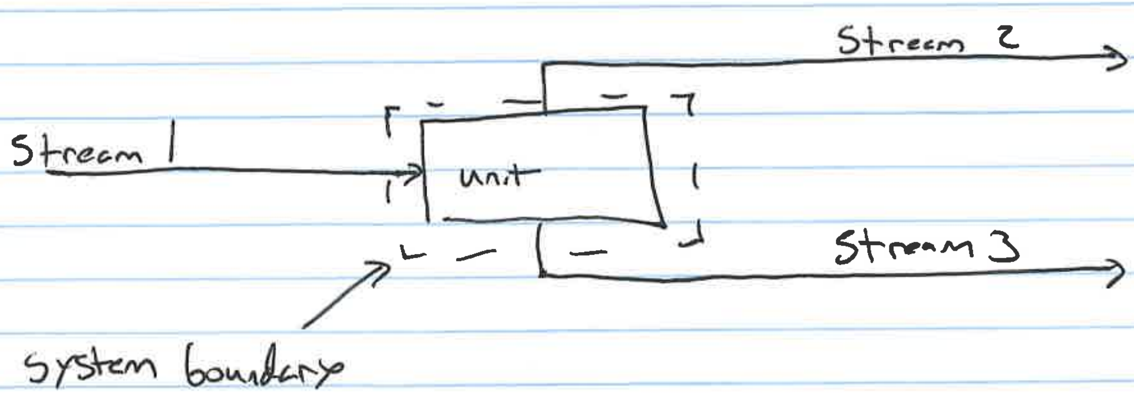
$n_{calculated} = 200\ lb_m$

$\frac{n_g}{n_c} = 0.5$

multiply this by all stream amounts

* If trying to scale mass flow rates to molar quantities (or vise versa) you need to convert using MW

Slide 9



Slide 10 Keep unknowns to a minimum

Mass and mole fractions of all components add to 1:

Don't label: $X_A \left(\frac{\text{mols A}}{\text{mol}}\right)$, $X_B \left(\frac{\text{mols B}}{\text{mol}}\right)$, $X_C \left(\frac{\text{mols C}}{\text{mol}}\right)$

Label as: $X_A \left(\frac{\text{mols A}}{\text{mol}}\right)$, $X_B \left(\frac{\text{mols B}}{\text{mol}}\right)$, $(1 - X_A - X_B)\left(\frac{\text{mols C}}{\text{mol}}\right)$

If given information on how streams relate:

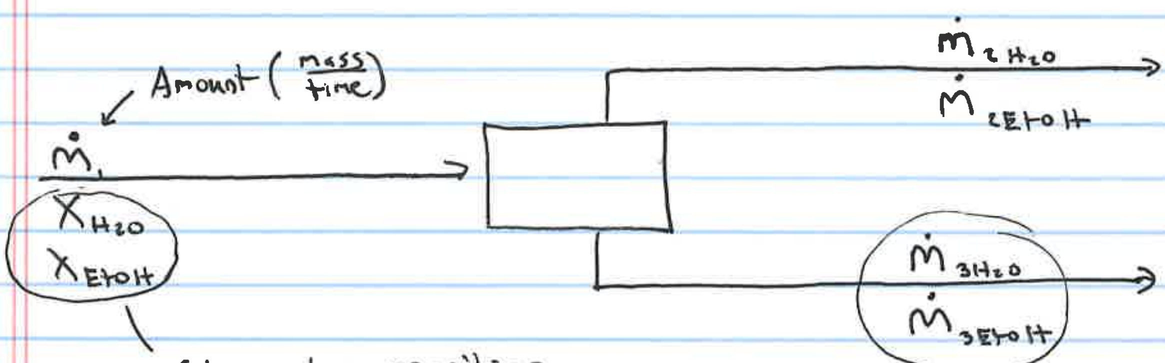
Given: Stream 1 mass is 5 times that of stream 2 mass

Don't Label: m_1 (kg), m_2 (kg)

Label as: $5m_2$ (kg), m_2 (kg) [OR m_1 (kg), $\frac{1}{5}m_1$ (kg)]

Slide 11 Each stream needs: Amount of material in stream
Chemical composition

Amount $\left(\frac{\text{mass}}{\text{time}}\right)$



Chemical composition $\left(\frac{\text{mass components}}{\text{mass total}}\right)$

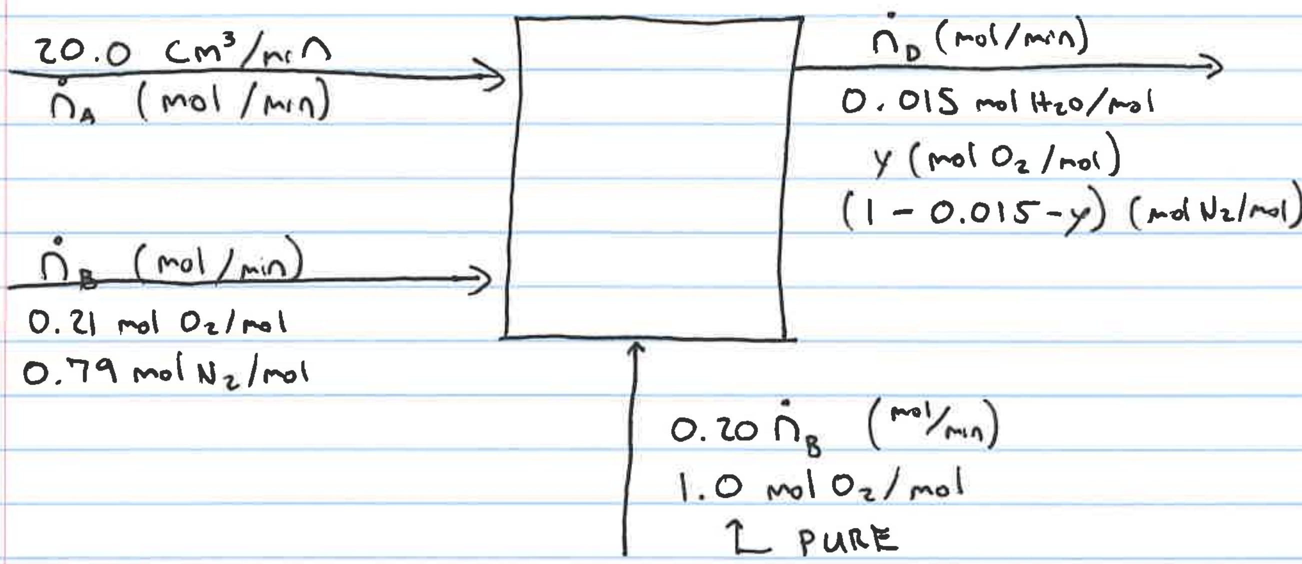
Amount and chemical composition combined $\left(\frac{\text{mass component}}{\text{time}}\right)$

$X_{EtOH} \rightarrow 1 - X_{EtOH}$

$$\dot{m}_{2H_2O} + \dot{m}_{2EtOH} = \dot{m}_2$$

Slide 12 Notation change

Slide 13 Start by drawing a "road map"



Slide 15 ~~[illegible]~~

Algebra DoF

$$2x + 3y + z = 8 \quad (1)$$
$$7x + 5y + 2z = 3 \quad (2)$$
$$4x + 6y + 2z = 16 \quad (3)$$

3 eqns, 3 unknowns but independent?

multiply eqn (1) by 2 ← value

$$2 * (1) = (3)$$

2 eqns, 3 unknowns => Degree of Freedom Analysis

$$3 - 2 = 1$$

$$DoF \neq 0$$

Slide 23 1. we are given an entering volumetric flow rate

* Book does this differently but I suggest converting volumetric flow rates in the first step

<u>Always</u> convert $\dot{V}$ to $\dot{m}$ or $\dot{n}$

very important $\Rightarrow$ Volume is <u>not</u> a conserved quantity
No volume Balances

Assuming pure H_2O @ 4°C $\Downarrow$

Problem gives most information in molar quantities

$$20.0 \frac{cm^3 H_2O}{min} \left(\frac{1.00\, g\, H_2O}{cm^3}\right)\left(\frac{1\, mol\, H_2O}{18\, g\, H_2O}\right) = 1.11 \frac{mol\, H_2O}{min} = \dot{n}_A$$

2. Done previously

3. Unknown stream variables : $\dot{n}_B$ $\dot{n}_D$ y

$\Downarrow$

MATERIAL BALANCES $\Leftarrow$ How do we solve these variables? What equations can we derive?

Start with general equation

$$X_{IN} - X_{OUT} + \cancel{X_{GEN}}^{\text{No Rxn}} - \cancel{X_{CON}} = \cancel{X_{ACC}}^{\text{S.S.}}$$

$$X_{IN} = X_{OUT}$$

X will be # of moles (mole balance)

4. No Need

5. Degree of Freedom:

$\dot{n}_B$ $\dot{n}_D$ y : 3 unknowns

There are 3 components in this <u>non-reactive</u> process

$\therefore$ only 3 independent balances

$$\begin{array}{lll} 3 \text{ unknowns} & (\dot{n}_B \quad \dot{n}_D \quad y) & \\ -\ 3 \text{ eqns} & (\text{MBs}) & \\ \hline 0 \Rightarrow \text{unique solution} & & \end{array}$$

6. $X_{IN} = X_{OUT}$

<u>Total Balance</u>

$$1.11 \text{ mol/min} + \dot{n}_B + 0.20\,\dot{n}_B = \dot{n}_D$$

$$1.11 \text{ mol/min} + 1.20\,\dot{n}_B = \dot{n}_D$$

<u>N_2 Balance</u>

$$\dot{n}_B\,(0.79 \text{ mol } N_2/\text{mol}) = \dot{n}_D\,(0.985 - y)\left(\frac{\text{mol } N_2}{\text{mol}}\right)$$

<u>H_2O Balance</u> (Pure components are good to balance)

$$1.11\,\frac{\text{mol}}{\text{min}}\left(1\,\frac{\text{mol } H_2O}{\text{mol}}\right) = \dot{n}_D\left(0.015\,\frac{\text{mol } H_2O}{\text{mol}}\right)$$

$\dot{n}_B \leftarrow 1.11 + 1.20\,\dot{n}_B = \dot{n}_D$ (2)

$\dot{n}_D \leftarrow 0.015\,\dot{n}_D = 1.11$ (1)

$y \leftarrow 0.79\,\dot{n}_B = (0.985 - y)\,\dot{n}_D$ (3)

7. (1) $\boxed{\dot{n}_D = 74 \text{ mol/min}}$

(2) $1.11 \text{ mol/min} + 1.20\,\dot{n}_B = 74$

$$\boxed{\dot{n}_B = 60.7 \text{ mol/min}}$$

(3) $0.79\left(60.7\,\frac{\text{mol}}{\text{min}}\right)\left(\frac{\text{mol } N_2}{\text{mol}}\right) = 74\,\frac{\text{mol}}{\text{min}}\,(0.985 - y)\,\frac{\text{mol } N_2}{\text{mol}}$

$$47.9\,\frac{\text{mol } N_2}{\text{mol}} = 74\,\frac{\text{mol } N_2}{\text{mol}}\,(0.985 - y)$$

$$\boxed{y = 0.338 \text{ mol } O_2/\text{mol}}$$

where did units come from? ⇒ Check flow chart

important to have properly labeled flowchart!

Lecture 7

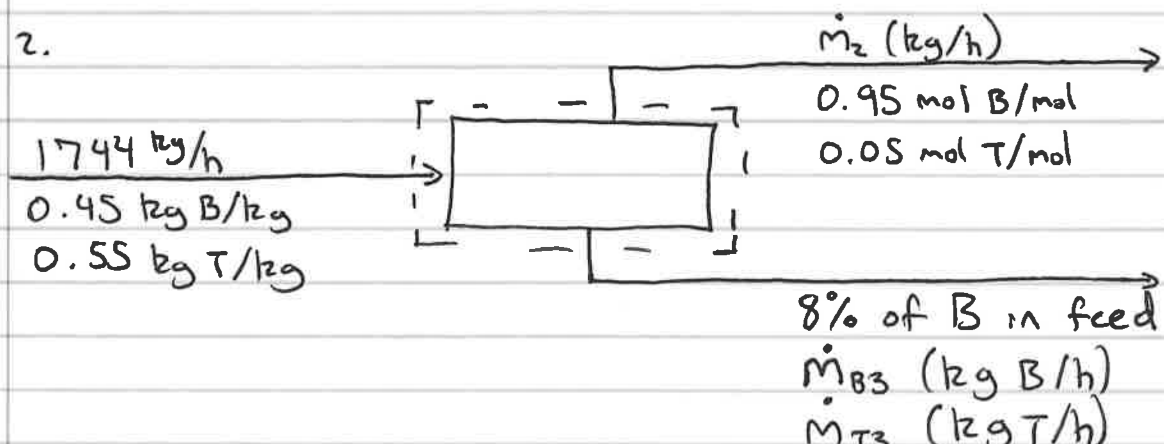
Slide 36 Example 4.3-5

1. Given 2000 L/h convert $\dot{m}$ (most info given in mass) (need density to do this)

$$SG = \frac{\rho_i}{\rho_{ref}} \Rightarrow \rho = 0.872\left(1000\ \frac{kg}{m^3}\right) = 872\ \frac{kg}{m^3}$$

$$\dot{m} = 2000\ \frac{L}{h}\left(\frac{1\ m^3}{1000\ L}\right)\left(872\ \frac{kg}{m^3}\right) = 1744\ kg/h$$

2.



3. unknowns ($\dot{m}_2$, $\dot{m}_{B3}$, $\dot{m}_{T3}$)

Problem wants: $\dot{m}_2$ $\dot{m}_3$ x_B x_T

$\dot{m}_2$ (solving for this)

$\dot{m}_3 = \dot{m}_{B3} + \dot{m}_{T3}$

$x_B = \dot{m}_{B3} / \dot{m}_3$

$x_T = 1 - x_B$

4. Need to convert mols fractions to mass fractions without known flow rates $\Rightarrow$ Basis of calculation

Assume 100 k-mol

Table B.1

$$0.95 \frac{\text{kmol B}}{\text{kmol}} (100 \text{ k-mol}) = 95 \text{ kmol B} \left(\frac{78.11 \text{ kg}}{1 \text{ k-mol}}\right) = 7420 \text{ kg B}$$

$$0.05 \frac{\text{kmol T}}{\text{kmol}} (100 \text{ k-mol}) \Rightarrow 461 \text{ kg T}$$

$$7420 + 461 = 7881 \text{ kg}$$

$$X_{B2} = \frac{7420 \text{ kg B}}{7881 \text{ kg}} = 0.942 \text{ kg B/kg}$$

$$X_{T2} = 0.058 \text{ kg T/kg}$$

5. 3 unknowns ($\dot{m}_2$ $\dot{m}_{B3}$ $\dot{m}_{T3}$)
 - 2 Material Balances (2 components)
 - 1 Specific Relationship (8% of B in feed)

 0

6. $X_{IN} - X_{OUT} + X_{GEN} - X_{CON} = X_{ACC}$

$$X_{IN} = X_{OUT}$$

Specified Relationship

$$\dot{m}_{B3} = 0.08[(1744 \text{ kg/h})(0.45 \text{ kg B/kg})] \quad ①$$

Benzene Balance

$$1744 \text{ kg/h} (0.45 \text{ kg B/kg}) = \dot{m}_2 (0.942 \text{ kg B/kg}) + \dot{m}_{B3} \quad ②$$

Total Balance

$$1744 \text{ kg/h} = \dot{m}_2 + \dot{m}_{B3} + \dot{m}_{T3} \quad ③$$

7. ① $\dot{m}_{B3} = 62.8 \ kgB/h$

② $784.8 \frac{kg\,B}{h} = \dot{m}_2 \left(0.942 \frac{kg\,B}{kg}\right) + 62.8 \frac{kg\,B}{h}$

$\dot{m}_2 = 766 \ kg/h$

③ $1744 \ kg/h = 766 \ kg/h + 62.8 \ kgB/h + \dot{m}_{T3}$

$\dot{m}_{T3} = 915.2 \ kgT/h$

8. Look @ step 3 : $\dot{m}_2 = 766 \ kg/h$

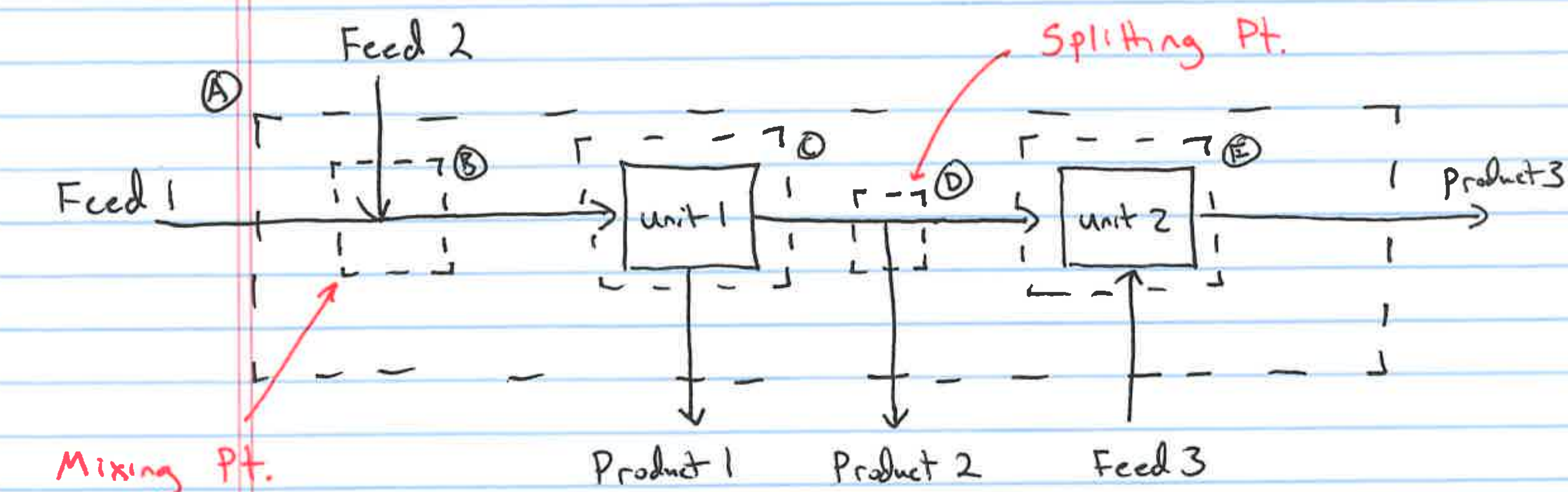
$\dot{m}_3 = 62.8 + 915.2 = 978 \ kg/h$

$x_B = 62.8/978 = 0.064 \ kgB/kg$

$x_T = 1 - 0.064 = 0.936 \ kgT/kg$

9. No Need

Slide 10 Two unit process Flowchart



To slide 11

Slide 11

Boundary Ⓐ (AKA the overall balance → includes entire process)

X_{IN}	X_{OUT}
Feed 1	Product 1
Feed 2	Product 2
Feed 3	Product 3

Boundary Ⓑ (mixing pt)

X_{IN}	X_{OUT}
Feed 1	Stream into unit 1
Feed 2	

same stream

Boundary Ⓒ (unit 1)

X_{IN}	X_{OUT}
Stream into unit 1	Product 1
	Stream out of unit 1

Boundary Ⓓ (splitting pt)

X_{IN}	X_{OUT}
Stream out of ~~split~~ unit 1	Product 2
	Stream out of split pt.

Boundary Ⓔ (unit 2)

X_{IN}	X_{OUT}
Stream out of split pt	Product 3
Feed 3	

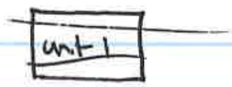
outputs of some boundaries will be inputs of others slide ~~10~~ 13 Given a labeled flowchart of a S.S. process

~~1 & 2) Two components A & B (non-reactive)~~

~~40.0 kg/h~~

~~0.9 kg A/kg~~

~~0.1 kg B/kg~~



1 & 2) Two components A & B (non-reactive)

Shown in slide

3) Total number of unknowns: 6

$\dot{m}_1 \quad x_1 \quad \dot{m}_2 \quad x_2 \quad \dot{m}_3 \quad x_3$

4) No Need

5) DoF Analysis

overall system: Two unknowns $(\dot{m}_3, x_3)$ $\quad 2$

Two independent MBs $\quad -2$

$\quad 0$

unit 1: Two unknowns $(\dot{m}_1, x_1)$ $\quad 2$

Two MBs $\quad -2$

$\quad 0$

mixing pt: Four unknowns $(\dot{m}_1, x_1), \dot{m}_2, x_2)$ $\quad 4$

Two MBs $\quad -2$

$\quad 2$

unit 2: Four unknowns ($\dot{m}_2$, x_2, $\dot{m}_3$, x_3)

$$\begin{array}{r} 4 \\ -2 \\ \hline 2 \end{array}$$

solving the overall system gives $\dot{m}_3$ x_3

use in unit 2 Balances ⇒ DoF

In general it is advisable to start with the overall system balance first to see if DoF is 0

Determine what the problem is asking and make a plan.
It may not be necessary to solve for every unknown
(In this problem we solve everything)

(c17) General Balance

$$X_{IN} - X_{OUT} + \cancel{X_{GEN}}^{\text{No Rxn}} - \cancel{X_{CON}}^{\text{No Rxn}} = X_{\cancel{ACC}}^{\text{S.S.}}$$

$$X_{IN} = X_{OUT}$$

Start with overall system

Overall

$$100 \text{ kg/h} + 30 \text{ kg/h} = 40 \text{ kg/h} + 30 \text{ kg/h} + \dot{m}_3 \text{ (kg/h)}$$

$$\boxed{\dot{m}_3 = 60 \text{ kg/h}}$$

Overall A

$$0.5(100) + 0.3(30) = 0.9(40) + 0.6(30) + 60(x_3)$$

$$\boxed{x_3 = 0.0833 \text{ kg A/kg}}$$

$\boxed{\text{Unit 1}}$

Overall unit 1 Balance

$$100 \text{ kg/h} = 40.0 \text{ kg/h} + \dot{m}_1$$

$$\boxed{\dot{m}_1 = 60 \text{ kg/h}}$$

unit 1 A Balance

$$100(0.5) = 40(0.9) + 60(x_1)$$

$$\boxed{x_1 = 0.233 \text{ kg A/kg}}$$

$\boxed{\text{unit 2}}$

Overall unit 2 Balance

$$\dot{m}_2 (\text{kg/h}) = 30.0 \text{ kg/h} + 60.0 \text{ kg/h}$$

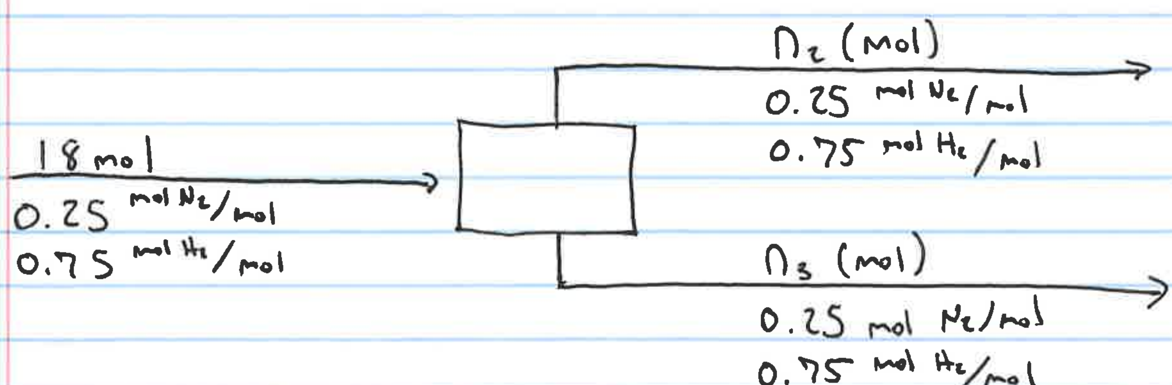
$$\boxed{\dot{m}_2 = 90 \text{ kg/h}}$$

unit 2 A Balance

$$90 x_2 = 30(0.6) + 60(0.0833)$$

$$\boxed{x_2 = 0.255 \text{ kg A/kg}}$$

Slide
6
5



Balances on N_2 & H_2

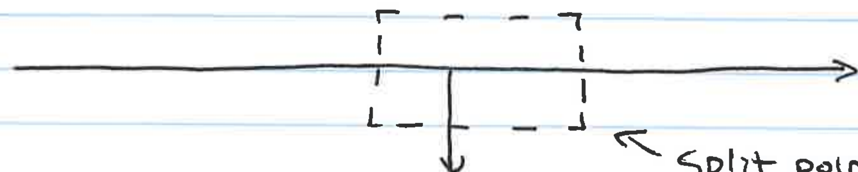
$N_2 \quad 0.25(18) = 0.25\, n_2 + 0.25\, n_3$ ①

$H_2 \quad 0.75(18) = 0.75\, n_2 + 0.75\, n_3$ ②

multiply ① $\frac{0.75}{0.25}$

Not independent : 2 species, 1 MB

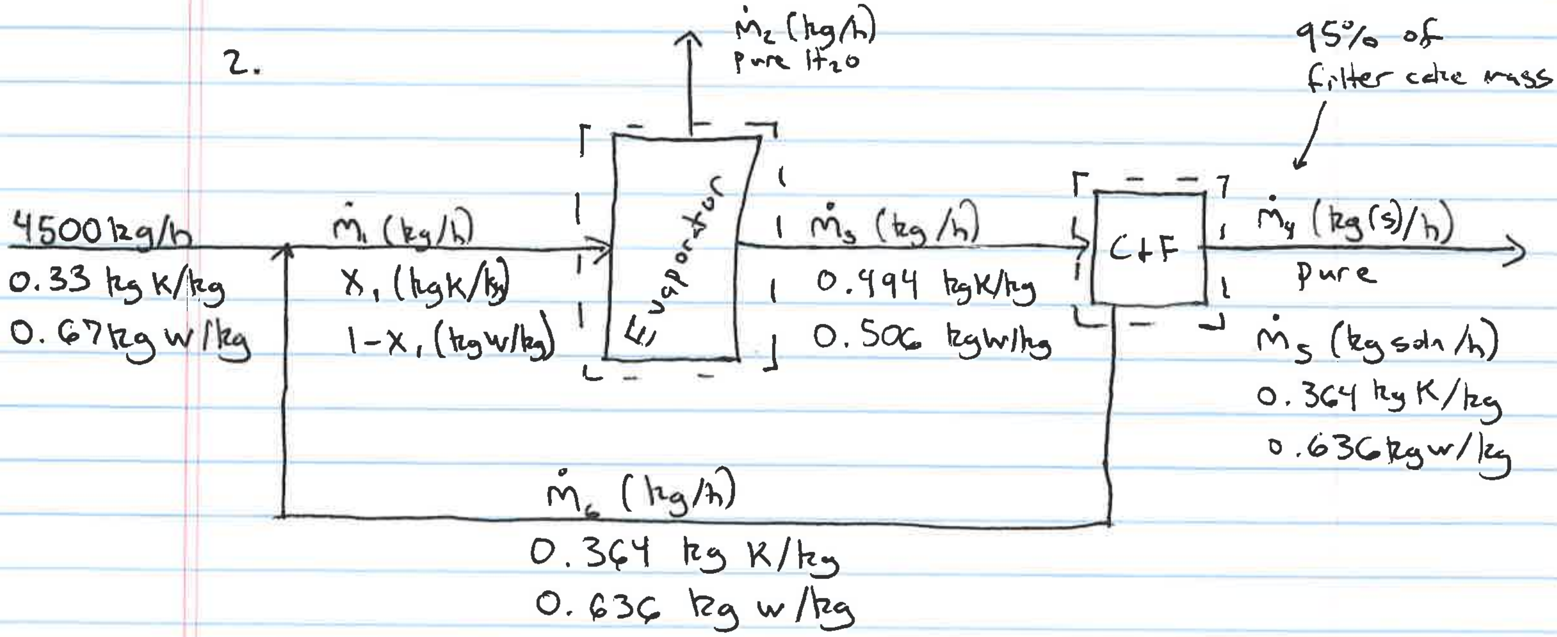
Most common case for us



Slide 7 $\quad K_2CrO_4 : K \qquad H_2O : W$

1. 4500 kg/h

2.



3. $\dot{m}_1 \quad \dot{m}_2 \quad \dot{m}_3 \quad \dot{m}_4 \quad \dot{m}_5 \quad \dot{m}_6 \quad x_1$ (unknowns)

Asked to solve for : $\dot{m}_2,\ \dot{m}_4,\ \dot{m}_1,\ \dot{m}_3,\ \frac{\dot{m}_6}{4500\ \text{kg/h}}$

Don't Erase

4. No Need

5. DoF Analysis

overall: unknowns $(\dot{m}_2 \;\; \dot{m}_4 \;\; \dot{m}_5)$ 3
2 MBs (K & W) -2
1 process relationship (95%) -1
0

Recycle pt: unknowns $(\dot{m}_1 \;\; \dot{m}_c \;\; x_1)$ 3
2 MBs -2
1

Evaporator: unknowns $(\dot{m}_1, \dot{m}_2, \dot{m}_3 \;\; x_1)$ 4
2 MBs -2
2

Crystal & Filter: unknowns $(\dot{m}_3 \;\; \dot{m}_4 \;\; \dot{m}_5 \;\; \dot{m}_6)$ 4 2
2 MBs -2 -2
~~1 process relationship (95%)~~
2 0

Order: Overall
C & F
Recycle (Evap works too)

Don't Erase

6. $X_{IN} - X_{OUT} + \cancel{X_{GEN}} - \cancel{X_{CON}} = \cancel{X_{ACC}}$ S.S

No RXN

$$X_{IN} = X_{OUT}$$

Overall

overall K Balance

$4500 \text{ kg/h } (0.33 \text{ kg K/kg}) = \dot{m}_4 (1 \text{ kg K/kg}) + \dot{m}_5 (0.364 \text{ kg K/kg})$ (1)

Total overall mass

$$4500\ kg/h = \dot{m}_2 + \dot{m}_4 + \dot{m}_5$$

1 Given Relationship

$$\dot{m}_4 = 0.95\ (\dot{m}_4 + \dot{m}_5)$$

$$\dot{m}_4 = 0.95\ \dot{m}_4 + 0.95\ \dot{m}_5$$

① $\dot{m}_5 = 0.0526\ \dot{m}_4$

7) $4500\ (0.33) = \dot{m}_4 + 0.0526\ \dot{m}_4\ (0.364)$

$$\dot{m}_4 = 1470\ kg/h$$
$$\dot{m}_5 = 77.3\ kg/h$$

$$4500\ kg/h = \dot{m}_2 + 1470\ kg/h + 77.3\ kg/h$$

$$\dot{m}_2 = 2950\ kg/h$$

C+F $\quad X_{IN} = X_{OUT}$

(6+7)

Total mass around C+F

$$\dot{m}_3 = 1470\ kg/h + 77.3\ kg/h + \dot{m}_6$$

H_2O balance around C+F

$$\dot{m}_3\ (0.506\ kgw/kg) = 77.3\ kg/h\ (0.636\ kgw/kg) + \dot{m}_6\ (0.636\ kgw/kg)$$

2 eqns, 2 unknowns $\quad \dot{m}_6 = 5650\ kg/h$

$\dot{m}_3 = 7200\ kg/h$

Recycle Pt

(6+7) $X_{IN} = X_{OUT}$ $\quad (\dot{m}_1\ X_1)$ unknowns

↖ problem doesn't ask for X_1

Total mass around Recycle pt.

$$4500 \text{ kg/h} + 5650 \text{ kg/h} = \dot{m}_1$$

$$\dot{m}_1 = 10150 \text{ kg/h}$$

8) $\dot{m}_2 = 2950$ kg/h
$\dot{m}_4 = 1470$ kg/h
$\dot{m}_1 = 10150$ kg/h
$\dot{m}_3 = 7200$ kg/h

$$\frac{\dot{m}_6}{4500} = 1.26$$

9) No Need