Name: ____________________
Section #: _________________
(Sections: **101** Tues 12:30, **102** Tues 2:00, **103** Thurs 12:30, **104** Thurs 5:00)

Chemical Engineering 40 Midterm Exam
Tuesday, March 3, 2020
50 minutes

This exam consists of 5 problems and is worth 100 points.

No communication with anyone inside or outside the classroom is permitted.
No use of outside materials other than a calculator is permitted.

Use appropriate significant figures in your answers.
Show all work and/or explain your reasoning.
Box your final answers.
You may use the back of pages, or additional pages at the end of this packet to show your work. Indicate where you have written your work for each problem.

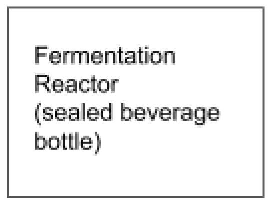
On my honor, this exam is my own work, and I have neither given nor received any assistance in taking this exam.

Signed: ____

1. (15 points) Fizzy fermented beverages like kombucha and beer undergo secondary fermentation within their sealed bottle. During this process, carbon dioxide evolves and is dissolved within the beverage.

You can represent secondary fermentation with this chemical reaction:

$$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$$



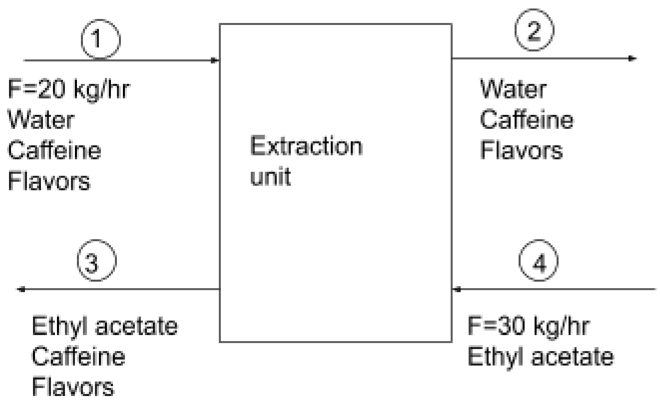
Write the full form of the general mass balance, then show how you would apply it to CO_2 in this system by cancelling terms that do not apply. Do not attempt to solve for any quantities.

+5 pts for full form.
+10 pts for correct simplification (can earn +5 pts for partially correct)

Accumulation = ~~In~~ - ~~Out~~ + Generation - ~~Consumption~~
Accumulation = Generation

2. (10 points) Write the underlined portion of the following process description in the form of a mathematical equation:

Decaffeination of coffee can be accomplished by charcoal filtration OR solvent extraction OR supercritical carbon dioxide extraction. In the following process, ethyl acetate, an organic solvent, is used to extract caffeine. The extraction removes 99.7% of the caffeine from the coffee feed stream.



$X_{c,3} * F_3 = 0.997\ x_{c,1} * F_1$

OR

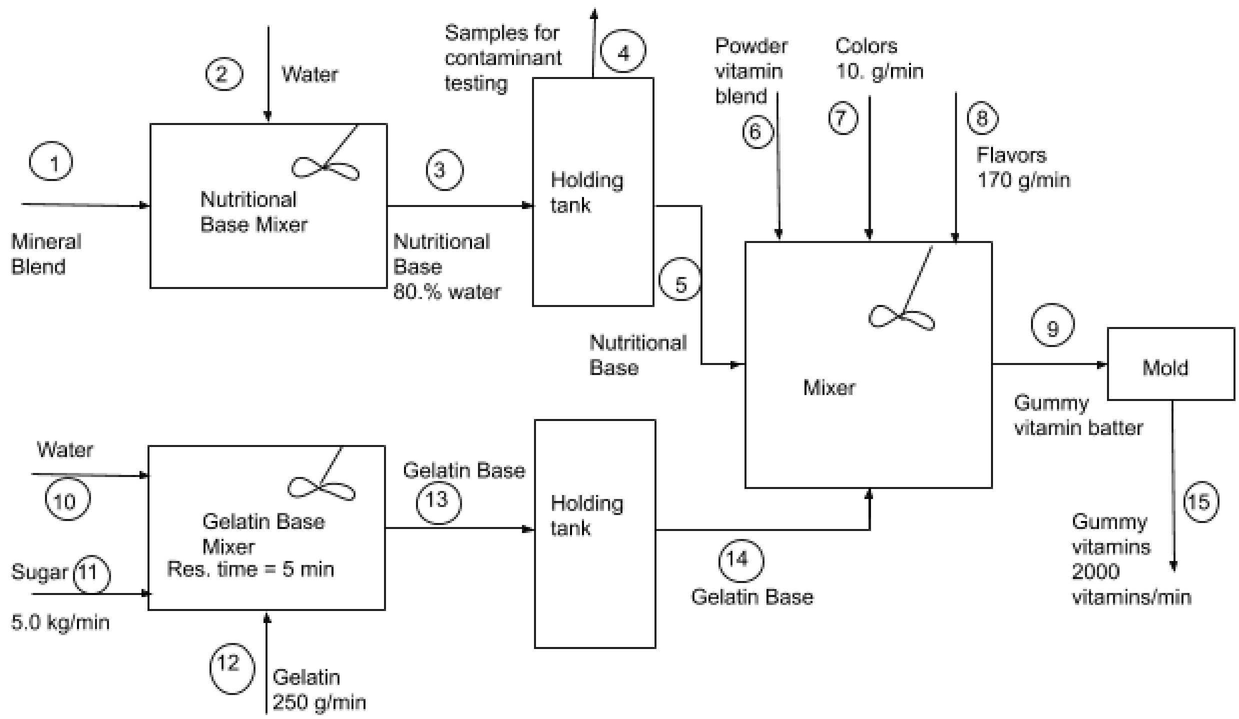
$X_{c,2} * F_2 = 0.003\ x_{c,1} * F_1$

OR

$F_{caffeine,1} * 0.997 = F_{caffeine,3}$

10 points for either correct equation.

3. (15 points) The process below makes gummy multivitamins at a rate of 2000 vitamins per minute. Each vitamin has a mass of 5.0 g. Find the mass fraction of sugar in the final product. (You may assume no sugar enters except where explicitly stated. It is not included in the flavors, etc.)



Mass balance of sugar on overall system:

~~Accumulation~~ = In - Out + ~~Generation~~ - ~~Consumption~~

In = Out

$F_{15} = F_{11} = 5kg/min$ (+5 points)

Fraction of sugar in vitamins

$Xsugar = F_{sugar,15} / F_{vitamin, 15}$ = 5.0kg/min/ (2000 vitamins/min) = 2.5g sugar per vitamin (+5 points)

Each vitamin is 5.0 g → mole fraction of sugar in vitamins = 2.5g/5.0g = 50% or 0.5 (+5 points)

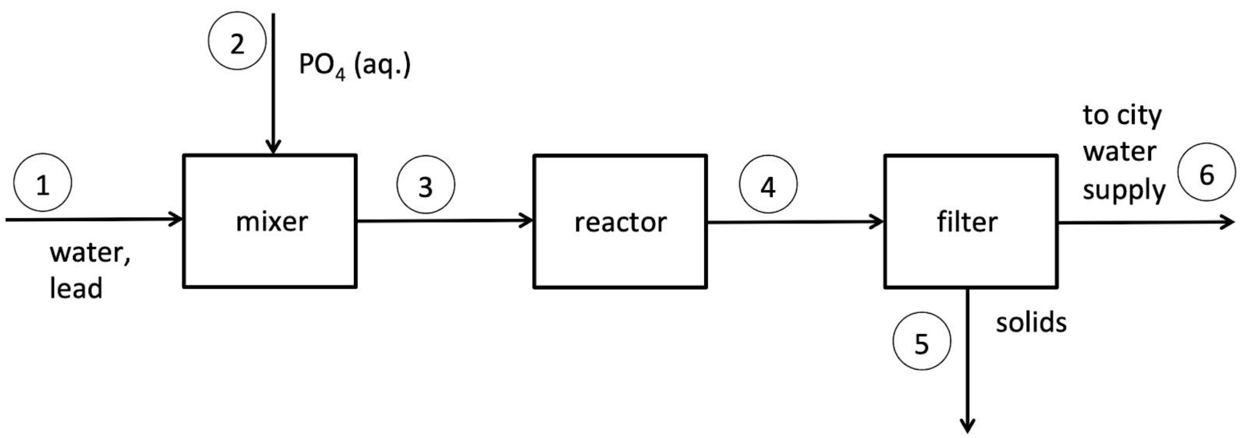
4. Purification of lead contaminated water (30 points)

Lead (Pb, 207 g/mol) in drinking water can have disastrous health effects. The US Environmental Protection Agency maximum contaminant level goal is for zero lead in drinking water, and the action level for required treatment technology is 0.015 mg/L. Lead can be reacted with orthophosphate (PO_4, 95 g/mol) to form $Pb_3(PO_4)_2$ (811 g/mol), which is insoluble in water and can therefore be removed easily.

a) Balance the reaction: (3 points)

3 Pb + 2 PO_4 ---> 1 $Pb_3(PO_4)_2$

1 point per coefficient



Aqueous PO_4 is added to drinking water contaminated with lead, and the reaction in (a) occurs. A filter removes 90.% of the produced $Pb_3(PO_4)_2$ from the water. You may assume that the solids are clean and dry when they leave the filter. PO_4 enters the mixer at 200. g/min, and Pb enters the mixer at 600. g/min.

b) Which reactant is limiting? (8 points)

Pb: 600 g/min / 207 g/mol = 2.899 mol/min (2 points)

PO4: 200 g/min / 95 g/mol = 2.105 mol/min (2 points)

To consume all Pb, we need 2.899/3*2 = 1.932 mol/min PO4. (2 points)

We have more than that, so **Pb is limiting**. (2 points)

OR

To consume all PO4, we need 2.105/2*3 = 3.16 mol/min Pb. (2 points)

We have less than that, so **Pb is limiting**. (2 points)

If failed to convert to moles, but did 200 g/min PO4 -> 300 g/min Pb, so PO4 limiting, 4 points (correct limiting reactant logic, wrong units)

c) What is the percent excess of the other reactant? (4 points)

(2.105-1.932)/1.932 = 0.08947 = **8.9% excess** PO4 (if you rounded intermediate answers from (b), you get (2.1-1.9)/1.9 = 0.105 = 11%)

2 points: correct equation (i.e. not 2.105 in denominator), 2 points for correct answer given equation used

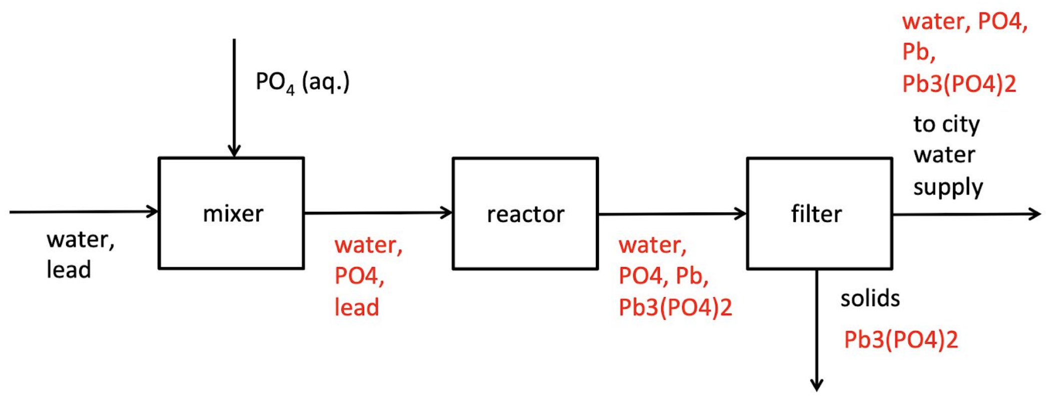
If math error from (b) as far as unit conversions carried over, full credit.

-1 for sig figs

?? for rounding early and getting 11%

Assume that the reactor has a 50.% conversion of the limiting reactant.

d) Label on the PFD above what molecules will be found in each stream. (4 points)



1 point per stream. If (4) is incorrect (i.e. assumes complete conversion) but (5) and (6) are correct given that, -1 only.

e) What is the flow rate in g/min of $Pb_3(PO_4)_2$ in the final water supply (stream 6)? (8 points)

2.899 mol/min lead is 50% consumed (2 points), generating 2.899/3/2 = 0.483 mol/min of $Pb_3(PO_4)_2$ (2 points). 90% is removed by the filter, leaving (0.1)(0.483) = 0.0483 mol/min in the water supply (2 points). 0.0483 mol/min * 811 g/mol = 39.17 g/min, rounding to **39 g/min** (2 points).

(note: rounding 0.48 a final answer of 38.9 g/min, which also rounds to 39)

-1 for sig figs

f) Make a suggestion for improving this process. (3 points)

Get a better filter to remove more $Pb_3(PO_4)_2$, remove PO4 somehow and recycle it, feed more excess PO4 to get a higher conversion…

Being really creative (like the ones in the book), try to find a way to prevent lead from getting into the water in the first place (i.e. replace pipes)

Full credit for reasonable suggestion

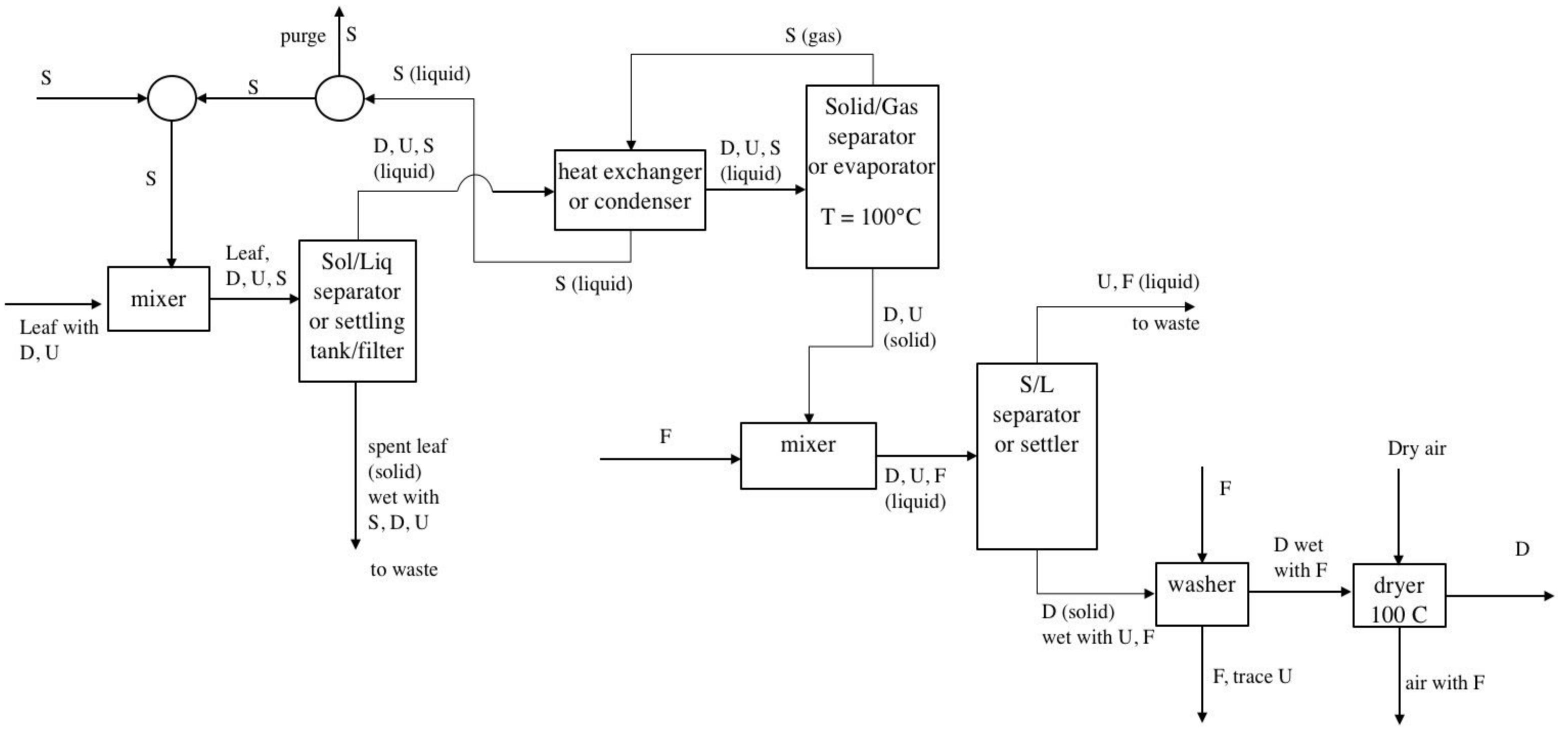
5. Process Design (30 points)

A pharmaceutical drug (D) can be made by performing a chemical extraction of species D from the leaves of a tropical plant. An undesired impurity U is also found in the leaves. The leaves enter the process already ground into a leaf powder. Design a process to produce a pure product stream of drug D using any of the following solvents with the physical properties listed below. Solvent A has been shown to be a carcinogen, whereas F and S are benign. Make your process safe and efficient in terms of material and energy. Be sure to label all streams and units with relevant information.

Note: assume any solid-gas or liquid-gas separations are ideal, ie. you can separate 100% of your gaseous species of interest.

Chemical Species	Boiling Pt (°C)	Soluble in Solvent F	Soluble in Solvent A	Soluble in Solvent S	Price ($/kg)
D	Decomposes at 120	no	yes	yes	200
U	Decomposes at 200	yes	yes	yes	5
Other Parts of Leaf	Decomposes at 300	no	no	no	2
Solvent F	82	--	yes	yes	20
Solvent A	75	yes	--	yes	30
Solvent S	84	yes	yes	--	60

Solution option 1: Use S to extract D&U, then use F to extract U

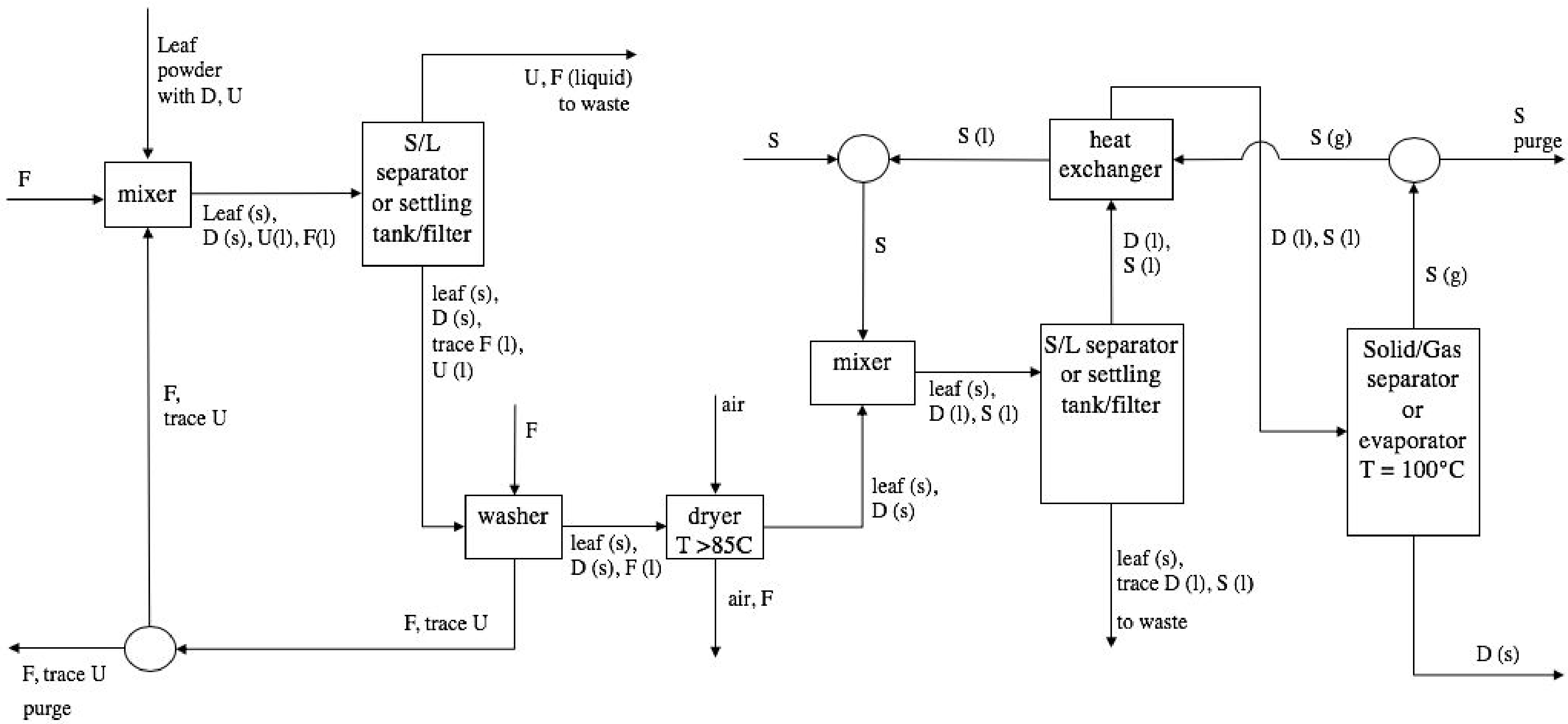


Answer key: 30 pts total

If solution used solvent S first, and then solvent F:

- +8: Perform chemical extraction using S/L separator, then a S/L separator (-2 if phases not labeled)
- +5 Pure stream of product D leaves PFD in logical way (-2 if D is still wet or in solution)
- +5 Correct temperature on any high temperature units (gas separator, dryer) (S/G separator: 90 < T < 110C) (dryer: 82C < T < 115C)
- +5 Includes recycle loop & purge (3 pts if recycle but no purge, 0pts if no recycle at all)
- +2: Use of heat exchanger
- +2: Includes a washer + dryer for the final product
- +3: if they chose solvent S over solvent A - safety is important!!
- -1: for every PFD convention mistake (arrows missing, overlapping streams, curved lines, mass balance magic, combiners instead of mixers, etc)
- -1: for recycling S without condensing first (S needs to be a liquid to mix it with feed stream)

Solution option 2: Use F to extract U, then use S to extract D



If solution used solvent F first, and then solvent S:

- +8: Perform chemical extraction using S/L separator, then a S/L separator (-2 if phases not labeled)
- +5 Pure stream of product D leaves PFD in logical way (-2 if D is still wet or in solution)
- +5 Correct temperature on any high temperature units (gas separator, dryer) (S/G separator: 90 < T < 110C), dryer (82C < T < 115C)
- +5 Includes recycle loop & purge (3 pts if recycle but no purge, 0pts if no recycle at all)
- +2: Use of heat exchanger
- +2: Includes a washer + dryer for the first S/L separation unit
- +3: if they chose solvent S over solvent A - safety is important!!
- -1: for every PFD convention mistake (arrows missing, overlapping streams, curved lines, mass balance magic, combiners instead of mixers, etc)