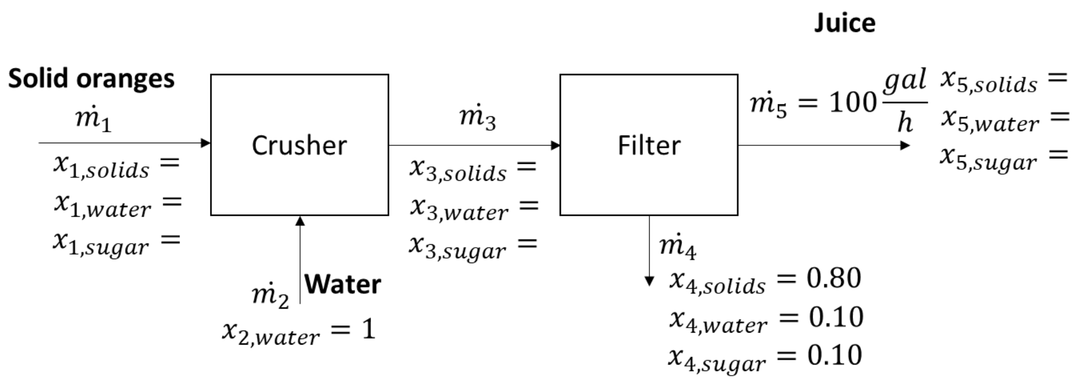
ECHE 260: Intro to Chemical Systems

Homework #2A (50 points)

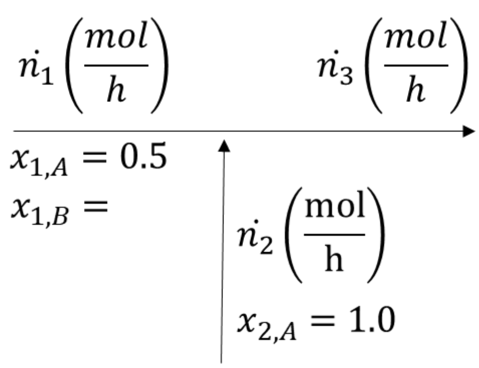
Assignments are due in Canvas as a single PDF file. Homework should follow the general formatting guidelines posted in Canvas. There is no excel component this week.

<u>Conceptual Questions and Short Answers (total of 16 points)</u>

1. **(4 points)** Consider the orange juice production process, below. **True or False**: When performing a degree of freedom analysis around the crusher, it is appropriate to assume a basis. *Justify your answer.*

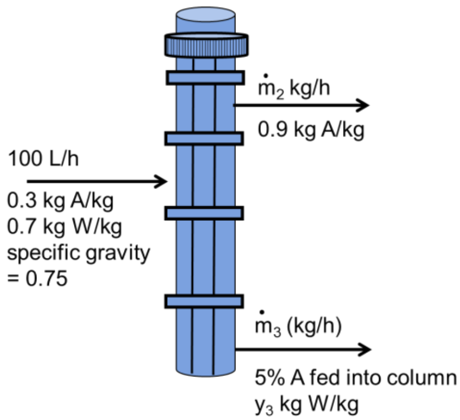


2. **(4 points)** In the process shown below, the mole fraction of A in stream 3 will be ______________ the mole fraction of A in stream 1.
   a. Greater than
   b. Less than
   c. Equal to



3. **(4 points)** Consider the distillation column below. The mass ratio of the top product (stream 2) to feed (stream 1) is _______ one. *Justify your answer.*

a. Greater than
b. Less than
c. Equal to
d. Need more information



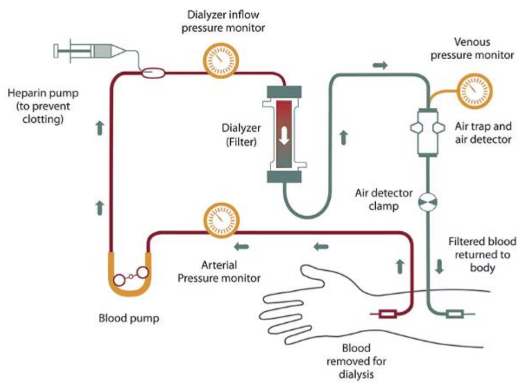
4. **(4 points)** Consider 100 moles of a gas stream containing 15 mol% CS_2, 18 mol% O_2, and 67 mol% N_2. The gas is fed to a continuous absorption tower, where it contacts liquid benzene, which absorbs CS_2, but not O_2 or N_2. Benzene is fed to a column in a 2:1 mole ratio to the feed gas. Some of the benzene entering as liquid evaporates and leaves the top of the tower as vapor. The gas leaving the absorber contains 2 mol% CS_2 and 2 mol% benzene. How many independent material balances can you write?

a. 2
b. 3
c. 4
d. 5
e. Need more information.

Quantitative Problems (30 points)

6. (15 points) Hemodialysis

Hemodialysis is a medical procedure used to treat kidney failure by filtering waste, excess fluids, and toxins from the blood when the kidneys can no longer perform these functions. The process involves diverting blood to a dialyzer which removes the toxins before the blood is returned to the body—helping to maintain the body's electrolyte balance and preventing complications from kidney dysfunction. The dialyzer is a membrane-based chemical engineering unit operation that uses the principles of diffusion to remove waste species, like urea and creatinine, from the blood while maintaining safe levels of electrolytes.



[Image] "Hemodialysis" National Institute of Diabetes and Digestive and Kidney Diseases. https://www.niddk.nih.gov/health-information/kidney-disease/kidney-failure/hemodialysis. *Accessed August 2024.*

The dialyzer has two feeds: 1) the dialysate which only contains electrolytes and 2) blood from the patient which we will call "fresh blood". The fresh blood enters the dialyzer at a volumetric flowrate of 400 mL/min. Blood will be approximated as a mixture of 250 mmol/L of electrolytes, 10 mmol/L of urea, and 4 mmol/L of creatine dissolved in water. The dialysate contains 250 mmol/L of electrolytes dissolved in water. The dialyzer removes 80% of the creatinine from the fresh blood (by mass) and it leaves behind 10% of the urea from the fresh blood (by mass). The volumetric flowrate of all streams is the same and is equal to 400 mL/min. You may assume that the density of blood and dialysate are equal to the density of water.

What is the composition of the blood exiting the dialyzer (e.g. mol fractions of all species)? What is the composition of the dialysate exiting the dialyzer (e.g. mol fractions of all species)? Why is it important for the dialysate and the blood to have the same concentration of electrolytes?

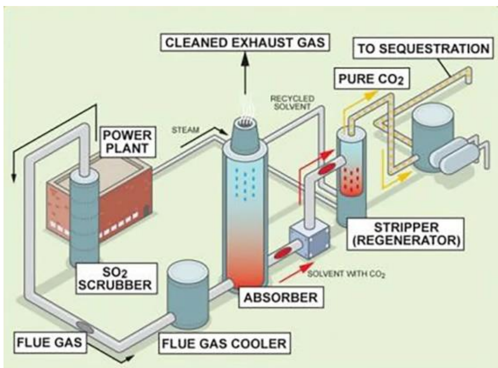
Using the general procedure from class, determine if this problem is solvable. If yes, write all material balances, additional equations and describe the order in which you would solve them. D<u>o not solve any equations or provide a numerical answer</u>. If no, state why and <u>indicate what information is missing</u>. Be sure to clearly define the naming convention for the streams.

<u>Remember, a complete solution:</u>

1) Contains a fully labeled PFD
2) Identifies the desired quantities and additional equations from the problem statement
3) Uses a DOF analysis to determine if the problem is solvable
4) If solvable, clearly outlines the material balances for each subsystem
5) Describes "how to solve" the system of equations for the desired quantities

7. (15 points) CO_2 Absorption

Post-combustion CO_2 capture is a technology used to reduce greenhouse gas emissions by removing CO_2 from the exhaust gases of fossil fuel power plants and industrial processes. This method involves removing CO_2 after the fuel has been burned, typically using chemical solvents that absorb the CO_2 from the flue gas. The absorber is the chemical engineering process unit that contacts the CO_2-rich flue gas with the solvents. A 500 MW coal-fired power plant can produce 9.6 million kWh of electricity per day which enough to power 11,000 light bulbs per day. Coal-fired plants produce 2.30 lbs. of CO_2 per kWh. Recent regulations from the US Environmental Protection Agency required coal-fired power plants to reduce CO_2 emissions by 90% using carbon capture or other means. At a 500 MW coal-fired power plant, the cooled flue gas entering the absorber contains a mixture of CO_2, N_2/O_2. By volume, the cooled flue gas is 12.3% CO_2 by volume and the rest is N_2/O_2. The amine-containing solvent is fed directly to the absorber and has an amine mass fraction of 0.30 and the balance is water. The feed ratio of amine to CO_2 is 10 to 1 by mass. The density of CO_2 at the process conditions is 1.96 g/L and the density of O_2/N_2 at the process conditions is 1.27 g/L.



"Carbon Capture" UKCCS Research Community. https://ukccsrc.ac.uk/ccs-explained/carbon-capture/ Accessed August 2024.

A. How many lbs. of CO_2 are fed to the absorber per day?

B. In the US, an average passenger vehicle with an internal combustion engine will emit 4.60 metric tons of CO_2 per year. For a 500 MW coal-fired power plant that meets the 90% CO_2 emission standard set by the EPA, calculate the "car equivalent" of CO_2 removed by the absorber each day. Another way to think of this is, removing 90% of the CO_2 emissions is equivalent to removing X number of cars from the road each day?

C. What is the composition of the solvent exiting the absorber (report all mass fractions)?

For A and B, calculate a numerical answer. For C, use the general procedure from class and determine if this problem is solvable. If yes, write all material balances, additional equations and describe the order in which you would solve them. For C, do not solve any equations or provide a numerical answer. Be sure to clearly define the naming convention for the streams.

Remember, a complete solution:
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Reflection (4 points)

8. **(4 points)** We have now concluded unit 1 & part of unit 2 which covered unit conversions, dimensional homogeneity and the general procedure for nonreactive single- and multi-unit processes.
    a. Is there anything about the content that you still find confusing?
    b. What (if anything) about the way the class is taught prohibiting your learning?
    c. What (if anything) about the way the class is taught helping your learning?