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1. *(35 points)* One growing problem in the realm of chemical engineering is the abundance of ethane from shale gas. A potential use of ethane is to convert it to ethanol for use as a biofuel. To do so, ethane is first converted into ethylene. This reaction produces hydrogen, an important chemical that can be used elsewhere in a refining facility. This is often done in a fluid catalytic cracker unit at 550 °C via the following reaction.

$$C_2H_6 \rightarrow C_2H_4 + H_2$$ @ 550 °C

ethane ethylene

Ethylene can then undergo a reaction with water to form ethanol. This reaction is often done at 300 °C and 60 atm in a reactor with phosphoric acid catalyst.

$$C_2H_4 + H_2O \rightarrow C_2H_5OH$$ @ 300 °C, 60 atm

This stream is then further processed to obtain a nearly pure stream of ethanol. A variety of chemical properties are listed below.

Chemical / Formula / PFD Label	*Boiling Point (°C)*	*Melting Point (°C)*
Ethane / C_2H_6 / Et	-89.0	-183
Ethylene / C_2H_4 / Ety	-104	-169
Ethanol / C_2H_5OH / EtOH	78.4	-114
Water / H_2O / H_2O	100.	0.00
Hydrogen / H_2 / H_2	-253	-259

a) Draw a PFD that is capable of converting a stream of pure ethane into pure product streams (ethanol and hydrogen). Be sure to label all reactors and separators with appropriate temperatures. List the components in each stream according to the PFD Labels listed above. You may assume that separations are perfect, but do not assume that reactions go to completion. Assume no reactions occur other than the two given above. Use recycle streams as much as possible. Use separators to avoid feeding reactor products into a reactor. If you use two or more separators sequentially think about the logical order. You may neglect heat exchangers.

b) If the conversion of ethylene to ethanol is 85%, how much ethanol can be produced *per year* assuming a feed of 480 mol/hr ethylene?

c) How could you increase the conversion of ethylene to ethanol? What would be potential drawbacks of doing so?

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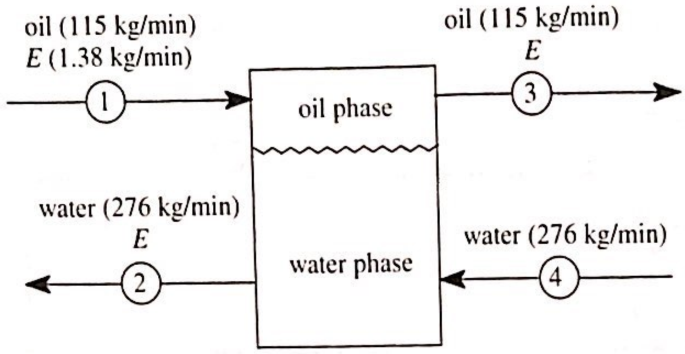
2. *(35 points)* The liquid-liquid absorber below partially absorbs enzyme E from an oil solution to a water solution.

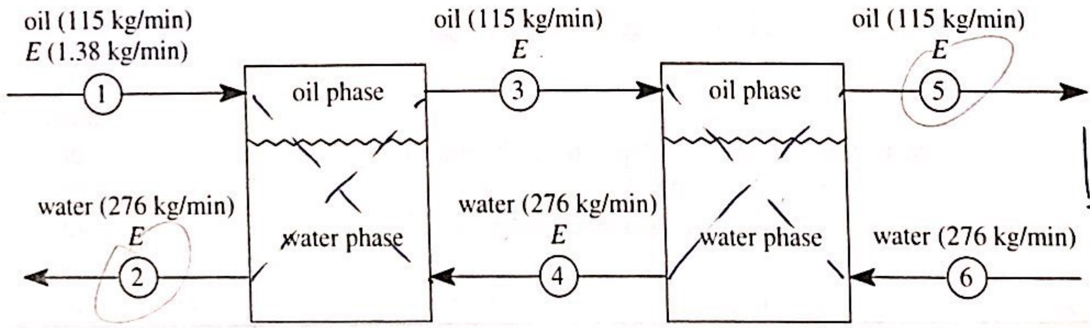


Absorber specifications:
The oil and water are immiscible; no water dissolves in the oil and no oil dissolves in the water. Streams 2 and 3 leave the absorber in equilibrium. Enzyme E preferentially (but *not* completely) dissolves in the water. At equilibrium, the partition of E between the oil and water phases is

$$\frac{\text{mass of } E \text{ dissolved in the oil phase}}{\text{mass of oil}} = \frac{1}{1.73} \times \frac{\text{mass of } E \text{ dissolved in the water phase}}{\text{mass of water}}$$

a) Calculate the flow rates of E in streams 2 and 3, in kg/min by using the absorber specifications above.

A second liquid-liquid absorber is added to absorb more E from the oil solution. As before, streams 2 and 3 leave the first absorber in equilibrium. In addition, streams 4 and 5 leave the second absorber in equilibrium. All other absorber specifications are the same as part (a).



$F_{3E} = F_{4E} + F_{5E}$

b) Calculate the flow rates of E in streams 2 and 5, in kg/min. Note: The flow rates of E in streams 2 and 3 are not necessarily the same as in part (a).

$F_{1E} + F_{4E} = F_{3E} + F_{2E}$

$\frac{F_{3,E}}{F_{3,E}} = \frac{1}{1.73} \cdot \frac{F_{E2}}{F_{w,2}}$

$\frac{F_{1E}}{F_{1,oil}} = \frac{1}{1.73} \cdot \frac{F_{2E}}{F_{2,water}} \Rightarrow \frac{1.38}{115} = \frac{1}{1.73} \cdot \frac{F_{2E}}{276}$

$F_1 + F_4 = F_2 + F_3$

$\frac{F_{5E}}{F_{5,oil}} = \frac{1}{1.73} \cdot \frac{F_{4,E}}{F_{4,water}}$

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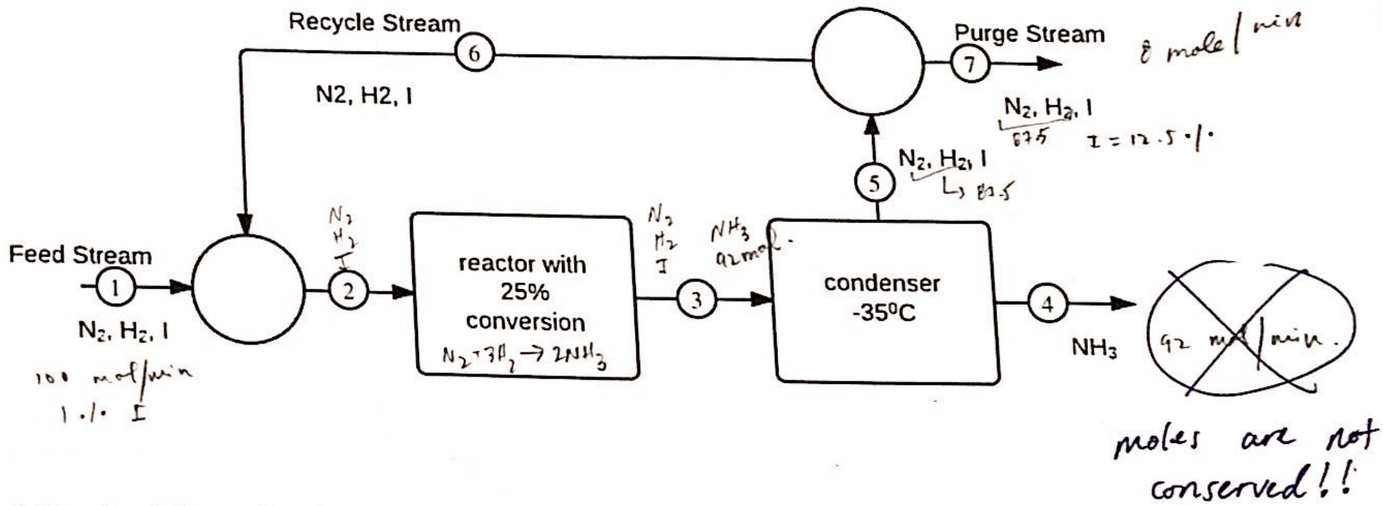
3. *(30 points)* The feed to an ammonia synthesis process usually contains a small fraction of inert gases, such as argon. These are not condensed and thus are recycled with the unconsumed nitrogen and hydrogen. To avoid a buildup of inerts in the system, which would eventually shut the process down, a purge stream is split off of the recycle stream, as shown in the PFD below:



The following information is known:

- The feed is 100. moles/min and contains 1.00% (molar) inerts and N_2 and H_2 in a **stoichiometric ratio**: 24.75% (molar) N_2, 74.25 % (molar) H_2.
- The single pass conversion of N_2 (through the reactor alone) is 25.0%.
- The mole percent of inerts in the purge stream is determined to be 12.5%.

a) Balance the reaction for ammonia synthesis:

$$N_2 + 3H_2 \rightarrow 2\ NH_3$$

Calculate:

b) the molar flow in the purge stream (Stream 7) per 100 moles/min of fresh feed 8 mol/min

c) the overall conversion of N_2 93.1 % *(Hint: Since the fresh feed is in stoichiometric proportions, this proportion of* ***reactants*** *remains the same throughout the process!)*

d) the total molar flow fed to reactor (Stream 2), including fresh feed and recycle stream 184

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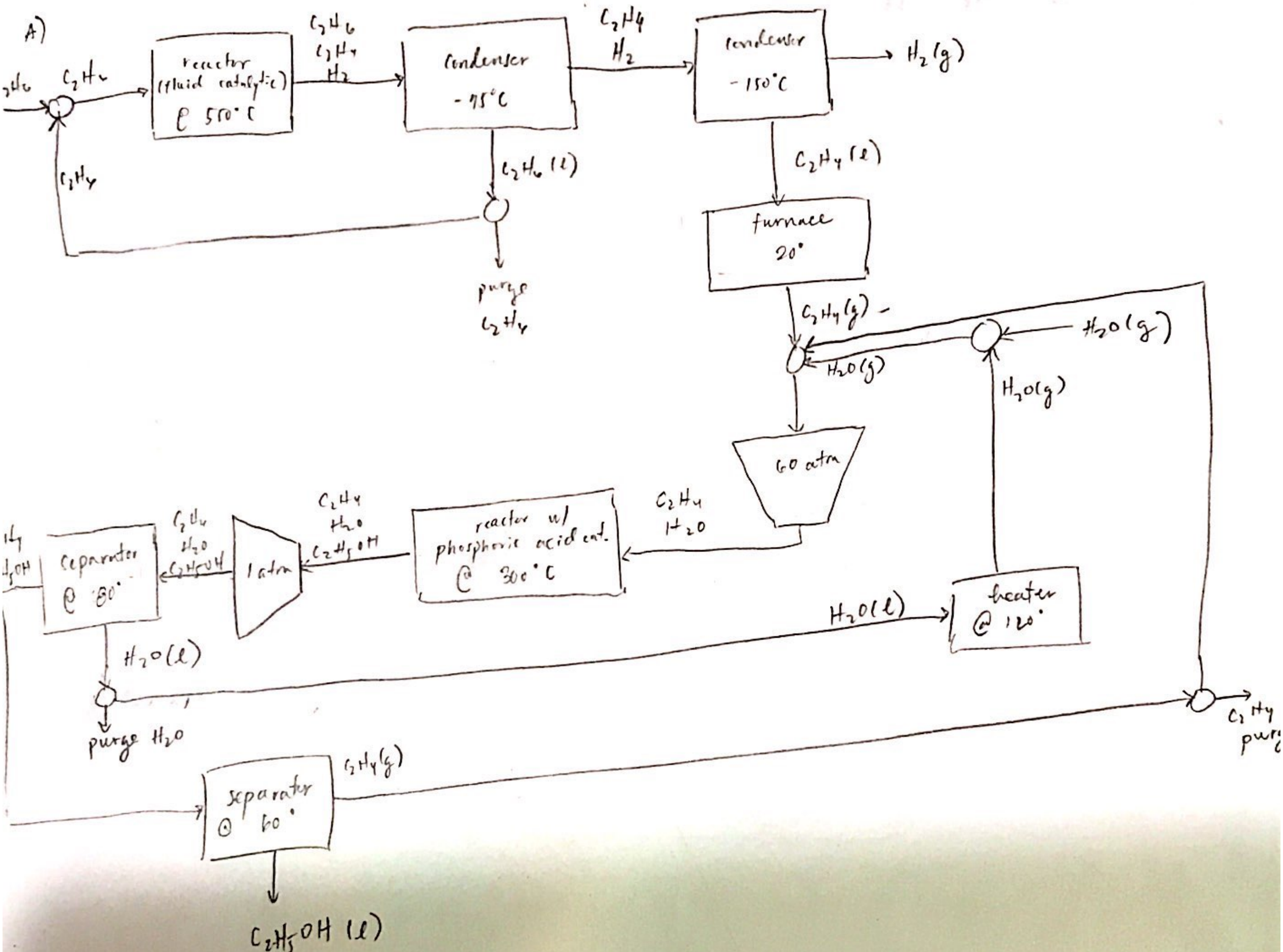
A)



B) $C_2H_4 + H_2O \longrightarrow C_2H_5OH$ is 85 %.

$$\frac{F_{Ety,in} - F_{Ety,out}}{F_{Ety,in}} = 0.85 \Rightarrow \frac{480 - F_{Ety,out}}{480} = 0.85 \Rightarrow -F_{Ety,out} = 0.85(480) - 480$$

$$\Rightarrow F_{Ety,out} = 72 \text{ mol}$$

$\therefore$ 480 - 72 = 408 mol EtOH made /hr

$$\frac{408 \text{ mol EtOH}}{\text{hr}} \cdot \frac{24 \text{ hr}}{1 \text{ day}} \cdot \frac{365 \text{ days}}{1 \text{ yr}} = 3574080 = \boxed{3.6 \cdot 10^6 \text{ mol EtOH/yr.}}$$

(two sig figs)

c) We could increase the conversion of Ety ⟶ EtOH by having a better reactor or possibly increasing the amount of phosphoric acid catalyst. Depending on the cost of these two items, it may not be worth to invest in an upgrade.

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