EPFL |ChE-201 Introduction to Chemical Engineering| Final Exam Questions - 31st January 2024

Rules:

1. This exam is paper-based: no electronic material is allowed, at the exception of a calculator.

2. You have access to your notes and any supplementary material you brought.

3. You have 180 minutes to solve the exam.

4. You are required to show valid photo ID. Please place it visibly on your desk.

5. If you need to go to the bathroom, please raise your hand and we will accompany you.

Instructions:

1. Write your name on this question booklet and on all of your answer sheets.

2. Answer all questions on your answer sheets or the question booklet.

3. At the end of the exam, turn in both the question booklet and all of your answer sheets.

4. Please show all of your work. Do not expect the grader to guess your reasoning. Your grade will depend on the reasoning that you used as well as the clarity and correctness of your answers.

5. There are three exercises in total, on the following topics: mass balance non-reactive, energy balance non-reactive, energy balance reactive If you are having difficulty on any question, you may wish to move on and return to the question later.

6. There are 100 scorable points in total. The number of points associated with each exercise is respectively indicated at the beginning of the exercise.

7. We wish you best of luck and much success!

First Name: ____________________

Last Name: ____________________

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Grading:

When the Midterm Exam Grade is higher than the Final Exam Grade, the Final Class Grade is calculated as 30% of the Midterm Exam Grade plus 70% of the Final Exam Grade.

When the Midterm Grade is lower than the Final Exam Grade, the Final Class Grade is simply equal to the Final Exam Grade.

Final Exam Grade:

Problem	Points
Mass Balance non-reactive	/35
Energy Balance Non-Reactive	/25
Energy Balance Reactive	/40
Total	/100

Class Grade:

Exam	Points
Midterm Exam Grade	/6
Final Exam Grade	/6
Weighted Average Grade	/6
Final Class Grade	/6

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Problem 1: Mass Balance Non-Reactive (35 points)

Instructions:

Recovery of the desired solute from a solution can sometimes be accomplished by using a second solvent which is immiscible with the solution but which preferentially dissolves the solute. This type of separation process is known as solvent extraction.

For our problem, benzene (B) is separated from a refinery stream containing 70% (mass) benzene in a mixture of paraffin and naphthene hydrocarbons (which we will designate from now as non-benzene (NB) compounds) by means of liquid SO_2. The feed (F1) stream flows through three subsequent units where benzene is concentrated to yield the raffinate stream (F4). At countercurrent, the solvent (F5) stream containing pure SO_2 captures non-benzene compounds and some benzene through the same three units to yield the extract stream (F8).

We use 3 kg SO_2 per 1 kg feed stream. The raffinate stream contains 1/6 (mass fraction) $S0_2$ and the remainder of benzene. The extract stream contains all of the non-benzene material, some $S0_2$, and ¼ kg benzene (B) per 1 kg non-benzene (NB) hydro-carbons.

Use a basis of 1000 kg/h for the feed stream.

Questions:

(a) Draw and label a flowchart of the process.

(b) Perform a degree of freedom analysis of the problem.

(c) Determine the percent recovery of benzene (kg benzene in raffinate per kg benzene in the feed)?

(d) Suppose further that the separation of benzene is 92% in unit I and 80% in unit II, and that the benzene compositions in the feed streams to units II and III are 86.25 and 95%, respectively F2 and F3. Calculate all the stream fluxes and compositions of this problem by filling the table below

	F1	F2	F3	F4	F5	F6	F7	F8
Total[kg/h]								
x_B [kg_B/kg]								
x_{NB} [kg_{NB}/kg]								
x_{SO2} [kg_{SO2}/kg]								

Problem 2: Energy Balance Non-Reactive (25 points)

Instructions:

An adiabatic membrane separation unit is used to dry (remove water vapor from) a gas mixture containing 10.0 mole% $H_2O(v)$, 10.0 mole% CO, and the balance CO_2. The gas mixture enters the unit at 30°C and flows past a semipermeable membrane. Water vapor from the gas mixture then permeates through the membrane into an air stream. Finally, the dried gas mixture leaves the separator at 30°C containing 2.0 mole% $H_2O(v)$ and the balance CO and CO_2. The air stream first enters the separator at 50°C with an absolute humidity of 0.002 kg H_2O/kg dry air and then leaves at 48°C with additional water content coming from the gas mixture.

Note that we assume that:

- Negligible quantities of CO, CO_2, O_2, and N_2 permeate through the membrane.
- All gaseous streams are at approximately 1 atm.
- The air stream is composed of dry air and H_2O.

Questions:

(a) Draw and label a flowchart of the process and carry out a degree-of-freedom analysis to verify that you can determine all unknown quantities on the chart.

(b) Calculate the ratio of entering air to entering gas (kg humid air/mol gas)

(c) Calculate the %-mole fraction of water of the exiting air.

Bonus:

(d) List at least two desirable properties of the membrane. (max. 2 points)

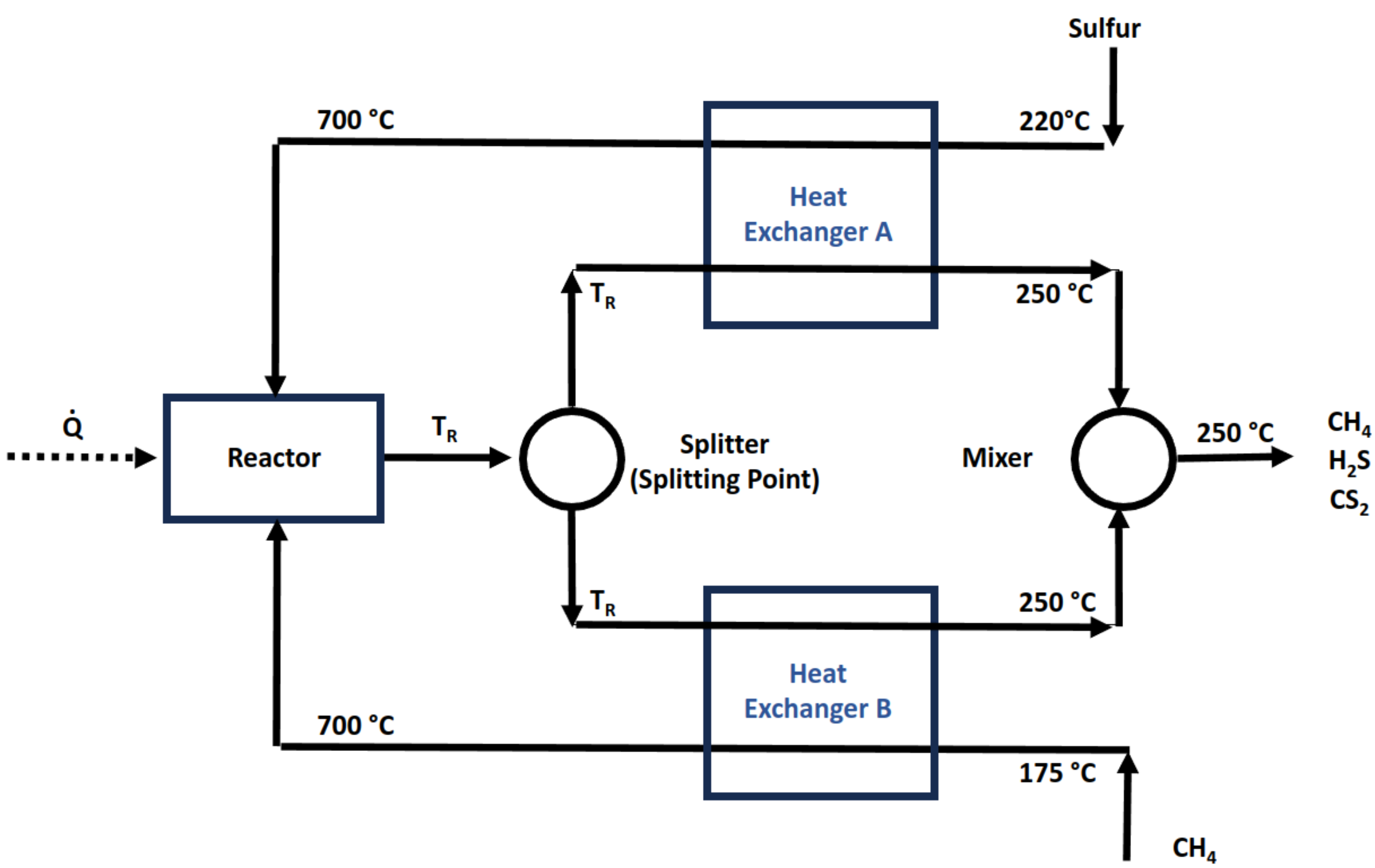
Problem 3: Energy Balance Reactive (40 points)

Instructions:

Carbon disulfide is manufactured by reacting methane with sulfur vapor via the reaction:

$$CH_4\,(g) + \tfrac{1}{2}\,S_8\,(g) \rightarrow CS_2\,(g) + 2H_2S\,(g)$$

In the process shown in the figure below, complete conversion of sulfur is obtained with a feed consisting of 3 mol CH_4 per 1 mol S_8. The sulfur is fed molten (liquid state) at 220°C, and the products leave the process at 250°C. To carry out the reaction, the materials of the reactor feed must be preheated to 700°C by heat exchange. The required heat to conduct this reaction is supplied through 2 heat exchangers, Heat Exchanger A and Heat Exchanger B. The output stream from the reactor leaves at temperature T_R and is then split into 2 streams. One is fed to Heat Exchanger A and the other is fed into Heat Exchanger B.



Note that we assume that:

- The heat of reaction for the above reaction is 22000 cal/mol at 250°C.
- The heat losses in heat exchangers are negligible
- The 2 heat exchangers are independent of each other
- The stream splitter and mixer both operate with no changes in stream temperatures.

Use **only** the following data:

Compound	**State**	**Heat Capacity (cal/mol °C)**	**ΔH_{VL} (cal/mol)**
CH_4	g	10.0	-
H_2S	g	9.5	-
CS_2	g	7.6	-
S_8	l	7.0	2200 at 445°C, 1 atm
S_8	g	8.0	-

As an example, the change in specific enthalpy from methane at initial temperature of 25° C relative to methane at final temperature of 1500°C is given by: $\left[10\ \frac{cal}{mol\cdot°C}\right](1500°C - 25°C) = 14750\ \frac{cal}{mol}$.

Assume a basis of 200 mol S_8 feed/h.

Questions:

(a) Determine the molar composition of the output stream.

(b) Calculate the heat input rate to the reactor per mole of carbon disulfide (cal / mol CS_2). (Energy balance on the overall process is often a good starting point!).

(c) Calculate the ratio in which the reactor effluent stream should be split to accomplish the preheating of the feed to 700°C.

Bonus:

(d) Do you think the set-up presented is realistic? Explain your reasoning. (max. 2 points)