



SCHOOL OF ENGINEERING

MAIN EXAMINATIONS: MAY/ JUNE 2025

COURSE AND CODE: CHEMICAL ENGINEERING PRINCIPLES 1 ENCH1EA

DURATION: 3 HOURS

TOTAL MARKS: 100

INTERNAL EXAMINER/S: MRS N.C. NYEMBE

INTERNAL MODERATOR: DR J. POCOCK

EXTERNAL MODERATOR: DR J.S. BALOYI

INSTRUCTIONS:

1. **ALL** questions should be attempted. Answer in **INK**.
2. Any programmable or non-programmable calculator may be used provided it has been cleared of any information that would subvert the purpose of the examination.
3. Calculations must be shown in sufficient detail to illustrate your understanding of the procedure.
4. **Two answer books are provided. Label them Book A and Book B. Answer Section A in Book A and Section B in Book B.**
5. This examination question paper, together with all associated diagrams, **MUST BE HANDED IN TOGETHER WITH YOUR SCRIPT.**

Student Number:

SECTION A

QUESTION 1

In the production of synthetic rubber, a homogenous mixture of butadiene, styrene, and hexane (solvent) is prepared in a stirred tank. Once the mixture reaches the desired composition and homogeneity, it is pumped into a catalytic-packed reactor. Inside the reactor, polymerization occurs, wherein the small monomer molecules (butadiene and styrene) chemically bond together in the presence of a catalyst. This reaction results in the formation of long-chain polymer molecules, which constitute the synthetic rubber. The polymerization reaction is exothermic, so heat removal from the systems is necessary. Therefore, the reactor is equipped with an external cooler. To stop the polymerization reaction, the mixture is pumped to a second reactor containing a different type of catalyst. This produces a liquid rubber with the appearance of milk. An additive and water are mixed with the milky rubber solution in the reactor to solidify the produced synthetic rubber. This reactor is internally heated to boil off the solvent. The solvent escapes as a gas while water remains because it has a high boiling point. In the reactor, the rubber particles coagulate and form small rubber particles, which are removed together with the remaining water to a centrifuge tank for separation. As the centrifuge spins, some of the water is drained as a top product while the now-thick mixture is conveyed to a sieve (filter) to separate the remaining water and the rubber particles. The rubber particles are then stored for further processing.

Draw a professional, detailed process flow diagram for the above process (use the blank paper provided).

TOTAL /25/

QUESTION 2

Which unit operation would you use to perform the following functions?

- 2.1. Separating ethanol from water in a mixture based on their different boiling points. (2)
- 2.2. Converting nitrogen and hydrogen into ammonia at high temperature using a catalyst. (2)
- 2.3. Transporting milk from a storage vessel to a pasteurizer. (2)
- 2.4. Cooling a vapor stream from 150 °C to 40 °C. (2)
- 2.5. Remove very fine sand from dirty water. (2)

TOTAL /10/

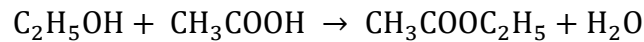
QUESTION 3

- 3.1. A cylindrical metal rod has a mass of 215 kg and a volume of 0.028 m³. What is its density in lbm/ft³? (4)
- 3.2. A pipe carries steam at a pressure of 3.5 MPa and a temperature of 450 °C. What is the pressure in psi, and the temperature in °F? (4)
- 3.3. A composite material has a specific heat capacity of 385 J/(kg·K). Convert this to Btu/(lb·°F). (4)
- 3.4. A cooling system circulates water at a flow rate of 0.025 m³/s through a pipe. Convert the flow rate to imperial gallons per minute (gal/min). (3)

TOTAL /15/

SECTION B**QUESTION 4**

In an industrial reactor, 250 kg/h of ethanol (C_2H_5OH) and 400 kg/h of acetic acid (CH_3COOH) are fed to produce ethyl acetate ($CH_3COOC_2H_5$) and water via the following reaction:



The reaction reaches 88% completion based on the limiting reactant.

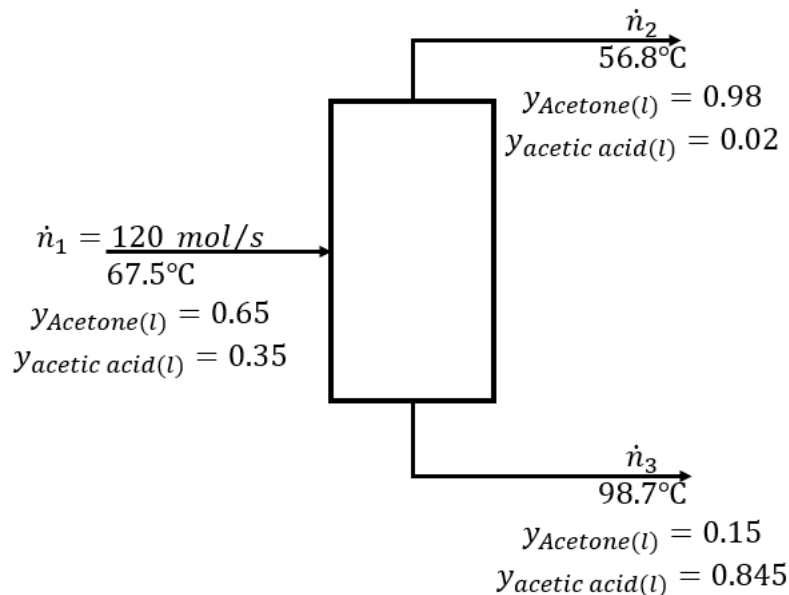
$$(M_{w,C_2H_5OH} = 46 \frac{g}{mol}; M_{w,CH_3COOH} = 60 \frac{g}{mol}; M_{w,CH_3COOC_2H_5} = 88 \frac{g}{mol}; M_{w,H_2O} = 18 \frac{g}{mol})$$

- 4.1. Draw a flowchart for the above process (3)
- 4.2. Calculate the total molar flow rate in the reactor feed in kmol/h. (3)
- 4.3. Determine the limiting reactant. (3)
- 4.4. Calculate the amount of ethyl acetate produced. (2)
- 4.5. Calculate the amount of water produced. (2)
- 4.6. Determine the amount of unreacted reactants (if any). (6)
- 4.7. What is the molar composition (fractions) of the product stream? (5)

TOTAL /24/

QUESTION 5

A liquid mixture containing acetone (Ac) and acetic acid (AA) is separated in a distillation column operating at steady state at 1 atm according to the flowchart given below.



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- 5.1. How would you simplify the general mass balance equation based on this given process? Explain why some terms are eliminated. (4)
- 5.2. Calculate the molar flow rates of the output streams (i.e. $\dot{n}_2$ & $\dot{n}_3$). (5)
- 5.3. Is this an open or closed system? Support your answer. (2)
- 5.4. Write a simplified energy balance equation for this system, stating all your assumptions. (5)
- 5.5. Calculate the net heat requirement (kcal) for the process. (Thermodynamic data is provided in page 5). (7)
- 5.6. Differentiate between an isothermal and an adiabatic process, and indicate which terms get eliminated in the energy balance equation for each case. (4)

TOTAL /26/

ADDITIONAL INFORMATION**FACTORS FOR UNIT CONVERSIONS**

Quantity	Equivalent Values
Mass	1 kg = 1000 g = 0.001 metric ton = 2.20462 lb _m = 35.27392 oz 1 lb _m = 16 oz = 5 × 10 ⁻⁴ ton = 453.593 g = 0.453593 kg
Length	1 m = 100 cm = 1000 mm = 10 ⁶ microns (μm) = 10 ¹⁰ angstroms (Å) = 39.37 in. = 3.2808 ft = 1.0936 yd = 0.0006214 mile 1 ft = 12 in. = 1/3 yd = 0.3048 m = 30.48 cm
Volume	1 m ³ = 1000 L = 10 ⁶ cm ³ = 10 ⁶ mL = 35.3145 ft ³ = 220.83 imperial gallons = 264.17 gal = 1056.68 qt 1 ft ³ = 1728 in. ³ = 7.4805 gal = 0.028317 m ³ = 28.317 L = 28,317 cm ³
Force	1 N = 1 kg·m/s ² = 10 ⁵ dynes = 10 ⁵ g·cm/s ² = 0.22481 lb _f 1 lb _f = 32.174 lb _m ·ft/s ² = 4.4482 N = 4.4482 × 10 ⁵ dynes
Pressure	1 atm = 1.01325 × 10 ⁵ N/m ² (Pa) = 101.325 kPa = 1.01325 bar = 1.01325 × 10 ⁶ dynes/cm ² = 760 mm Hg at 0°C (torr) = 10.333 m H ₂ O at 4°C = 14.696 lb _f /in. ² (psi) = 33.9 ft H ₂ O at 4°C = 29.921 in. Hg at 0°C
Energy	1 J = 1 N·m = 10 ⁷ ergs = 10 ⁷ dyne·cm = 2.778 × 10 ⁻⁷ kW·h = 0.23901 cal = 0.7376 ft·lb _f = 9.486 × 10 ⁻⁴ Btu
Power	1 W = 1 J/s = 0.23901 cal/s = 0.7376 ft·lb _f /s = 9.486 × 10 ⁻⁴ Btu/s = 1.341 × 10 ⁻³ hp

Example: The factor to convert grams to lb_m is $\left(\frac{2.20462 \text{ lb}_m}{1000 \text{ g}}\right)$.

A change in temperature of 1 °C is equivalent to a change in temperature of 1 K and equivalent to a change in temperature of 1.8 °F.

To convert absolute temperatures: $T(^{\circ}\text{F}) = 1.8T(^{\circ}\text{C}) + 32$

$$T(\text{K}) = T(^{\circ}\text{C}) + 273.15$$

Table 1: Thermodynamic data

$\hat{H}(\text{cal/mol})$				
	Acetone		Acetic acid	
$T(^{\circ}\text{C})$	$\hat{H}_l$	$\hat{H}_v$	$\hat{H}_l$	$\hat{H}_v$
56.8	0	7205	0	5723
67.5	354	7403	335	6884
98.7	1385	7946	1312	7420