UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
JANUARY 2025 SEMESTER

COURSE	**:**	**ECM5133 – ADVANCED DISTILLATION DESIGN**
DATE	**:**	**20 APRIL 2025 (SUNDAY)**
TIME	**:**	**2:30 PM – 5:30 PM (3 HOURS)**

INSTRUCTIONS TO CANDIDATES

1. This is an **OPEN BOOK** exam.
2. Answer **ALL** questions in the Answer Booklet.
3. Begin **EACH** answer on a new page in the Answer Booklet.
4. Indicate clearly answers that are cancelled, if any.
5. Where applicable, show clearly steps taken in arriving at the solutions and indicate **ALL** assumptions, if any.
6. **DO NOT** open this Question Booklet until instructed.

Note :

i. There are **SIX (6)** printed pages in this **double-sided** Question Booklet including the cover page .

1. A four-component liquid mixture as shown in **TABLE Q1** is fed at a molar flow rate of 150 kmol/hr to a distillation unit.

TABLE Q1: Data for four component liquid mixtures

Component	Mole fraction in feed	Normal boiling point (°C)	K-value
n-Pentane	0.40	36.3	1.88
n-Hexane	0.25	69.0	0.71
n-Heptane	0.20	98.5	0.27
n-Octane	0.15	125.7	0.11

a. Propose the most effective sequences for the separation of mixtures into their pure components based on heuristic approach. Justify your answer.

[10 marks]

b. Evaluate the vapor load in **part(a)** and compare it with an indirect sequence. Assume the feed is a saturated liquid, with total recovery of both the light key and heavy key components, and the actual to minimum reflux ratio of 1:1.1. Justify your proposed column sequencing that can lead to the most economic separation for above mixture.

[15 marks]

2. a. **FIQURE Q2** illustrates the current configuration of columns for hydrocarbon separation. The objective function aims to modify the current system to decrease energy usage. Develop an appropriate complex column configuration accompanied by relevant diagrams and detailed explanations, given that the imposed limits necessitate the retrofitting of just two out of the three columns.

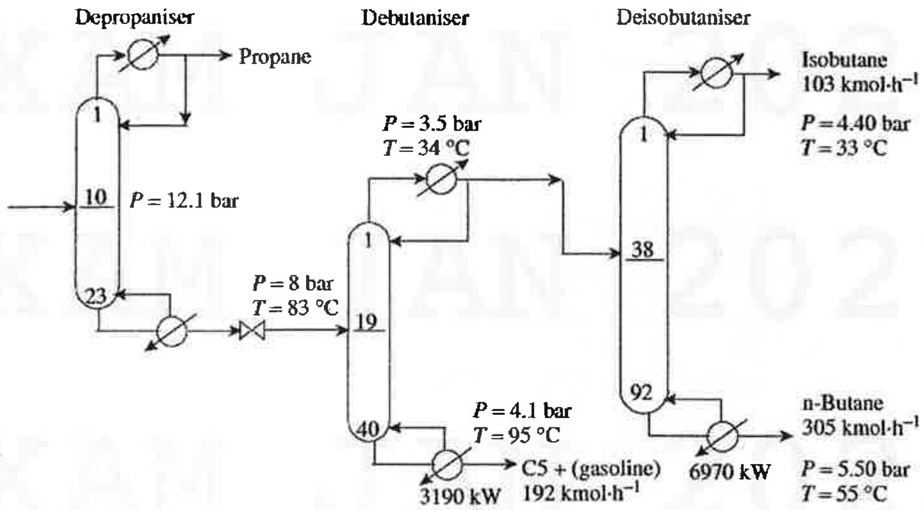

FIGURE Q2: Existing arrangement of columns for the separation of light hydrocarbons.

[10 marks]

b. A ternary mixture has the following composition of 30 mol% A, 50 mol% B and 20 mol% C, respectively. The components have relative volatilities of 2.6, 2.4 and 1.0 for A, B and C, respectively. A distillation column is designed to recover 90% of the moles A in the feed at the distillate product and only 1% of total moles of distillates flow is the heavy key. The feed flow rate is assumed to be 100 kmol/hr. Estimate the vapor load with a minimum reflux ratio of 1:1. Develop the best sequence of distillations to produce pure product A, B and C by comparing your findings with vapor load calculation and heuristic sequencing. Provide your assumptions wherever necessary.

[15 marks]

3. Vapor flowrate in kmol/hr for each simple distillation task separating a **FOUR (4)** component mixture are given in **TABLE Q3**.

TABLE Q3: Task based distillation vapor flow rates.

Task Number	Task	Vapor flow rate (kmol/h)
1	A/BCD	100
2	AB/CD	120
3	ABC/D	240
4	B/CD	90
5	BC/D	250
6	A/BC	130
7	AB/C	140
8	A/B	70
9	B/C	100
10	C/D	220

a. Examine the tasks that can be combined for all possible sequences of simple distillation columns and evaluate the vapor flowrate of all possible sequences assuming there is no interaction between the simple distillation tasks. Recommend the distillation sequence which performs the best.

[16 marks]

b. Recommend **THREE (3)** key insights to further minimize total vapor load in **part (a)** based on the application of grand composite curve with appropriate examples.

[9 marks]

4. A side-rectifier or side-stripper is used to separate a three-product mixture. Assume that thermally coupled columns operate at isobaric conditions and feed enters as saturated liquid. The data for the operation for both arrangements are given in **TABLE Q4a** and **TABLE Q4b**.

Cooling water is available with a return temperature of 30°C at a cost of \$5 kWh/year. Low-pressure steam is available at a temperature of 140°C at a cost of \$80 kWh/year and medium-pressure steam is available at a temperature of 200°C at a cost of \$150 kWh/year. The minimum temperature difference allowed is 10°C.

TABLE Q4a: Side rectifier data.

P (bar)	$T_{cond,1}$ (°C)	$T_{reb,1}$ (°C)	$Q_{cond,1}$ (kW)	$Q_{reb,1}$ (kW)	$T_{cond,2}$ (°C)	$Q_{cond,2}$ (kW)
1	90	140	2000	4500	120	2500
2	110	165	2500	5500	140	3000

TABLE Q4b: Side stripper data.

P (bar)	$T_{cond,1}$ (°C)	$T_{reb,1}$ (°C)	$Q_{cond,1}$ (kW)	$Q_{reb,1}$ (kW)	$T_{cond,2}$ (°C)	$Q_{cond,2}$ (kW)
1	90	140	5000	3000	120	2500
2	110	165	6000	3500	140	2500

a. Determine which of the two independent complex column arrangements with lower utility costs if both columns operate constantly at 1 bar pressure.

[10 marks]

b. Compare your findings in **part (a)** against direct sequence of heat-integrated simple columns operating at 1 bar for the separation of a three-products mixture. Data for simple columns at 1 bar is given at **TABLE Q4c**. Justify your answer accordingly.

TABLE Q4c: Data for Column 1 and Column 2 at 1 bar pressure.

Column	T_{cond} (°C)	T_{reb} (°C)	Saturated liquid feed		Saturated vapor feed	
			Q_{cond} (kW)	Q_{reb} (kW)	T_{feed} (°C)	Q_{feed} (kW)
1	90	130	3000	3000	110	2000
2	120	140	3000	3000	130	1500

[15 marks]

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