UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
MAY 2024 SEMESTER

COURSE	**:**	**CEB4313 - PROCESS INTEGRATION**
DATE	**:**	**2 AUGUST 2024 (FRIDAY)**
TIME	**:**	**9.00 AM - 12.00 NOON (3 HOURS)**

INSTRUCTIONS TO CANDIDATES

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

Note :

i. There are **EIGHT (8)** pages in this Question Booklet including the cover page .

ii. **DOUBLE-SIDED** Question Booklet.

iii. **Graph papers will be provided.**

1. **FIGURE Q1** shows the process flow of an existing plant. **TABLE Q1** provides the list of available utilities for process heating and cooling.

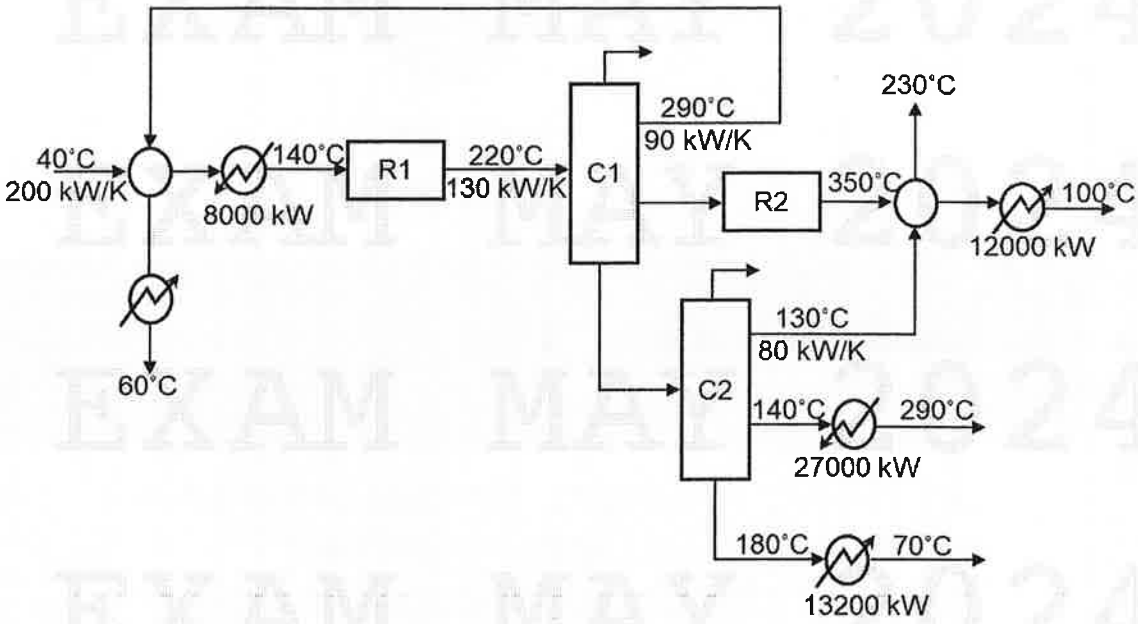

FIGURE Q1: Process flowsheet of the plant

TABLE Q1: Available utilities in the plant

Utility	Temperature, °C	Price (buy or sell), RM/kW·yr
Flue gas	450	200
High pressure steam	300	170
Low pressure steam	120	100
Cooling water	25	80

a. If the allowed ΔT_{min} is 20 °C, estimate the maximum saving of utilities that can be achieved in the plant.

[15 marks]

b. Propose a combination of hot and cold utilities that can give the minimum annual operating cost. Show the profile of each utility in Grand Composite Curve. Low pressure steam may be raised from boiler feedwater at 40 °C. Given that the heat capacity of the boiler feedwater is 4.2 kJ/kg·K and the latent heat of saturated steam at 120 °C is 2202 kJ/kg.

[10 marks]

2. You are assigned to design a heat exchanger network for a section of a process plant as shown in **FIGURE Q2.** For analysis with ΔT_{min} = 10 °C, it was found that the pinch temperatures are at 159 °C for hot streams and 149 °C for cold streams.

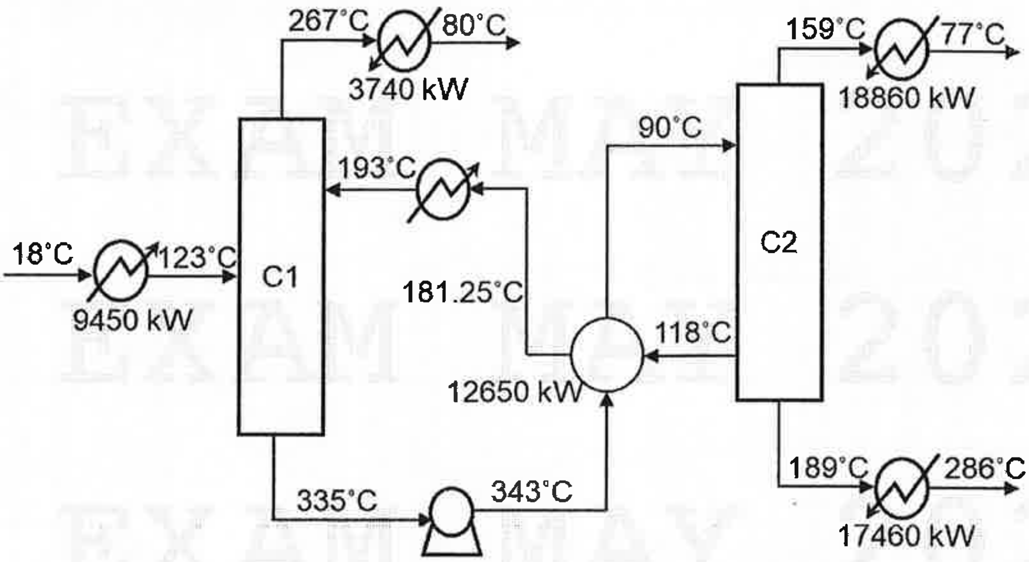

FIGURE Q2: Process flowsheet of the plant

a. Design the heat exchanger network for maximum energy recovery.
[15 marks]

b. Optimise the design in **part (a)** by breaking a loop that is present in the network.
[10 marks]

3. You are assigned to retrofit the existing heat exchanger network (HEN) shown in **FIGURE Q3**. **TABLE Q3** tabulates the additional information that you can use for your assignment.

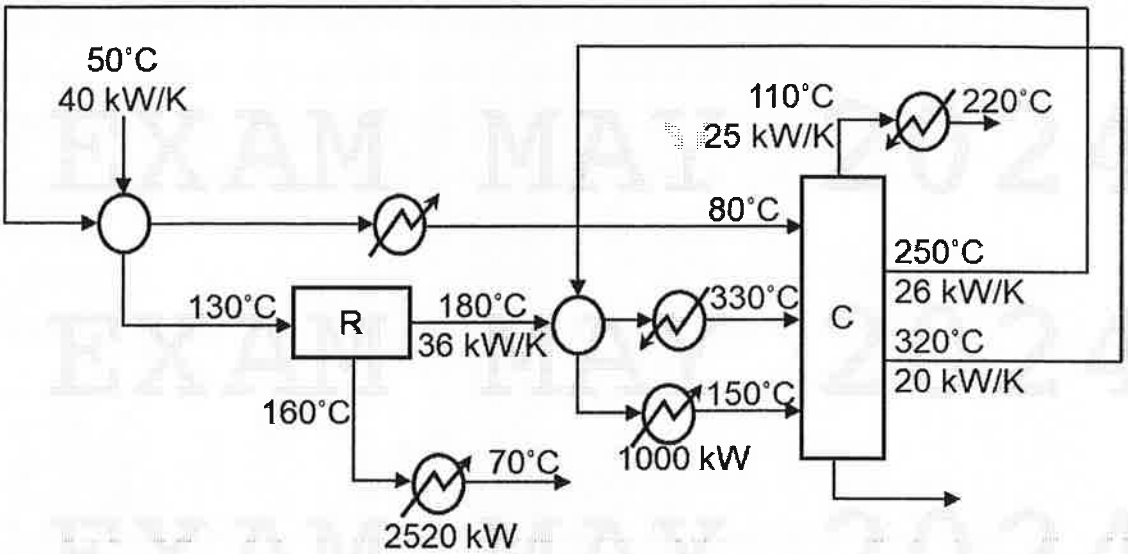

FIGURE Q3: Existing HEN design

TABLE Q3: Additional data for the plant

Hot pinch temperature, °C	190
Cold pinch temperature, °C	180
Overall heat transfer coefficient, W/(m²·°C)	1000
Price of hot utility, RM/(kW·yr)	250
Price of cold utility, RM/(kW·yr)	50
Cost of a new heat exchanger (RM)	$90000+4000A^{0.75}$, where A is the heat transfer area (m²)
Cost of piping, additional areas, demolitions	Negligible

a. Identify **THREE (3)** pinch rule violations in the current HEN design. Show your answer in a grid diagram.

[5 marks]

b. Retrofit the current HEN design to reduce the hot and cold utilities requirement by a minimum of 1500 kW each. Only **ONE (1)** new heat transfer unit can be added to the retrofit design. Other modifications such as re-piping, additional areas and demolition are allowed.

[10 marks]

c. Determine the payback period for the retrofit design proposed in **part (b)**.

[10 marks]

4. An oil-recycling plant has two main sources of wastewater, R_1 and R_2, with phenol as the principal pollutant. Several techniques have been considered to separate phenol from the wastewater streams. Solvent extraction using two process mass separating agents (MSAs), S_1 and S_2 is a potential option for the separation. Three other technologies using external MSAs, S_3, S_4 and S_5 are also considered for the removal of phenol. The data for the source streams and the candidate MSAs are given in **TABLE Q4a** and **TABLE Q4b,** respectively. The minimum allowable composition difference for all MSAs should not be less than 0.001. The equilibrium data for the transfer of phenol to the j^{th} MSA is given by $y = m_j x_j$, where y and x_j are the mass fraction of phenol in the wastewater source streams and the j^{th} MSA, respectively.

TABLE Q4a: Data for the wastewater source streams

Source	**Flowrate, G_i (kg/s)**	**Supply composition, y_i^s**	**Target composition, y_i^t**
R_1	2	0.050	0.010
R_2	1	0.030	0.006

TABLE Q4b: Data for the MSAs

MSA	**Upper bound on flowrate, L_j^c (kg/s)**	**Supply composition, x_j^s**	**Target composition, x_j^t**	m_j	c_j **($/kg MSA)**
S_1	5	0.005	0.015	2.00	-
S_2	3	0.010	0.030	1.53	-
S_3	∞	0.080	0.200	0.02	0.081
S_4	∞	0.108	0.130	0.09	0.009
S_5	∞	0.000	0.029	0.04	0.060

a. Estimate the minimum load of phenol to be removed by the external MSAs and the excess capacity of the process MSAs.

[10 marks]

b. Discuss how the excess capacity of the process MSAs obtained in **part (a)** can be eliminated. No calculation is required.

[5 marks]

c. Evaluate the **THREE (3)** external MSAs and determine the minimum operating cost of the mass exchanger network assuming 8760 operating hours per year.

[10 marks]

-END OF PAPER-