UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
JANUARY 2025 SEMESTER

COURSE : ECM5053 – OPTIMISATION

DATE : 19 APRIL 2025 (SATURDAY)

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 **FIVE (5)** printed pages in this **double-sided** Question Booklet including the cover page .

1. It has been reported that the efficiency of a batch reactor for production of a desired chemical species is primarily governed by the operating variables, including the temperature, x_1, and initial reactant concentrations, x_2.

The two operating variables are found to form the following inequality constraints by plant operators.

$$g_1(\hat{x}) = {x_1}^2 + {x_2}^2 - 9 \leq 0$$
$$g_2(\hat{x}) = 1 - x_1 - {x_2}^2 \geq 0$$
$$g_3(\hat{x}) = x_1 + x_2 - 1 \leq 0$$

As a process engineer working in the plant, investigate convexity of the region bounded by the constraints with justifications.

[25 marks]

2. The chemists in your company have synthesised new catalysts for a consecutive reaction. They are operating the reactions at 180°C and 3 barg at the moment. The mass yields of the main product in each reactor are as follows:

$$y_1 = TP$$

$$y_2 = \frac{1}{P}(370 - T) - \frac{1}{T}\left(\frac{5}{2}P + 550\right) - \frac{34160}{TP} + 3$$

where,

y_1 is the mass yield in reactor 1,

y_2 is the mass yield in reactor 2,

T is the reaction temperature in °C, and

P is the reaction pressure in barg.

Your plant has two existing packed bed reactors, one standalone (reactor 1) and one embedded in a distillation column (reactor 2), as shown in **FIGURE Q2**. These reactors are going to be used to facilitate the reactions.

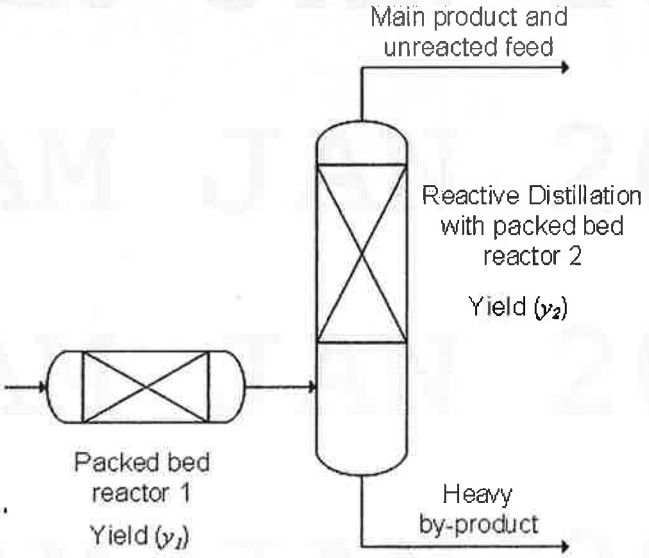

FIGURE Q2: A consecutive reaction with reactors in series

Evaluate the required pressure (barg) and temperature (°C) that maximizes the yield of the main product for the reactors. Provide solution up until **TWO (2)** iterations.

[25 marks]

3. In a distillation process, the reflux ratio is the ratio of the liquid returned to the column as reflux to the liquid collected as distillate. The reflux ratio significantly impacts both energy consumption and capital costs. For a given product purity specification, a higher reflux ratio means more liquid is recycled within the column, leading to increased reboiler duty (LP steam) and, consequently higher energy costs. However, the trade-off is that a higher reflux ratio reduces the number of distillation stages, hence reducing column cost.

Your process engineering team has been tasked with studying the optimum reflux ratio for a distillation column in a process plant. Your team has collected the required plant data to calculate the trade-off between energy and capital costs of the distillation column, as shown in **FIGURE Q3**. The energy and capital cost data have been regressed, and the model equations are shown on the graph, where x is the reflux ratio. Additionally, the product specification requires the following constraint to be satisfied:

$$g(x) = x - 3 \geq 0$$

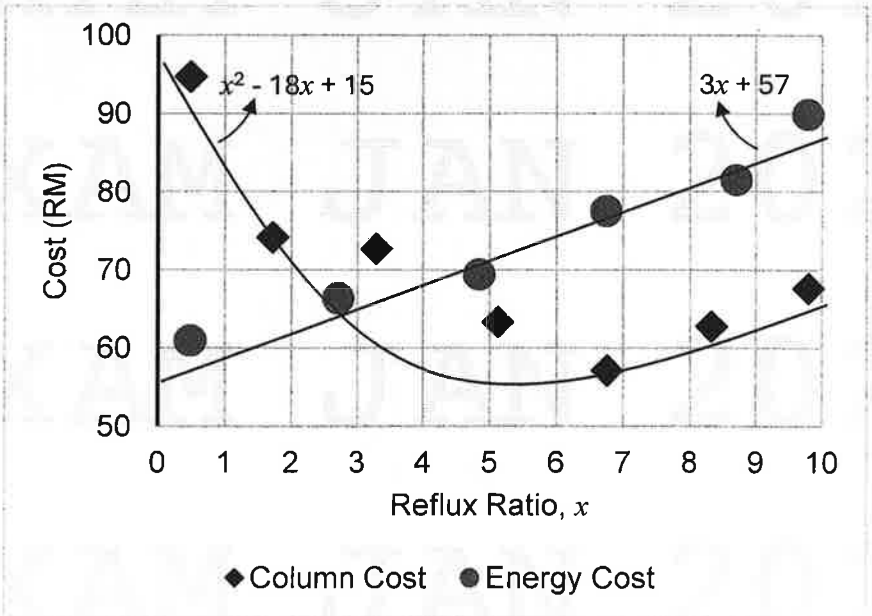

FIGURE Q3: Distillation cost vs. reflux ratio

Develop an augmented form of Lagrange multiplier function for the objective function and constraint to minimise the total distillation cost. Then, use Newton's method to solve the Lagrange multiplier function, starting at $x^0 = 2$.

[25 marks]

4. SpeeDGum produces two types of quick-drying adhesives: Sonic, which sells for RM 300 per ton, and Flash, which sells for RM 600 per ton. The company has a total of 300 production workers for manufacturing both Sonic and Flash. Additionally, 360 hours of production time are available, with Flash requiring three times more labor hours per unit than Sonic. The objective is to determine the optimal production quantities of Sonic and Flash in order to maximise revenue.

For the given variables to be optimized:

x_1 – tons of Sonic produced

x_2 – tons of Flash produced

Formulate the linear programming (LP) problem for SpeeDGum in the standard mathematical format. Solve the problem using the LP Simplex method, showing the tableau at each iteration.

[25 marks]

-END OF PAPER-