UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
MAY 2024 SEMESTER

COURSE : CEB4013/CFB3023 - PROCESS PLANT DESIGN

DATE : 9 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 **SEVEN (7)** pages in this Question Booklet including the cover page and appendix.

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

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

1. A saturated liquid mixture is fed to a distillation column operating at 20 bar. The feed composition and relative volatilities are given in **TABLE Q1**. The mixture is to be separated into overhead product of 99.5 mole% of n-Butane and 99.5 mole% of n-Hexane in the bottoms.

TABLE Q1

Component	Molar flowrate (kmol/hr)	Relative volatility, α_{ij}
Propane	40.8	5.46
n-Butane	160.2	3.10
n-Pentane	210.3	1.73
n-Hexane	109.8	1.00

a. Estimate the number of stages and distribution of components molar flowrate in the distillate and bottoms.

[10 marks]

b. It is assumed θ is around 4.92. Justify if this value is correct for the system and calculate the minimum reflux ratio.

[8 marks]

c. It is intended to separate the mixtures into its pure component. Propose distillation column flowsheet for each direct and indirect sequence with proper labelling. In your opinion which is the most feasible flowsheet and justify your answer.

[7 marks]

2. Esters can be made from the reaction between alcohols and acid anhydrides. When ethanoic anhydrides react with ethanol, a slow reaction occurs at room temperature to form ethyl ethanoate and ethanoic acid. The reaction equation is as follows:

$$(CH_3CO)_2O + CH_3CH_2OH \rightarrow CH_3COOCH_2CH_3 + CH_3COOH \quad (1)$$

An experimental run was carried out in an ideal batch reaction at room temperature. The measured concentration of ethanoic anhydrides versus time is given in **TABLE Q2**. At first the reactor model was expressed by the following second order equation:

$$\left(\frac{1}{C_A} - \frac{1}{C_{A0}}\right) = k_A t \quad (2)$$

TABLE Q2

Reaction time (min)	Ethanoic anhydrides concentration (kg/m^3)
0	20.0
5	16.5
10	13.2
20	10.1
35	8.5
45	7.2
60	6.4

Based on the experimental data, derive a kinetic model for the reaction **AND** predict the concentration of A after 40 minutes of reaction. An engineer repeated the experiment and actual analysis shows that the concentration of A after 40 minutes was 7.9 kg/m^3. Suggest a way to improve the prediction.

[25 marks]

3. As a process engineer, you have been assigned to design a heat exchanger network (HEN) for the following process streams shown in **TABLE Q3**.

TABLE Q3

Stream No.	Heat capacity, CP (kW/°C)	Temperature in (°C)	Temperature out (°C)
1	20	400	320
2	40	300	100
3	30	90	310
4	20	170	310

Using appropriate method determine the pinch temperatures, the minimum hot and cold utilities **AND** design the heat exchanger network (HEN) for maximum energy recovery of the process. Assume $\Delta Tmin$ is 10 °C.

[25 marks]

4. The process flow diagram (PFD) for the ethylbenzene (EB) process is shown in **FIGURE Q4**. The production of EB occurs in liquid phase in a continuous stirred tank reactor, R-601, with three reactions occurring. The liquid phase production of EB takes place via the direct addition reaction between ethylene and benzene. A secondary reaction occurs between EB and ethylene to produce a by-product of diethylbenzene (DEB). A third reaction also occurs with formed diethylbenzene and benzene to yield ethylbenzene. The effluent stream leaving the reactor contains products, byproducts, unreacted benzene, and small amounts of unreacted ethylene and other non-condensable gases. The reactor effluent is cooled in a heat exchanger and then fed to a two-phase separator (V-602), where the light gases are separated and, because of the high ethylene conversion, the stream is highly combustible. The condensed liquid is then sent to the benzene tower, T-601, where the unreacted benzene is separated as the overhead product and the bottoms product from the first column is sent to T-602, where product EB is taken as the top product. The bottoms product from T-602 contains all the DEB and trace amounts of higher ethylbenzenes. However, after further analysis, it was found that the stream contains considerable amounts of other contaminants namely heavy metals and suspended solid.

Propose a treatment system to treat the non-product streams. Your proposal should include a block flow diagram (BFD) of the treatment system which includes block naming, material flows etc. and provides justification for your system. Apart from waste treatment, suggest and discuss **TWO (2)** ways to make the process greener.

[25 marks]

- END OF PAPER -

V-601 Benzene Feed Drum	C-601 Ethylene Compressor	R-601 Ethylbenzene Reactor	T-601 Benzene Column	E-603 Benzene Condenser	P-602A/B Benzene Reflux Pumps	T-602 Ethylbenzene Column	E-605 Ethylbenzene Condenser	E-606 Ethylbenzene Reboiler
P-601A/B Benzene Feed Pumps	E-601 Reactor Feed Heater	E-602 Reactor Effluent Cooler	V-602 Phase Separator	V-603 Benzene Reflux Drum	E-604 Benzene Reboiler	P-603A/B Ethylbenzene Reflux Pumps	V-604 Ethylbenzene Reflux Drum	E-607 Ethylbenzene Product Cooler

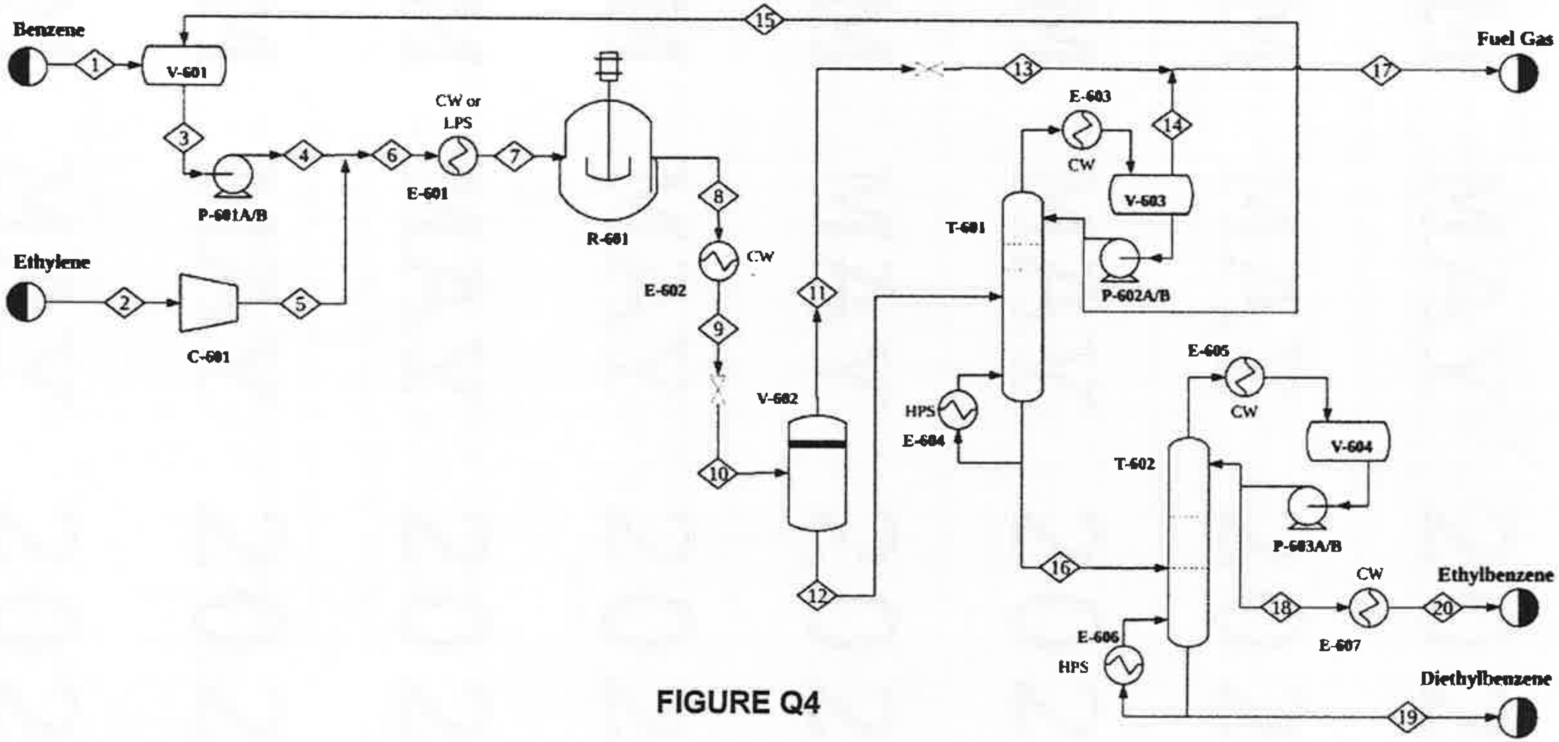

FIGURE Q4

APPENDIX

Fenske equations:

$$N_{min} = \frac{\log\left[\frac{r_{L,D}}{1 - r_{L,D}} \cdot \frac{r_{H,B}}{1 - r_{H,B}}\right]}{\log \alpha_{LH}}$$

$$N_{min} = \frac{\log\left[\frac{x_{L,D}}{x_{H,D}} \cdot \frac{x_{H,B}}{x_{L,B}}\right]}{\log \alpha_{LH}}$$

$$d_i = \frac{\alpha_{ij}^{N_{min}} f_i \left(\frac{d_j}{b_j}\right)}{1 + \alpha_{ij}^{N_{min}} \left(\frac{d_j}{b_j}\right)}$$

$$\frac{d_H}{b_H} = \frac{1 - r_{H,B}}{r_{H,B}}$$

Underwood equations:

$$\sum_{i=1}^{NC} \frac{\alpha_{ij} x_{i,F}}{\alpha_{ij} - \theta} = 1 - q$$

$$R_{min} + 1 = \sum_{i=1}^{NC} \frac{\alpha_{ij} x_{i,D}}{\alpha_{ij} - \theta}$$