UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
JANUARY 2025 SEMESTER

COURSE	**:**	**CEB4013/CFB3023 - PROCESS PLANT DESIGN**
DATE	**:**	**19 APRIL 2025 (SATURDAY)**
TIME	**:**	**2.30 PM - 5.30 PM (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 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 molar flowrate and relative volatilities are given in **TABLE Q1**. It is intended to separate the mixture into an overhead product that recovers more than 99% of *n*-butane and more than 99% of *n*-hexane in the bottoms.

TABLE Q1: Feed molar flowrate and relative volatilities

Component	Molar flowrate (kmol/h)	α_{ij}
Propane	20	9.45
n-Butane	35	5.35
n-Pentane	30	2.99
n-Hexane	25	1.73
n-Heptane	25	1.00

a. Design a distillation column with minimum number of stages and reflux ratio and estimate the molar flowrate (kmol/h) of all components in the distillate and bottom stream. Assume θ between 3.6 and 3.8.

[25 marks]

b. During plant operation it is found that the *n*-butane recovery is only 95%. Increasing the number of stages can improve the column performance. Is this feasible? Explain your answer.

[5 marks]

2. In the production of the hydrocarbon solvent S, reactant A undergoes conversion in a CSTR (continuous stirred tank reactor) using a homogeneous catalyst, W, to the desired solvent S and another valuable solvent R, following the reaction:

$$2A \rightarrow S + R$$

The conversion efficiency of A is 90%. The feed stream contain mixture of A and considerable amount of contaminant B. Assuming that components A, B, S, R, and W can be separated through simple distillation, with relative volatilities in the order of B > W > S > A > R, propose and sketch **ONE (1)** possible block flow diagram (BFD) for each pre- and post-treatment with recycle systems to enhance and minimize the environmental impact of the process. Both BFDs should include naming of the equipment used and labeling each stream component. Compare these BFDs by describing their key differences, advantages and disadvantages.

[25 marks]

3. It is intended to store CO_2 in a storage tank with an operation pressure of 30 bara and temperature of 60 ^oC. The plant manager suggested using an unused hemispherical head vertical cylindrical vessel. The material construction is low alloy steel. Welds will be fully radiographed with no joints. The internal diameter of the vessel is 3 meters with 15 millimeters of cylindrical wall thickness and hemispherical head thickness of 12.5 millimeters.

   a. As a process engineer, evaluate the suitability of the unused vessel to store CO_2. Assume corrosion allowance of 2 millimeters. Justify your answer with appropriate calculations.

   [15 marks]

   b. In order to save cost, the plant manager decides to use the vessel at the same temperature but at lower pressure. Estimate the safest operating pressure of the vessel. **Note:** Only consider the cylindrical wall thickness.

   [10 marks]

4. A chemical plant produces flue gas and wastewater from its facilities. The air pollution monitoring system indicates the flue gas contains oxygen, carbon dioxide and significant amounts of hydrogen sulfide and particulate matter of less than 10 μmeter. Whereas a sample of liquid from the wastewater stream was found to contain water and considerable amounts of ammonia, heavy metals and suspended solids. Propose a treatment system to treat the flue gas and wastewater stream as such it can be discharged safely. Your proposal should include a block flow diagram (BFD) for each treatment system, naming the equipment used and labeling each stream component. Additionally, provide a justification for the selection of each equipment involved in the BFDs.

[20 marks]

- END OF PAPER -

APPENDIX

Fenske equations:

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

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

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

Underwood equations:

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

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

Terminal velocity:

$$v_T = \frac{g d^2 (\rho_P - \rho_F)}{18 \mu_F} \qquad 0 < Re < 2$$

$$v_T = \left(\frac{g d^{1.6} (\rho_P - \rho_F)}{13.875 \rho_F^{0.4} \mu_F^{0.6}}\right)^{0.7143} \qquad 2 < Re < 500$$

$$v_T = \sqrt{\frac{g d (\rho_P - \rho_F)}{3.03 \rho_F}} \qquad 500 < Re < 200{,}000$$

APPENDIX

Reynolds number

$$Re = \frac{d v_T \rho_F}{\mu_F}$$

Where

v_T = terminal velocity

d = particle diameter

ρ_F = density fluid

μ_F = viscosity fluid

Mean residence time:

$$\tau = \frac{H}{v_T}$$

$$\tau = \frac{V}{F} = \frac{LBH}{F}$$

Where

τ = mean residence time

H = height of the settling chamber

V = volume of settling chamber

F = volumetric flowrate

L = length of settling chamber

B = breadth of settling chamber

Cylinders and spherical shells thickness:

$$e = \frac{P_i D_i}{2f - P_i}$$

APPENDIX

Where

D_i = internal diameter

f = design stress factor

P_i = internal pressure

Hemispherical heads thickness

$$e = \frac{P_i D_i}{4Jf - 0.4P_i}$$

Ellipsoidal heads thickness

$$e = \frac{P_i D_i}{2Jf - 0.2P_i}$$

Where

J = Welded joint factor

TABLE A: Design stress factor table

Material	Tensile strength (N/mm^2)	Design stress at temperature °C (N/mm^2)									
		0 to 50	100	150	200	250	300	350	400	450	500
Carbon steel (semi-killed or silicon killed)	360	135	125	115	105	95	85	80	70		
Carbon-manganese steel (semi-killed or silicon killed)	460	180	170	150	140	130	115	105	100		
Carbon-molybdenum steel, 0.5 per cent Mo	450	180	170	145	140	130	120	110	110		
Low alloy steel (Ni, Cr, Mo, V)	550	240	240	240	240	240	235	230	220	190	170
Stainless steel 18Cr/8Ni unstabilised (304)	510	165	145	130	115	110	105	100	100	95	90
Stainless steel 18Cr/8Ni Ti stabilised (321)	540	165	150	140	135	130	130	125	120	120	115
Stainless steel 18Cr/8Ni Mo $2\frac{1}{2}$ per cent (316)	520	175	150	135	120	115	110	105	105	100	95