L-4/T-1/CHE

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-4/T-1  B. Sc. Engineering Examinations 2017-2018

Sub: CHE 403 (Process Control)

Full Marks: 210        Time: 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are FOUR questions in this section. Answer any THREE.

1. (a) Sketch a typical architecture of a DCS control system.

   (b) Describe the concepts of cascade control and auctioneering control using an example for each case.

   (c) Draw a block diagram for feedback-feedforward control system and find the relation for designing a feedforward controller. Design a feedforward controller for the following system:

   \[ G_t = K_f, G_v = K_v, \quad G_p = \frac{K_p e^{-\theta_s}}{(\tau_p S + 1)}, \quad G_d = \frac{K_d}{(\tau_d S + 1)} \]

   How can this feedforward controller be made physically realizable?

   (d) What is a root-locus diagram? How is it useful?

2. (a) Describe the basic modes of feedback controllers with their respective merits and demerits.

   (b) Mathematically show that a purely integrating process with \( G_d(s) = K_p/s \) and \( G_d(s) = K_d(2s+1) \) does not require an integral action in the controller for rejecting a step-type disturbance, while a purely integrating disturbance transfer function with \( G_d(s) = K_d/s \) and \( G_p(s) = K_p(2s+1) \) does require an integral action for rejection of step-type disturbances.

3. (a) Figure 3(a) shows a Bode diagram of a first-order plus time delay (FOPTD) process for \( G_v = 1, G_c = K_c = 1 \) and \( G_m = 1 \). Find the following:

   (i) The steady state gain of the process

   (ii) The critical frequency of the system

   (iii) The ultimate gain and the ultimate period of the system

   (iv) How much additional delay can be system tolerate before it becomes unstable?

   (v) Design a PI controller for the process using Zeigler-Nichols tuning criteria \((K_c = 0.45K_{oa} \text{ and } T_i = P_d/1.2)\)

   (b) Describe the relay auto-tuning method for tuning controllers. What are its advantages over continuous cycling method for tuning controllers?

Contd ............ P/2
For Figure 4(a).

(i) Derive the closed loop response relationship between $Y$ and $Y_{sp}$  
(ii) From this relationships, find the expression of Internal Model controller, $G_p^*$.  
(iii) For a first-order plus time delay process (FOPTD), find the Internal Model Controller, $G_p^*$.  
(iv) Show that for the FOPTD process, the IMC method can produce the identical feedback controller tuning relations as can be obtained from Direct Synthesis method (use Taylor series approximation for time delay).

(b) Explain the concept of split-range control with an example.

SECTION – B

There are FOUR questions in this section. Answer any THREE.

5. (a) For the CSTR as shown in figure for Q. no. 5(a) Complete Table 1 by filling in the selected controlled and manipulated variables, sensor principle (e.g., thermocouple/pressure difference etc) for the measurements and the possible disturbances occurring in the CSTR. You may add valves and sensors to the figure, if necessary.  

Table 1 Control objectives for the non-isothermal CSTR.

<table>
<thead>
<tr>
<th>Control Objectives</th>
<th>Controlled Variable</th>
<th>Sensor Principle</th>
<th>Manipulated Variable</th>
<th>Disturbances that would affect the controlled variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Maintain liquid in the reactor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment Protection</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Maintain flow through the pump</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smooth Plant Operation and</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production Rate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6. (a) A perfectly stirred, constant-volume heating tank as shown in figure for Q. no. 6(a) has two input streams, both consisting of the same liquid. The temperature and flow rate of each of the streams can vary with time.

(i) Derive a dynamic model that will describe transient operation and simplify your model
(ii) Make a degrees of freedom analysis assuming that both Streams 1 and 2 come from upstream units (i.e., their flow rates and temperatures are known functions of time).

Notes: w; denotes mass flow rate for stream i.

Liquid properties are constant (not functions of temperature).

(b) Consider the system as given by the following equation, \( \frac{d^2 x}{dt^2} + \frac{dx}{dt} = 4 \)

(i) What is the initial value of the system
(ii) Will the system ever reach a steady state? What will be the value?
(iii) Will it oscillate? Explain why or why not.

7. (a) A simple surge tank with a valve on the exit line is illustrated in Figure for Q. no. 7(a). If the exit flow rate is proportional to the square root of the liquid level, an unsteady-state model for the level in the tank is given by

\[ A \frac{dh}{dt} = q_i - C \sqrt{h} \]

As usual, you can assume that the process initially is at steady state: \( \bar{q}_i = \bar{q} = C \bar{h}^{-0.5} \)

(i) Find the transfer function \( H(s)/Q_i(s) \). Put the transfer function in standard gain/time constant form.
(ii) Find the transfer function \( Q(s)/Q_i(s) \) and put it in standard form.

(b) Distinguish between a transducer and a transmitter.

Contd ............  P/3
c) An operator introduces a step change in the flow rate \( q_1 \) to a particular process at 3:05 A.M., changing the flow from 500 to 540 gal/min. The first change in the process temperature \( T \) (initially at 120°F) occurs at 3.09 A.M. After that, the response in \( T \) is quite rapid, slowing down gradually until it appears to reach a steady-state value of 124.7°F. The operator notes in the logbook that there is no change after 3:34 A.M. What approximate transfer function might be used to relate temperature to flow rate for this process in the absence of more accurate information? What should the operator do next time to obtain a better estimate? 

8. (a) The overall transfer function of a process is given by, \( G = G_1 G_2 \)

Where, \( G_1 = \frac{K_1}{\tau_1 s + 1} \) and \( G_2 = \frac{K_2}{\tau_2 s + 1} \) let, \( \tau_1 = 5 \) and \( \tau_2 = 3 \)

(i) What is the overall gain of \( G \)?

(ii) Is the equivalent the constant for the step response of the second order system \( G \) equal to, \( \tau_1 + \tau_2 \)? Show supporting calculation for the step response formula,

\[
y(t) = KM \left( 1 - \frac{e^{-\frac{t}{\tau_1}} - e^{-\frac{t}{\tau_2}}}{\tau_1 - \tau_2} \right)
\]

(iii) Will \( y(t) \) oscillate for a step input? Explain.

(b) For the process described by the exact transfer function

\[
G(s) = \frac{K(1-s)e^{-s}}{(10s + 1)(4s + 1)(s + 1)(0.2s + 1)}
\]

(i) Find an approximate transfer function of first order plus-time-delay form that describes this process.

(ii) Find an approximate transfer function of second-order plus-time-delay form that describes this process.

(c) The dynamic behavior of a transfer function model can be characterized by the numerical value of its poles and zeros. Explain.
Figure 3(a) Figure for Question 3(a)
Figure for Q. no. 5(a)

Figure for Q. no. 6(a)

Figure for Q. no. 7(a).
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA
L-4/T-1  B. Sc. Engineering Examinations 2017-2018
Sub: CHE 405 (Process Design I)
Full Marks : 210          Time : 3 Hours
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USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are FOUR questions in this Section. Question No 1 is compulsory. Answer any TWO from the rest.

1. **This question is compulsory.** Aniline is produced by highly exothermic catalytic hydrogenation of nitrobenzene. A small amount of cyclo-hexylamine is produced as a byproduct. The reactions are:

   \[ C_6H_5NO_2 + 3H_2 \rightarrow C_6H_5NH_2 + 2H_2O \]

   \[ C_6H_5NO_2 + 6H_2 \rightarrow C_6H_11NH_2 + 2H_2O \]

Nitrobenzene is fed to the reactor as a vapor, with three times the stoichiometric quantity of hydrogen for the first reaction. The reactions take place at 400°C and 10 bar. The hydrogen and nitrobenzene are supplied at 7 bar and 1 bar, respectively at 25°C. The conversion of nitrobenzene, to all products, is 96%, and the selectivity for aniline is 95%. The un-reacted hydrogen is separated from the reactor products and recycled to the reactor. A purge is taken from the recycle stream to maintain the inerts in the recycle stream below 5%. The fresh hydrogen feed is 99.5% pure, the remainder being inerts. All percentages are molar. Show the following for the above mentioned aniline synthesis.

   (a) Input-output model with necessary assumptions

   (b) Separation, Recycle and Purge scheme as block diagram

   (c) Heating/cooling and pressurization scheme

   (d) For a feed rate of 100 kmol/h of nitrobenzene, calculate

      (i) the purge rate required

      (ii) the composition of the product aniline

Table for Question No. 1: Boiling point of different components

<table>
<thead>
<tr>
<th>Component</th>
<th>b.p. @ 1 atm</th>
</tr>
</thead>
<tbody>
<tr>
<td>H_2</td>
<td>-252.879°C</td>
</tr>
<tr>
<td>Cyclo-hexylamine</td>
<td>134.5°C</td>
</tr>
<tr>
<td>Aniline</td>
<td>184.1°C</td>
</tr>
<tr>
<td>Nitrobenzene</td>
<td>210.9°C</td>
</tr>
</tbody>
</table>

2. (a) Bangladesh Chemical Industries Corporation (BCIC) has six urea fertilizer factories. Shahjalal Fertilizer Company Limited is the most recently built one that started operation in 2016 with a capacity of 1700 metric ton per day. A newly proposed plant with 2800 metric ton urea per day capacity is to be built in Ghorashal. Which method would you recommend for the initial estimation of capital investment for this new project? Justify your recommendation.

Contd ..........., P/2
(b) The delivered equipment cost of a 100 metric ton per day 98% sulfuric acid plant is $2.8 million. The plant is to be established in an existing plant site. The market price for 98% sulfuric acid is $275 per metric ton.

(i) Estimate the total capital investment using the table for question no 2 b.

(ii) The typical values of turnover ratio of a sulfuric acid plant is 0.5. Does it agree with your estimation?

(iii) The estimated annual operating cost (including variable and fixed cost of running the plant) is $1 million. What is the production cost of 98% sulfuric acid per metric ton? Consider 15% annual depreciation.

3. (a) ‘Break-even Analysis is important for minimum product pricing’-explain.

(b) A sieve tray distillation column is being used to separate a hydrocarbon mixture. Write down different components of variable and fixed cost of this process. Draw the plots of cost vs reflux ratio.

(c) How do you apply the concept of pinch technology in designing heat exchanger network?

(d) The fundamental canons of AIChE code of professional ethics includes the following, “Engineers shall continue their professional development throughout their careers and shall provide opportunities for the professional development of those engineers under their supervision”. Suggest different ways a practicing engineer can fulfill this duty.

4. (a) ‘Methods to control exposure to toxic material are adopted according to the entry route of toxicant to human body’– elaborate this statement with examples.

(b) A distillation column separates benzene from toluene using the control scheme shown in the figure for Q. No. 4(b). Toluene is highly flammable, whereas benzene is flammable and toxic. Carry out a HAZOP study on the column using pressure and level as parameters and make necessary recommendations.
CHE 405

SECTION – B

There are **FOUR** questions in this Section. Answer any **THREE** questions. Assume any reasonable value for any missing data.

5. (a) Describe properties of ferrous metals and alloys as design materials for process equipment. (15)

(b) A centrifugal pump delivers 0.0063 m³/s of water at a temperature of 15°C when the impeller speed is 1800 r/min and the pressure developed across the pump is 105 kPa. If the speed of the impeller is reduced to 1200 r/min, estimate the water delivering rate and the head that is developed by the pump if pump operation is ideal. (10)

(c) With simple sketch write different parts of a shell-and-tube heat exchanger. (10)

6. Estimate heat-transfer coefficient and pressure drop on the shell side of a shell-and-tube exchanger by using KERN Method where the exchanger having one shell and one tube pass is being used as a cooler. The cooling medium is water with a flow rate of 11 kg/s on the shell side of the exchanger. With an inside diameter of 0.584 m, the shell is packed with a total of 384 tubes in a staggered (triangular) array. The outside diameter of the tube is 0.019 m with a clearance between tubes of 0.00635 m. Segmental baffles with a 25 percent baffle cut are used on the shell side, and the baffle spacing is set at 0.1524 m. The length of the exchanger is 3.66 m.

The average temperature of the water is 30°C and the average temperature of the tube walls on the water side is 40°C. (35)

<table>
<thead>
<tr>
<th>Physical Properties data:</th>
<th>30°C</th>
<th>40°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal conductivity, ( k_s ), ( \text{kJ/m·K} )</td>
<td>0.000616</td>
<td>0.000632</td>
</tr>
<tr>
<td>Heat Capacity ( C_p, \text{kJ/kg·K} )</td>
<td>4.179</td>
<td>4.179</td>
</tr>
<tr>
<td>Viscosity, ( \mu, \text{Pa·s} )</td>
<td>0.000803</td>
<td>0.000637</td>
</tr>
<tr>
<td>Density, ( \rho, \text{kg/m}^3 )</td>
<td>995</td>
<td>995</td>
</tr>
</tbody>
</table>

**Exchanger Configuration**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell internal diameter, ( D_i )</td>
<td>0.584 m</td>
</tr>
<tr>
<td>Tube Outside diameter, ( D_o )</td>
<td>0.019 m</td>
</tr>
<tr>
<td>Tube Pitch (triangular), ( P_T )</td>
<td>0.0254 m</td>
</tr>
<tr>
<td>No. of tubes, ( N_t )</td>
<td>384</td>
</tr>
<tr>
<td>Baffle spacing, ( L_B )</td>
<td>0.1524 m</td>
</tr>
<tr>
<td>Shell length, ( L_S )</td>
<td>3.06 m</td>
</tr>
<tr>
<td>Bindle-to-shell diametral clearance, ( \Delta_b )</td>
<td>0.035 m</td>
</tr>
<tr>
<td>Tube-to-baffle diametral clearance, ( \Delta_{tb} )</td>
<td>0.005 m</td>
</tr>
<tr>
<td>Tube-to-baffle diametral clearance, ( \Delta_{hb} )</td>
<td>0.0008 m</td>
</tr>
<tr>
<td>Thickness of baffle, ( t_b )</td>
<td>0.005 m</td>
</tr>
<tr>
<td>Sealing strips per cross-flow row, ( N_{st}/N_c )</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Contd ............. P/4
7. (a) Write distillation design procedures for column with sieve trays.

(b) Absorption has been selected as the separation process to remove a hydrocarbon from a gas mixture by counter current scrubbing with a lean oil. The absorption column packed with 0.0254 m metal pail rings, must handle a gas rate of 900 kg/h and a liquid rate of 2700 kg/h. A gas velocity equal to 70 percent of the maximum allowable velocity at the given liquid and gas rates will be used. Densities of the gas and liquid are 1.2 and 881 kg/m³, respectively. The viscosity of the oil is 20 cP. Under these operating conditions, estimate the required column diameter and the pressure drop through the column in Pascal per meter of packed height.

8. In a depropanizer described by King, a six-component feed at 96°C and 2170 kPa has the following composition:

<table>
<thead>
<tr>
<th>Component</th>
<th>Feed, mol%</th>
<th>K value at 96°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>26.0</td>
<td>15.0</td>
</tr>
<tr>
<td>Ethane</td>
<td>9.0</td>
<td>3.8</td>
</tr>
<tr>
<td>Propane</td>
<td>25.0</td>
<td>1.55</td>
</tr>
<tr>
<td>n-Butane</td>
<td>17.0</td>
<td>0.80</td>
</tr>
<tr>
<td>n-Pentane</td>
<td>11.0</td>
<td>0.38</td>
</tr>
<tr>
<td>n-Hexane</td>
<td>12.0</td>
<td>0.19</td>
</tr>
</tbody>
</table>

The feed is to be separated in a sieve tray distillation column with a recovery of 98.4 percent of the Propane in the distillate product and 98.2 percent of the n-Butane in the bottom product. The feed quality is 66 percent vapor. The column is equipped with a partial condenser. What are the minimum number of stages and minimum reflux required for the separation? If a reflux ratio of 1.5 is selected, how many theoretical stages are required and where is the feed location.
Table for question No 2 b

<table>
<thead>
<tr>
<th>Direct costs</th>
<th>Solid processing</th>
<th>Solid-Bulk Processing</th>
<th>Total-Processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchased equipment delivered</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>(including fabricated equipment)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process machinery, pumps, and</td>
<td>45</td>
<td>39</td>
<td>47</td>
</tr>
<tr>
<td>compressors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instrumentation and conveyors (installation)</td>
<td>48</td>
<td>96</td>
<td>96</td>
</tr>
<tr>
<td>Piping (installed)</td>
<td>16</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>Electrical systems (installed)</td>
<td>10</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Buildings (including services)</td>
<td>25</td>
<td>20</td>
<td>28</td>
</tr>
<tr>
<td>Yard improvements</td>
<td>15</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td>Service facilities (installed)</td>
<td>40</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>Total direct plant cost</td>
<td>209</td>
<td>302</td>
<td>300</td>
</tr>
<tr>
<td>Indirect costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering and supervision</td>
<td>33</td>
<td>32</td>
<td>33</td>
</tr>
<tr>
<td>Construction expenses</td>
<td>39</td>
<td>34</td>
<td>41</td>
</tr>
<tr>
<td>Legal expenses</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Contractor's fee</td>
<td>17</td>
<td>19</td>
<td>22</td>
</tr>
<tr>
<td>Contingency</td>
<td>35</td>
<td>27</td>
<td>41</td>
</tr>
<tr>
<td>Total indirect plant cost</td>
<td>128</td>
<td>126</td>
<td>144</td>
</tr>
<tr>
<td>Fixed-capital investment</td>
<td>367</td>
<td>428</td>
<td>504</td>
</tr>
<tr>
<td>Working capital (15% of total capital investment)</td>
<td>70</td>
<td>75</td>
<td>89</td>
</tr>
<tr>
<td>Total capital investment</td>
<td>437</td>
<td>503</td>
<td>593</td>
</tr>
</tbody>
</table>

Figure for Question No 4 b

```
Feed -> 1 -> 11 -> 12 -> Distillate

13 -> 10 -> 2
```

Bottom product
1. (a) Explain briefly the mechanisms how temperature, pressure and catalyst affect the rate of reaction in homo/hetero-geneous systems. 

(b) Discuss the relative merits and demerits of integral and differential general techniques used for the interpretation of reaction rate data. Also state the conditions at which Guggenheims and initial rate measurement specific techniques are applied.

(c) Name and classify the techniques used for monitoring reaction progress.

(d) Researchers studied the thermal decomposition of nitrous oxide. Consider the following “adjusted” data at 1030 K.

<table>
<thead>
<tr>
<th>Initial Pressure of N₂O (torr)</th>
<th>Half-life (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>82.5</td>
<td>860</td>
</tr>
<tr>
<td>139</td>
<td>470</td>
</tr>
<tr>
<td>296</td>
<td>255</td>
</tr>
<tr>
<td>360</td>
<td>212</td>
</tr>
</tbody>
</table>

Determine the order of the reaction and the reaction rate constant.

2. (a) What are the two crucial criteria with which a proposed reaction mechanism must be consistent? Discuss with example(s).

(b) The following mechanism has been proposed for the oxidation of NH₃ in the presence of ClO:

\[ \text{NH}_3 + \text{ClO} \xrightarrow{k_1} \text{NH}_2 + \text{HOCl} \]
\[ \text{NH}_2 + \text{O}_2 \xrightarrow{k_2} \text{NO} + \text{H}_2\text{O} \]
\[ \text{NH}_2 + \text{O}_2 \xrightarrow{k_3} \text{HNO} + \text{OH} \]
\[ 2\text{HNO} \xrightarrow{k_4} \text{H}_2\text{O} + \text{N}_2\text{O} \]

(i) Derive an expression for the rate of formation of N₂O that contains the concentration of O₂, NH₃ and ClO and the reaction rate constants.

(ii) What are the limiting case of the derived expression if \( k_2 \gg k_3 \).

(c) Derive the general rate expression for variable value system following Levenspiel Approach.
3. (a) Write down the differential rate governing equations for the following cases:
   
   (i) Reversible second-order parallel reaction

   (ii) Second-order reaction opposed by first-order reaction

(b) State the conditions at which relaxation technique becomes the method of choice for kinetic study. Deduce the expression of relaxation time for first-order reversible reaction

(c) A consecutive reaction is given by

\[ 2A \xrightarrow{k_1} B \xrightarrow{k_2} 2C \]

with a clear hand-drawing, show the time dependant concentration profiles with appropriate coordinates when

(i) \( k_2 = 0.5 \ k_1 \) and \( B_0 = 0.5 \ A_0 \)

(ii) \( k_2 = 4 \ k_1 \) and \( B_0 = 0.5 \ A_0 \)

(d) A coupled enzyme assay system may be represented as

\[ A \xrightarrow{k_1} B \xrightarrow{k_2} C \]. The reactions are irreversible and no B is present initially. First reaction (\( A \rightarrow B \)) is of zero-order and the second reaction (\( B \rightarrow C \)) is of first-order. Determine the steady state value of the concentration of B. Given: \( k_1 = 0.835 \ \text{mol/m}^3\cdot\text{sec} \) and \( k_2 = 0.705 \ \text{sec}^{-1} \)

4. (a) Write down the distinguishing features of Langmuir and BET isotherms.

(b) The decomposition of ammonia over a heated platinum filament was studied at 1138°C. The stoichiometry of the reaction is

\[ 2\text{NH}_3 \leftrightarrow \text{N}_2 + 3\text{H}_2 \]

Initially, pure \( \text{NH}_3 \) was present in the reaction vessel. The following data are representative of the kinetics of the reaction; the reactor volume is constant.

<table>
<thead>
<tr>
<th>Time, t</th>
<th>Total pressure (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>26.7</td>
</tr>
<tr>
<td>10</td>
<td>30.4</td>
</tr>
<tr>
<td>60</td>
<td>34.1</td>
</tr>
<tr>
<td>120</td>
<td>36.3</td>
</tr>
<tr>
<td>240</td>
<td>38.5</td>
</tr>
</tbody>
</table>

Ascertain if a rate expression of the form \( r = \frac{k \cdot P_{NH_3}}{P_{H_2}} \) provides a reasonable representation of the experimental data. Indicate the type of Hougen-Watson model that leads to this type of rate expressions.

(c) Discuss properly the uses of the following adsorption data:

<table>
<thead>
<tr>
<th>( \text{H}_2 ) on ( \text{Cu} ) powder at 25°C</th>
<th>( \text{N}_2 ) on ( \text{silica} ) gel at -196°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure (cm Hg)</td>
<td>Volume adsorbed/g sample (cm²at STP)</td>
</tr>
<tr>
<td>0.097</td>
<td>0.163</td>
</tr>
<tr>
<td>0.190</td>
<td>0.221</td>
</tr>
<tr>
<td>0.405</td>
<td>0.321</td>
</tr>
<tr>
<td>0.555</td>
<td>0.371</td>
</tr>
</tbody>
</table>

Contd .......... P/3
CHE 401

SECTION – B

There are FOUR questions in this Section. Answer any THREE questions.

5. (a) You can planning to operate a batch reaction to convert A into R. This is a liquid phase reaction, the stoichiometry is A → R. The rate of reaction is given in Table 5(a). How long must you react each batch for the concentration to drop from $C_{AO} = 1.3$ mol/liter to $C_{AR} = 0.3$ mol/liter. (20)

(b) Margarine is an imitation butter spread used for flavoring, baking and cooking. The method of making margarine consists of emulsifying a blend of vegetable oils and fats. Your company is going to start producing margarine and gave you the responsibility to design the process. So, what type of reaction will you chose for the job and why?

6. The aqueous reaction $A + B →$ products with known kinetics

$$-r_A = 500 \text{ litre/mol.min } C_A C_B$$

is to take place in plug flow reactor under the following conditions:

Volume of reactor, $v = 0.1$ liter

Volumetric feed rate, $v_f = 0.05$ liter/min

Concentration of reactants in feed, $C_{A_0} = C_{B_0} = 0.01$ mole/liter using figure 6.1 and 6.2 answer the following.

(a) What fractional conversion of reactants can be expected? (7)

(b) For the same conversion as in part (a), what size of CSTR is needed? (8)

(c) What conversion can be expected in a CSTR equal in size to the plug flow reactor? Two CSTRs both having the equal size is used, then what conversion is expected? (20)

7. (a) Derive the performance equation for recycle reactors. Using the performance equation, find the expression for the optimum recycle ratio. (25)

(b) “Heat transfer to and from a large fixed bed of catalysts often represents a significant problem” – However, in some cases it is possible to circumvent this potential difficulty. How? (10)

8. Xin et al. studied the kinetics of catalytic oxidation of ethylene over cylindrical pellets of palladium oxide between 620 to 740 K at atmospheric pressure. They found that the surface catalytic reaction rate is the first order in ethylene concentration. The reaction is pore diffusion controlled for temperatures above 700 k. Starting with the basic material balance equation, find the expression for the concentration profile of ethylene inside the pore. Also find the expression for the effectiveness factor when the reaction temperature is (a) 720 K and, (b) 650 K. (15+10+10=35)
Table 5a

<table>
<thead>
<tr>
<th>$C_x$, mol/liter</th>
<th>$-r_{rx}$, mol/liter.min</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>0.6</td>
<td>0.25</td>
</tr>
<tr>
<td>0.7</td>
<td>0.10</td>
</tr>
<tr>
<td>0.8</td>
<td>0.06</td>
</tr>
<tr>
<td>1.0</td>
<td>0.05</td>
</tr>
<tr>
<td>1.3</td>
<td>0.045</td>
</tr>
</tbody>
</table>

Figure 6.1 Comparison of performance of single mixed flow and plug flow reactors for the $n$th-order reactions.
Figure 6.6 Comparison of performance of a series of $N$ equal-size mixed flow reactors with a plug flow reactor for elementary second-order reactions

Formula sheet for CHE401

\[
N_{AI} \frac{dX}{dV} = -r_A V
\]

\[
V = \frac{F_{AI}X}{-r_A}
\]

\[
F_{AI} \frac{dX}{dV} = -r_A
\]

\[
F_{AI} \frac{dX}{dW} = -r_A
\]

\[
C_A = \frac{F_A}{u} - \frac{F_{AI}(1-X) T_0 P}{u_0 (1+\epsilon X)} - \frac{C_{AI0} (1-X) T_0 P}{1+\epsilon X}
\]

\[
C_B = \frac{F_B}{u} - \frac{F_{BI} \left( \theta_B - \frac{b}{a} X \right) T_0 P}{u_0 (1+\epsilon X)} - \frac{C_{AI0} \left( \theta_B - \frac{b}{a} X \right) T_0 P}{1+\epsilon X}
\]

\[
\theta_I = \frac{F_{II}}{F_{AI} u_0} = \frac{C_{II} u_0}{C_{AI0} u_0} = \frac{Y_{II}}{Y_{AI0}}
\]

\[
\delta = \frac{d}{a} + \frac{c}{a} - \frac{b}{a} - 1
\]

\[
\frac{dP}{dz} = -\frac{G}{P_0 G_c D_p} \left( \frac{1-\phi}{\phi^2} \right) \left[ \frac{150 (1-\phi)\mu}{D_p} + 1.75 G \right] - \frac{P_0 T F_T}{P T_0 F_{T0}}
\]

\[
\beta_0 = \frac{G}{P_0 G_c D_p} \left( \frac{1-\phi}{\phi^2} \right) \left[ \frac{150 (1-\phi)\mu}{D_p} + 1.75 G \right]
\]

\[
W = Z A_c \rho_b = Z A_c (1-\phi) \rho_c
\]

\[
\frac{d(P/P_o)}{dW} = -\frac{a}{2} \frac{1}{(P/P_o) T_0 (1+\epsilon X)}
\]

\[
\frac{dy}{dW} = -\frac{a}{2y} (1+\epsilon X)
\]

\[
k = k_1 \exp \left[ \frac{E}{RT} \left( \frac{1}{T_1} - \frac{1}{T} \right) \right]
\]
\[ \int_{0}^{x} \frac{dx}{1-x} = \ln \frac{1}{1-x} \]

\[ \int_{x_1}^{x_2} \frac{dx}{(1-x)^2} = \frac{1}{1-x_2} - \frac{1}{1-x_1} \]

\[ \int_{0}^{x} \frac{dx}{1-x} = \frac{x}{1-x} \]

\[ \int_{0}^{x} \frac{dx}{1+ex} = \frac{1}{e} \ln (1+ex) \]

\[ \int_{0}^{x} \frac{(1+ex)dx}{1-x} = (1+e) \ln \frac{1}{1-x} - ex \]

\[ \int_{0}^{x} \frac{(1+ex)dx}{(1-x)^2} = \frac{(1+e)x}{1-x} - e \ln \frac{1}{1-x} \]

\[ \int_{0}^{x} \frac{(1+ex)^2dx}{(1-x)^2} = 2e(1+e)\ln(1-x) + e^2x + \frac{(1+e)^2x}{1-x} \]

\[ \int_{0}^{x} \frac{dx}{(1-x)(\Theta_B-x)} = \frac{1}{\Theta_B-1} \ln \frac{\Theta_B-x}{\Theta_B(1-x)} \quad \Theta_B \neq 1 \]

\[ \int_{0}^{w} (1-\alpha W)^{1/2}dW = \frac{2}{3\alpha}[1-(1-\alpha W)^{3/2}] \]

\[ \int_{0}^{x} \frac{dx}{ax^2+bx+c} = \frac{-2}{2ax+b} + \frac{2}{b} \quad \text{for } b^2 = 4ac \]

\[ \int_{0}^{x} \frac{dx}{ax^2+bx+c} = \frac{1}{a(p-q)} \ln \left( \frac{q}{p} \frac{x-p}{x-q} \right) \quad \text{for } b^2 > 4ac \]

where \( p \) and \( q \) are the roots of the equation.

\[ ax^2 + bx + c = 0 \quad \text{i.e., } p, q = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \]

\[ \int_{0}^{x} \frac{a+bx}{c+gx} \ dx = \frac{bx}{g} + \frac{ag-bc}{g^2} \ln \frac{c+gx}{c} \]
1. (a) (i) Give examples for Model use in 4 different chemical engineering areas.
(ii) Consecutive reactions occur continuous stirred-tank reactor (CSTR). Reactant A goes to
B at a specific reaction rate $k_1$, but B can react at a specific reaction rate $k_2$, to form a third
component C. Assuming first-order reactions, $A \xrightarrow{k_1} B \xrightarrow{k_2} C$
Write the continuity equations for the above system. \((8+7=15)\)
(b) Benzene (1), toluene (2), styrene (3) and xylene (4) are to be separated in the sequence of
distillation column shown in Figure Q. 1(b). Determine the molar flow rates of streams $D_1,
B_1, D_2, B_2$. The composition of the feed streams $D_1, B_1, D_2, B_2$ are shown in Figure Q 1(b).
Write the material balance equations. Solve the materials balance using Gauss Elimination
Technique. \((15)\)
(c) Write the Precautions in Model Building. \((5)\)

2. (a) Derive the following equations form $J \xi = -f$. Notations indicate their usual meaning. \((18)\)
(b) Using Taylor series expansion solve the equations below
\[ f_1(x_1, x_2) = 2x_1^2 - 3x_1x_2 + 5 = 0 \]
\[ f_{12}(x_1, x_2) = -x_1^2 - x_2 + 2 = 0 \]
Start with initial assumption around $x_1^2 = 3, x_2^2 = 3$ \((17)\)

3. (a) Write a short note on
(i) Step size control of ODE system
(ii) Stiffness
(iii) Stability
(b) Using Newton backward interpolation formula, derive the Explicit Euler Method. \((17)\)

4. (a) It is desired to find the required number of ideal stages in the extraction cascade
illustrated in figure below. Take the feed-to-solvent ratio (L/V) and equilibrium distribution
constant (K) to be unity, then $\beta = L/(KV) = 1$. \((18)\)
CHE 455
Contd ... Q. No. 4(a)

Pure solvent is specified, so $Y_{N+1} = 0$ kg solute/ kg solvent, and the feed is $X_0 = 1$ kg solute/kg carrier. It is desired to produce a rich extract product such that $y_1 = 0.9$ kg solute/kg solvent.

This problem can be solved by classical methods, using graphical construction as illustrated in Fig. Q. 4(a). The stage-to-stage calculations require linear connections between equilibrium line (i.e. departing streams) and operating line. However, find the Number of stage using Finite Difference method. Make necessary assumptions.

Figure: Continuous countercurrent extraction cascade.

(b) A hot vapor stream containing 0.4 mole fraction ammonia and 0.6 mole fraction water is to be enriched in a distillation column consisting of enriching section and total condenser. The saturated vapor at 6.8 atm pressure (100 psia) is injected at a rate 100 moles/hour at the bottom of the column. The liquid distillation product withdrawn from the total condenser has a composition 0.9 mole fraction NH$_3$. Part of the distillation is returned as reflux, so that 85% of the NH$_3$ charged must be recovered as distillate product. Complete the material balance and show that $X_N = 0.096$ (mole fraction NH$_3$ in liquid leaving $N$th tray) and that the required reflux ratio is $R = 1.65$.

(17)

SECTION – B

There are FOUR questions in this Section. Answer Q. No. 5 is (Compulsory) and answer any TWO from the rest.

5. (a) Write a short note on

(i) Reasons for selecting Numerical method over Analytical Methods
(ii) Difficulties faced while solving an optimization problem
(iii) Discuss the salient feature of Matlab optimization Toolbox
(iv) Relation of the Curvature Matrix and selection criteria the Convex and Concave Functions.

(b) Describe the merits and demerits of SLP, SQP, and GRG method

(7×4=28)

6. (a) Minimize $f = (x - 1)^4$ via

(i) Newton's method and
(ii) the quasi-Newton (secant) method,
starting at (1) $x = -1$, (2) $x = -0.5$, and (3) $x = 0.0$.

(b) Determine the convexity or concavity of the following objective functions:

(i) $f(x_1, x_2) = (x_1 - x_2)^2 + x_2^2$
(ii) $f(x_1, x_2, x_3) = x_1^2 + x_2^2 + x_3^2$

(12)

Contd ............ P/3
7. (a) Minimize \( f = x_1^2 + x_2^2 + 10x_1 + 20x_2 + 25 \)

Subject to: \( x_1 + x_2 = 0 \)

Using the lagrange multiplier technique. Calculate the optimum values of \( x_1, x_2, \lambda, \) and \( f. \) \hfill (15)

(b) Use a penalty function

Minimize: \( x_2^2 - x_1^2 \)

Subject to: \( x_1^2 + x_2^2 = 4. \) \hfill (15)

8. (a) A refinery has available two crude oils that have the yields shown in the following table. Because of equipment and storage limitations, production of gasoline, kerosene, and fuel oil must be limited as also shown in this table. There are to plant limitations on the production of other products such as gas oils. The profit on processing crude #1 is $1.00/bbl and on crude #2 it is $0.70/bbl. Find the approximate optimum daily feed rates of the two crudes to this plant via a simplex method. \hfill (18)

<table>
<thead>
<tr>
<th>Crude</th>
<th>Volume percent yields</th>
<th>Maximum allowable product rate (bbl/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crude #1</td>
<td>Crude #2</td>
</tr>
<tr>
<td>Gasoline</td>
<td>65</td>
<td>31</td>
</tr>
<tr>
<td>Kerosene</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>24</td>
<td>60</td>
</tr>
</tbody>
</table>

(b) What are the shadow prices for incremental production of gasoline, kerosene, and fuel oil? Suppose the profit coefficient for crude #1 is increased by 10 percent and crude #2 by 5 percent. Which change has a larger influence on the objective function? \hfill (12)
Figure Schematic diagram of Q1(b)

Figure Schematic diagram of Q4(a)
SECTION – A

There are FOUR questions in this section. Answer any THREE.

1. (a) Transform the x component of equation of motion given below into Navier-stokes equation and Euler equation by making necessary assumptions and simplifications:

\[ \frac{\partial (\rho v_x)}{\partial t} = - \frac{\partial (\rho v_x v_y)}{\partial x} + \frac{\partial (\rho v_x v_y)}{\partial y} + \frac{\partial (\rho v_y v_z)}{\partial z} - \frac{\partial (\rho v_y v_z)}{\partial y} + \frac{\partial (\rho v_z v_y)}{\partial z} \]

(b) What are the conditions required to be maintained between two systems to make it dynamically similar?

2. (a) A fluid is flowing through a long horizontal cylindrical tube of radius R and length L. Find the time smooth velocity distribution for turbulent flow using Prandtl mixing length relation. Prandtl’s mixing length relation can be defined as:

\[ \tau_{xy} = -\rho \frac{d \bar{v}_y}{dy} \frac{d \bar{v}_x}{dy} \]

All the symbols used in the above relation have their usual meaning.

2. (b) In a gas absorption experiment, a viscous fluid flows upward through a small circular tube and then downward on the outside as shown in figure for Q. 2(b). Set up a momentum balance over a shell of thickness \( \Delta r \) in the film.

(i) Determine the velocity distribution in the film.

(ii) Obtain an expression for the volume flow rate of flow in the film.

(c) State the comparison of momentum, mass and heat transport process in laminar region.

3. (a) Determine \( V_0(r) \) between two coaxial cylinders of radii R and kR rotating at angular velocities \( \Omega_0 \) and \( \Omega_r \), respectively. Assume the space between cylinders is filled with as incompressible isothermal fluid in laminar flow.

(b) Explain Taylor-Prandtl analogy for heat and momentum transport and show that

\[ St_n = \frac{1}{2} \frac{C_f}{1 + \frac{U_L}{U_m} (\rho_r - 1)} \]

Extend the analogy for mass transfer in turbulent flow.

Contd ............. P/2
4. A semi-infinite body of liquid with constant density and viscosity is bounded below by a horizontal surface. Initially the fluid and solid are at rest. Then at time \( t = 0 \), the solid surface is set in motion in the positive x direction with velocity \( v_0 \) as shown in Figure for Q. 4. Find the velocity \( v_x \) as a function of \( y \) and \( t \). Clearly mention all your assumptions.

\[ = 2 = \]

\[ \text{CHE 453} \]

5. (a) Heat is flowing through an annular wall of inside radius \( r_0 \) and outside radius \( r_1 \). The thermal conduction varies with temperature \( K_0 \) at \( T_0 \) and \( K_1 \) at \( T_1 \).

(i) Develop an expression for the heat flow through wall at \( r = r_0 \).

(ii) Show that for small value of \((r_1 - r_0)\),

\[ Q_0 = 2\pi r_0 L \left( \frac{k_0 + k_1}{2} \right) \left( \frac{T_0 - T_1}{r_1 - r_0} \right) \]

(b) Discuss the commonest types of boundary conditions encountered in shell energy balance.

\[ \text{(35)} \]

\[ \text{SECTION B} \]

There are FOUR questions in this section. Answer any THREE.

6. (a) Determine the temperature distribution in an incompressible Newtonian fluid held between two coaxial cylinders, the outer one of which is rotating at a steady angular velocity \( \Omega_0 \) [See Fig. 6a]. The velocity distribution is given by

\[ v_\theta = \frac{\Omega_0 k_0 R}{1 - k} \left( \frac{r}{k_0 R} - \frac{k R}{r} \right) \]

Make appropriate assumptions to solve the problem.

(b) Define thermal diffusivity. Discuss the relationship of thermal diffusivity and heat capacity of a material.

\[ \text{(30)} \]

\[ \text{(30)} \]

\[ \text{(5)} \]

7. (a) Energy flux is a scalar quantity while momentum is a vector quantity. True/False. Explain your answer.

(b) How does the thermal conductivity vary with the change of temperature for liquid and gases?

(c) Show that for a binary system, the molar diffusion fluxes of individual component \( J_{A}^x \) and \( J_{B}^x \) are equal of magnitude but are oppositely directed.

(d) Consider a catalytic reactor (Fig. 7d) in which the dissociation reaction is carried out are \( A \rightarrow 2B \). With necessary assumptions, develop the differential mole balance equation and find the concentration profile of a hypothetical gas film.

\[ \text{(7)} \]

\[ \text{(7)} \]

\[ \text{(16)} \]

Contd .......... P/3
8. (a) Compare Fick's law of diffusion with Newton's law of viscosity and Fourier's law of thermal conductivity. To what extent are these three relations analogous?

(b) When is mass fraction equal to mole fraction?

(c) Consider absorption of gas A by a laminar falling film of B as shown in Fig. 8c. with necessary assumption and shell materials balance (i) Show that

\[ \nu_m \left[ 1 - \left( x / \delta \right)^2 \right] \frac{\partial C_A}{\partial z} = D_{AB} \frac{\partial^2 C_A}{\partial x^2} \]

(ii) What are the boundary conditions required to solve this PDE?
$= 4 =$

$t < 0$
Fluid at rest

$t = 0$
Wall set in motion

$t > 0$
Fluid in unsteady flow

Fig for Q. 4
The Equations of Change in Curvilinear Coordinates

TABLE 3.4-1
THE EQUATION OF CONTINUITY IN SEVERAL COORDINATE SYSTEMS

Rectangular coordinates \((x, y, z)\):

\[
\frac{\partial p}{\partial t} + \frac{\partial}{\partial x}(\rho u_x) + \frac{\partial}{\partial y}(\rho u_y) + \frac{\partial}{\partial z}(\rho u_z) = 0
\]  

(A)

Cylindrical coordinates \((r, \theta, z)\):

\[
\frac{\partial p}{\partial t} + \frac{1}{r} \frac{\partial}{\partial r}(\rho u_r) + \frac{1}{r} \frac{\partial}{\partial \theta}(\rho u_\theta) + \frac{\partial}{\partial z}(\rho u_z) = 0
\]  

(B)

Spherical coordinates \((r, \theta, \phi)\):

\[
\frac{\partial p}{\partial t} + \frac{1}{r^2} \frac{\partial}{\partial r}(\rho u_r) + \frac{1}{r \sin \theta} \frac{\partial}{\partial \theta}(\rho u_\theta) + \frac{1}{r \sin \theta \partial \phi}(\rho u_\phi) = 0
\]  

(C)

---

TABLE 3.4-6
COMPONENTS OF THE STRESS TENSOR FOR NEWTONIAN FLUIDS IN CYLINDRICAL COORDINATES \((r, \theta, z)\)

\[
\tau_{rr} = -\mu \left[ 2 \frac{\partial u_r}{\partial r} - \frac{2}{3}(\nabla \cdot \mathbf{v}) \right]  
\]  

(A)

\[
\tau_{r\theta} = -\mu \left[ \frac{1}{r} \frac{\partial u_\theta}{\partial \theta} + \frac{u_r}{r} \right] - \frac{2}{3}(\nabla \cdot \mathbf{v})  
\]  

(B)

\[
\tau_{zz} = -\mu \left[ -2 \frac{\partial u_z}{\partial z} - \frac{2}{3}(\nabla \cdot \mathbf{v}) \right]  
\]  

(C)

\[
\tau_{r\phi} = \tau_{\phi r} = -\mu \left[ \frac{r}{r} \frac{\partial u_\phi}{\partial r} + \frac{1}{r} \frac{\partial u_\phi}{\partial \theta} \right]  
\]  

(D)

\[
\tau_{\theta\phi} = \tau_{\phi\theta} = -\mu \left[ \frac{\partial u_\phi}{\partial \theta} + \frac{1}{r} \frac{\partial u_\theta}{\partial \theta} \right]  
\]  

(E)

\[
\tau_{rr} = \tau_{zz} = -\mu \left[ \frac{\partial u_r}{\partial r} + \frac{\partial u_z}{\partial z} \right]  
\]  

(F)

\[(\mathbf{v} \cdot \nabla) = \frac{1}{r} \frac{\partial}{\partial r}(ru_r) + \frac{1}{r} \frac{\partial u_\theta}{\partial \theta} + \frac{\partial u_\phi}{\partial \phi} \]  

(G)
TABLE 4-3
The Equations of Motion in Cartesian Coordinates (x, y, z)

\[ \frac{d^2(\mathbf{r})}{dt^2} = \mathbf{F} \]

\[ \frac{d}{dt} \left( \frac{d\mathbf{r}}{dt} \right) = \mathbf{F} \]

\[ \frac{d}{dt} \left( \frac{d\mathbf{r}}{dt} \right) = \mathbf{F} \]

\[ \frac{d}{dt} \left( \frac{d\mathbf{r}}{dt} \right) = \mathbf{F} \]

\[ \frac{d}{dt} \left( \frac{d\mathbf{r}}{dt} \right) = \mathbf{F} \]

\[ \frac{d}{dt} \left( \frac{d\mathbf{r}}{dt} \right) = \mathbf{F} \]

\[ \frac{d}{dt} \left( \frac{d\mathbf{r}}{dt} \right) = \mathbf{F} \]

\[ \frac{d}{dt} \left( \frac{d\mathbf{r}}{dt} \right) = \mathbf{F} \]

\[ \frac{d}{dt} \left( \frac{d\mathbf{r}}{dt} \right) = \mathbf{F} \]

\[ \frac{d}{dt} \left( \frac{d\mathbf{r}}{dt} \right) = \mathbf{F} \]

\[ \frac{d}{dt} \left( \frac{d\mathbf{r}}{dt} \right) = \mathbf{F} \]

\[ \frac{d}{dt} \left( \frac{d\mathbf{r}}{dt} \right) = \mathbf{F} \]

\[ \frac{d}{dt} \left( \frac{d\mathbf{r}}{dt} \right) = \mathbf{F} \]
The Equations of Change for Nonconservative Systems
SEASON – A

There are FOUR questions in this section. Answer any THREE.

1. (a) A PVT cell is charged with a pure liquid substance. Explain what will happen if the volume of the cell is increased gradually by a frictionless piston.
   (10)
(b) Draw a P-T diagram of a binary fluid mixture illustrating all its major features.
   (10)
(c) Explain Gas Cycling with appropriate diagrams.
   (10)
(d) What is a dry gas reservoir? Explain briefly.
   (5)

2. (a) Write down the reasons to remove water from natural gas.
   (5)
(b) Find the water content of a 0.9 gravity gas at 1500 pisa and 120°F.
   (10)
(c) An isochronal test is shown in Figure 2(c). Assume the well stabilize after 3 hours. Determine the following
   (6+6)
   (i) \( n \), \( C_{nab} \), and AoF
   (ii) Construct inflow performance curve.
   (d) What is performance coefficient? Why does it change with time and flow rate? How can various exponent of \( n \) of the deliverability equation indicate well bore flow condition?
   (4+4)

3. (a) Name three types of deliverability test method and explain how they are performed with appropriate sketches.
   (15)
(b) Write down the process description of adsorption and regeneration process of a two-tower solid bed dehydration plant.
   (12)
(c) In a glycol dehydration plant, the glycol to water circulation rate is 3.5 gal TEG/lb \( H_2O \). Lean glycol concentration = 99.5%. Determine the Rich glycol concentration. Specific Gravity of TEG = 1.111.
   (8)

4. (a) A gas made up of following components-
   25 lb methane
   4 lb ethane
   2 lb propane
   (15)
PMRE 413/CHE

Contd... Q. No. 4(a)

Calculate the following-
(i) Express the gas compositions in wt. fraction and mole fractions.
(ii) Apparent molecular wt. of gas.
(iii) Specific gravity of the gas.
(iv) Density of the gas at standard conditions.
(v) Gas compressibility factor of the gas at 150°F and 3,500 psia.
(vi) Gas formation volume factor at 150°F and 3,500 psia.
(vii) Viscosity of the gas at 200°F and 1 atmosphere pressure. Check Figures 4(a1) and 4(a2) for additional information.

Critical properties are given in Table 4(a)

<table>
<thead>
<tr>
<th>Component</th>
<th>Critical Temperature (°R)</th>
<th>Critical Pressure (psia)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>344</td>
<td>667</td>
</tr>
<tr>
<td>Ethane</td>
<td>550</td>
<td>708</td>
</tr>
<tr>
<td>Propane</td>
<td>666</td>
<td>616</td>
</tr>
</tbody>
</table>

(b) What is Associated and Non-associated Gas? Explain briefly. (8)
(c) Draw the phase equilibrium diagram for gas-water hydrate system. (12)

SECTION-B

There are FOUR questions in this section. Answer any THREE.

5. (a) Draw a typical Production pressure profile showing pressure drop across all the system elements. Derive a Christmas Tree and label the major components. (5+5)
(b) Provide a comparative analysis between Vertical and Horizontal separators. (5)
(c) Explain how Liquid carryover and Gas blowby are two potential operating hazards for Separators. (5)
(d) Determine the actual gas and oil capacity of a horizontal separator having a diameter of 36 in. and a seam to seam length of 14 ft given the following operating conditions:

- Gas Specific Gravity: 0.6
- Oil gravity: 40° API
- Operating Pressure: 1015 psi
- Operating Temperature: 60° F
- Retention time: 3 minutes
- Gas compressibility factor at given condition: 0.84
- Gas Viscosity: 0.013 cp
- \( C_d \): 1.1709
- Liquid droplet to be separated: 100 micron

Contd ......... P/3
6. (a) Why is gas sweetening required? Elaborate the classification of Sweetening processes.

(b) Differentiate between MEA and DEA as solvent for Amine process.

(c) To design an Amine process for Gas sweetening using DEA as solvent. Below information is available:

\[ Q_g = 90\text{MMscfd} \]
\[ \text{S.G.} = 0.6 \]
\[ \text{H}_2\text{S inlet} = 10 \text{ ppm} \]
\[ \text{H}_2\text{S outlet} = 4 \text{ ppm} \]
\[ \text{CO}_2 \text{ inlet} = 4.33\% \]
\[ \text{CO}_2 \text{ outlet} = 2\% \]
\[ C_0 \text{ (contactor)} = 0.689 \]
\[ \text{Droplet diameter} = 150 \text{ micron} \]
\[ \text{Gas Compressibility factor} = 0.84 \]
\[ P = 1000\text{psig} \]
\[ T = 100^\circ \text{F} \]

(i) Determine DEA circulation rate using 35% DEA and an acid loading of 0.5 mole acid/g mole DEA.

(ii) Determine preliminary height and diameter of DEA contact tower.

(iii) Calculate approximate reboiler duty with 250\(^\circ\)F reboiler temperature.

7. (a) Mention the composition and other properties of LNG. Illustrate the LNG value chain.

(b) Explain LNG re-gasification mechanism with sketches. Also mention the two types of LNG storage systems.

(c) The annual Natural gas demand of country X is 1.5 TCF. The shortage of gas supply is 50% which the government has decided to fulfill by importing LNG. If the capacity of an example LNG plant is 5 MTPA then how many of those would be required to meet the shortage of energy.

(d) Name the highest producing gas field in Bangladesh and its operating Company. Name the three producing companies under Petrobangla.
8. (a) For the following data given for a horizontal pipeline, predict gas flow rate in ft³/hr through the pipeline by applying trial and error method for friction factor calculation.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter of pipeline</td>
<td>16 in</td>
</tr>
<tr>
<td>Length</td>
<td>190 miles</td>
</tr>
<tr>
<td>Average temperature</td>
<td>80°F</td>
</tr>
<tr>
<td>Specific gravity of gas</td>
<td>0.63</td>
</tr>
<tr>
<td>Upstream pressure</td>
<td>1050 pisa</td>
</tr>
<tr>
<td>Downstream Pressure</td>
<td>430 pisa</td>
</tr>
<tr>
<td>Absolute roughness of pipe</td>
<td>0.0006 in</td>
</tr>
<tr>
<td>Standard temperature</td>
<td>60°F</td>
</tr>
<tr>
<td>Standard pressure</td>
<td>14.7 pisa</td>
</tr>
<tr>
<td>Average z factor</td>
<td>0.8533</td>
</tr>
<tr>
<td>Viscosity of gas</td>
<td>0.0097 cp</td>
</tr>
<tr>
<td>Tolerance limit</td>
<td>1500 ft³/hr</td>
</tr>
</tbody>
</table>

(b) Give 5 examples of both Drilling and Produced Water wastes.

(c) Explain Joule-Thomson process for NGL extraction (Use sketches).
Equations and other relevant information:

For Horizontal Separator

\[ dL_{\text{eff}} = 420 \left( \frac{TZQ_g}{P} \right) \left( \frac{\rho_g}{\rho_l - \rho_g} \right) \left( \frac{C_D}{d_m} \right)^{1/2} \]

Gas capacity constraint

\[ d^2L_{\text{eff}} = \frac{t_rQ_l}{0.7} \]

Liquid capacity constraint

\[ L_{ss} = L_{\text{eff}} + \frac{d}{12} \]

Gas capacity constraint

\[ L_{ss} = (4/3)L_{\text{eff}} \]

Liquid capacity constraint

\[ \rho_l = \rho_{\text{water}} \left( \frac{141.5}{131.5 + \text{API Gravity}} \right) \]

\[ \rho_g = 2.7 \frac{SP}{TZ} \]

For Amine process Design

\[ L_{\text{DHA}} = \frac{192Q_g \cdot MF}{c \cdot \rho \cdot A_L} \]

20% MEA = 8.41 lb/gal = 0.028 mole MEA/gal
35% DEA = 8.71 lb/gal = 0.029 mole DEA/gal

\[ d^2 = 5,040 \frac{TZQ_g}{P} \left( \frac{\rho_g}{\rho_l - \rho_g} \right) \left( \frac{C_D}{d_m} \right)^{1/2} \]

Typically for a stripper with 20 trays, the reboiler duties will be as follows:

MEA system—1,000 to 1,200 Btu/gal lean solution
DEA system—900 to 1,000 Btu/gal lean solution

For Pipeline Design

Weymouth Equation:

\[ q_h = \frac{3.237_b}{P_b} \sqrt{1 \left( \frac{p_1^2 - p_2^2}{D^5} \right)} \sqrt{\frac{1}{f} \left( 1.14 - 2 \log \left( \frac{e_D + 21.25}{N_{Re}^{0.9}} \right) \right)} \]
SECTION – A

There are FOUR questions in this Section. Answer Q. No. 1 and any TWO from the rest.

1. What is ‘Vernacular Architecture’? Critically discuss vernacular architecture of Bangladesh in terms of physiography of the land, climatic context, availability of building resources and construction techniques. (26)

2. “There is a strong relationship between domestic architecture and socio-cultural variables” – explain in reference to house form in Anatolia of Turkey and farm houses in Cameroons. (22)

3. How does climate shape architecture and urban settlement pattern? Discuss in reference to traditional Malay house, towns in Chinese loess belt and village of Al-Qasr in Egypt. (22)

4. Write short notes on the following (Any Two): (11×2=22)
   (a) Fujian Tulou, China.
   (b) Mudhif of Basra Plain, Iraq.
   (c) ‘Mongolian Ger’ and ‘Black tent’.

SECTION – B

There are FOUR questions in this Section. Answer Q. No. 5 and any TWO from the rest.

5. Write short notes on any three of the followings: (10×3=30)
   (a) Un-vernacular
   (b) Thinking re-vernacular
   (c) Dhaiji dewari construction
   (d) Transdisciplinary participatory action research
   (e) Changing factors in vernacular architecture.

6. (a) Briefly discuss Rapoport’s theory for the assessment of vernacular environments by discussing process characteristics and product characteristics. (8+12=20)
   (b) Explain the patterns of vernacular architecture of Bangladesh and its changes over places (rural, semi-urban and urban settings.)

Contd .......... P/2
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7. (a) Describe Undirectional windcatcher (MALQAF) and Multi-directional windcatcher (BADGIR) with necessary sketches. (10×2=20)
(b) Describe the earthquake resistant vernacular architecture in the Himalayas describing “Cator and Cribbage” and Taq (bhatar) construction with necessary sketches.

8. (a) “Architecture of critical regionalism is a product of distinctive local awareness, which catalyzed by a high level of critical self-consciousness to vernacular architecture” – (Kenneth Frampton). – Explain Critical Regionalism with example. (8+12=20)
(b) Explain the six points for an Architecture of Resistance by architectural historian-theorist Kenneth Frampton.

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SECTION – A

There are FOUR questions in this section. Answer any THREE.

1. (a) Describe why the concepts of clean rooms and containment areas are important in a biomanufacturing facility. State three ways by which a class 10,000 clean rooms might be maintained. (12)

(b) What are some disadvantages of using filter aids in downstream bioprocessing?

(c) An enzyme is to be recovered from disrupted bacteria cells using an aqueous two-phase extraction system on an industrial scale.

(i) Which method of disruption of cells would you use and why?

(ii) The initial culture volume is 5 litres. The aqueous two-phase polymer solution of volume 2 litres is added to this liquid: the volume of the bottom phase is 1 litre. The enzyme partition coefficient is $10^2$. Calculate the yield of the enzyme. (7+10)

2. (a) Describe briefly in your own words the five stages of biomanufacturing. OR Draw the block diagram involved in the five stages of biomanufacturing. (15)

DO NOT DO BOTH.

(b) Describe what you understand by step-wise and linear elution, and comment on its applicability. (6)

(c) The BIO-RAD company has the following table in its catalog for chromatographic resins.

(i) Comment on the use of such 'base bead chemistry' for making chromatographic resins.

<table>
<thead>
<tr>
<th>Product name</th>
<th>Base Bead chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHT ®</td>
<td>Ceramic</td>
</tr>
<tr>
<td>Nuvia ®</td>
<td>Acrylamido polymer</td>
</tr>
<tr>
<td>Macro Prep ®</td>
<td>Polymethacrylate</td>
</tr>
<tr>
<td>Biobead ®</td>
<td>Polystyrene</td>
</tr>
</tbody>
</table>

Contd ............ P/2
(ii) Copy and complete the following table.

<table>
<thead>
<tr>
<th>Common / Proprietary name of resin</th>
<th>Contact point with protein</th>
<th>Chromatographic type</th>
<th>Possible Eluting solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuvia-S</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Nuvia-Q</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>MacroPrep SUPrA</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>MacroPrep DEAE</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>MacroPrep t-butyl</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>BioBead Fine</td>
<td>?</td>
<td>?</td>
<td>Toluene</td>
</tr>
<tr>
<td>CHT Ceramic Hydroxyapatite</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

3. Consider the following chromatogram separating species 1 and 2

(a) Express the terms, Resolution ($R_d$), capacity factor of species 2 ($k_2$), separation factor ($\alpha$), and theoretical plate number ($N$) in terms of the expressions mentioned in the diagram.

(b) In chromatography, the resolution ($R_d$) between two peaks of the same base width, $w_b = w_{b1} = w_{b2}$ can be described as follows:

\[
R_d = \frac{\sqrt{N}}{4} \left( \frac{\alpha - 1}{\alpha} \right) \left( \frac{k_2}{1 + k_2} \right)
\]

Derive the above expression using the help of your definitions.

(c) If the resolution between two peaks is 1.1, the value of $k_2$ is 2.0 and $t_M$ is 1.5 min, what value of $k_2$ would be required to increase the resolution to 1.5? Comment on the changes made (do you think this increase of resolution was justified, given the changes that have to be made to $k_2$?)

4. (a) Pick any one optical and any one acoustic method of biosensing, discuss them in detail and write down their advantages and disadvantages.

Contd ............ P/3
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Contd ... Q. No. 4

(b) "In biosensors, it is often observed that an increase in sensitivity leads to a decrease in selectivity". From your knowledge of definition of these terms, do you think this statement is true? Why or why not?

(c) Discuss the 5 classes of detection elements in biosensors and mention their working principle.

SECTION – B

There are FOUR questions in this section. Answer any THREE.

5. (a) What is a cell receptor? Discuss the functions of some of the major receptors found in cell.

(b) With a neat schematic explain the steps involved in typical signal transduction process.

(c) A two-stage chemostat system is used for production of secondary metabolite. The volume of each reactor is 0.5 m$^3$; the flow rate of feed is 50 l$h^{-1}$. Mycelial growth occurs in the first reactor, the second reactor is used for product synthesis. The concentration of substrate in the feed is 10 g$l^{-1}$. Kinetic and yield parameters for the organism are:

$Y_{xs} = 0.5 \text{ kg kg}^{-1}$

$K_S = 1.0 \text{ kg m}^{-3}$

$\mu_{max} = 0.12 \text{ h}^{-1}$

$m_t = 0.025 \text{ kg kg}^{-1} \text{ h}^{-1}$

$q_p = 0.16 \text{ kg kg}^{-1} \text{ h}^{-1}$

$Y_{ps} = 0.85 \text{ kg kg}^{-1}$

Assume that product synthesis is negligible in the first reactor and growth is negligible in the second reactor.

(i) Determine the cell and substrate concentrations entering the second reactor.

(ii) What is the overall substrate conversion?

6. (a) How is biorefinery different from typical refinery? Discuss the basic differences between these two.

(b) With simple schematics discuss the salient features of different levels of protein structure.

(c) List the typical steps followed during traditional gene cloning. Explain the differences between cloning and expression vectors.

7. (a) Discuss the importance of live cell microscopy over traditional approaches of biological signal quantification.
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Contd... Q. No. 7

(b) What are the purposes of image analysis? List the basic steps involved in image analysis.

(c) What is critical dissolved oxygen concentration? Escherichia coli is cultured in a bioreactor at 20°C for production of antibody. The oxygen requirement is 0.08 mol l⁻¹ h⁻¹; the critical oxygen concentration is 4 μM. The solubility of oxygen in the fermentation broth can be assumed same as in water at that temperature. Solubility of oxygen in water under 1 atm air pressure is 7.25×10⁻³ kg/m³. What is the minimum aeration capacity necessary to sustain this culture if air at approximately 1 atm pressure is supplied? What aeration capacity is required if pure oxygen is used instead of air? (3+13=16)

8. (a) What are the possible cloning problems related to re-ligation and misorientaion? How would you deal with the issues?
(b) Design two 16-nucleotide long primers for the following gene of interest (underlined). List the amino acid that can be expressed from this gene of interest.

5'CTTACGTA
ATGGAAACGCGTTACGATCGTACATACGGTTCACATCGAGTAA ACGATACG 3'

(c) Write down note on the followings:
(i) Airlift Bioreactor
(ii) Aseptic operation
(iii) Biodiesel production.

(5×3=15)