2014-15
B.TECH. (SUMMER SEMESTER) EXAMINATION
CHEMICAL ENGINEERING
CHEMICAL PROCESS INDUSTRIES-I
CH-320

Maximum Marks: 60 Credits: 04 Duration: Three Hours

Answer all the questions. Assume suitable data if missing. Notations used have their usual meaning.

Q.No. Question M.M.

1(a) What do you mean by Industrial Gases? Explain briefly about properties and industrial applications of Oxygen. [01+05]

OR

1(a)' Mention important industrial applications of soda Ash Outline various stages in the manufacture of soda Ash by Solvay process. [02+04]

1(b) What are different methods for the manufacture of Acetic Acid. Outline the various steps in the manufacture of Sulphuric acid along with chemical Reactions by contact process. [04+04]

OR

1(b)' Discuss the important properties of Soda Ash with respect to health and safety. Explain briefly the production of CO₂ with the help of PFD. [03+05]

2(a) List various steps involved in the manufacture of Ammonia by steam reforming process. [03]

2(b) What are the major engineering problems associated in the production of Urea. [05]

2(c) Explain briefly about the production of superphosphate with the help of process flow diagram specifying process conditions. [07]

OR

2'(a) What are pesticides? How pesticides are classified? List different methods of applications of pesticides? [01+04+03]

2'(b) Explain briefly about compound fertilizers. [07]

3(a) What is Portland cement? Explain a suitable method for production of Portland cement. [07]

3(b) What do you mean by ceramics? What are important raw material used in ceramic production classify various type of ceramics. [02+03+03]

4 Explain with the help of flow diagram industrial production of starch. [15]
Answer all the questions.
Assume suitable data if missing.
Notations used have their usual meaning.

Q.No. Question M.M.
1(a) Explain the production of Methanol with the help of flow diagram along with process conditions. [08]
(b) What are the important properties of Ethylene oxide (EO)? What is its specification as per BIS? [04]
(c) List different industrial application of Aniline. [03]

OR

1'(a) Compare Air based and Oxygen based processes for the production of Ethylene oxide EO w.r.t. different parameters.
1'(b) Mention important industrial applications of BTX.
1'(c) Explain the direct hydration process for the manufacture of ethanol with the help of process flow diagram along with chemical reactions and process conditions.

2(a) What are the properties of natural rubber? What is meant by rubber compounding? Explain the manufacturing process of SBR. [2+2=7]
2(b) Differentiate between Sulfite and Sulfate Processes for Pulping of cellulose Fibers. [04]

OR

2'(a) How plastics are classified? Give examples of each category Explain with the help of process flow diagram the manufacturing of PVC? [3+6]

contd...
2*(b) Write Short notes on any one of the following:

1. Synthetic Fibre
2. Pulping of Bamboo

3(a) Explain with the help of sulfation/sulfonation process for the production of LABS used in the manufacture of synthetic detergent.

(b) Nickel preparation is the most vital part of hydrogenation of oil. Mention different methods for preparation of Ni catalyst to be used in hydrogenation Industry.

(c) List various industrial application of Glycerine.

4(a) How crude oil is defined? List different methods of classification of crude oil. Discuss the US Bureau of Mines method of classification of crude oil.

(b) List important petroleum products obtained from crude oil distillation.

(c) Explain the following:
   - Octane Number
   - Cetane Number
   - Smoke point
   - Viscosity Index
2014-15
B.TECH. (VI SEMESTER) EXAMINATION
CHEMICAL ENGINEERING
CHEMICAL PROCESS INDUSTRIES – I
CH 321N (Backlog)

Maximum Marks: 60  
Credits: 03  
Duration: Three Hours

Answer all the questions. 
Notations used have their usual meaning.

Q.No.  
Question  

1(a)  
What is the largest (quantity wise) ore of India? Describe the characteristics of Indian phosphate rock? Discuss the production of \( \text{H}_3\text{PO}_4 \) with the help of a process flow sheet, chemical reactions involved, and pertinent engineering problems.

OR

1(a')  
Discuss the manufacturing process of \( \text{H}_2\text{SO}_4 \) from a useful source of Sulphur giving the process flow sheet, reaction conditions, catalyst, and kinetics. What are the pertinent engineering problems?


1(b)  
What are various production methods of Caustic Soda? Discuss the modern method of manufacturing \( \text{NaOH} \) in India. Also describe the important engineering problems of this industry with possible solution.

OR

1(b')  
Compare the merits and demerits of manufacturing processes of Soda ash. Discuss with the help of a neat process flow sheet, the production steps, important variables affecting the process efficiency Which is largest producing unit of Soda ash in India?

2(a)  
Enlist the various sources of feed stock of hydrogen for manufacturing ammonia. Discuss Urea production by the latest technology, giving a neat process flow sheet.

contd... 2
and pertinent engineering problems. Enumerate some major producer of Urea in India. Also compare nitrogen contents present in various nitrogenous fertilizers.

2(b) What do you understand by a Bio fertilizer? Discuss one of the methods of manufacturing bio fertilizer along with it's agricultural applications. [05]

OR

2'(a) Explain precisely the merits of Di ammonium phosphate (DAP) over Urea. Discuss the manufacturing process of DAP in details with the help of a process flow diagram and their related engineering problems. Is triple super phosphate is better than DAP? If yes, explain why?[10]

2'(b) What are critical air and water pollutants emitted by fertilizer industries? Discuss the air emission and effluents guide lines for a nitrogenous fertilizer’s plants. [05]

3(a) Provide a list of important constituents of Portland cement? Discuss the manufacturing scheme of this cement furnishing a neat flow sheet, and reactions involved therein. What are air pollution and other problems of cement industries in India and suggest their possible remedies. [10]

3(b) Discuss briefly the chemical composition and applications of glass and ceramic materials which find good applications in chemical industries. [05]

4(a) The starch industry in India has very strong presence in industrial sector. Is it technology or economics which makes it so? Explain the manufacturing scheme of Starch with the help of a neat process flow sheet, pertinent engineering problems and reaction conditions. Also explain the significance of modified Starch and it’s derivatives in Indian market. [10]

4(b) Clearly differentiate between paints and dyes. Also explain their compositions and applications in chemical industries. [05]
Q.No. Question

1(a) Name the various levels at which the transport phenomena can be studied?
Write down the general momentum balance equation for steady flow. Explain the steps involved in transport analysis of any viscous flow problem.

1(b) An oil has a kinematic viscosity of $2 \times 10^{-4}$ m$^2$/s and density of $0.8 \times 10^3$ kg/m$^3$. What should be the mass flow rate (w) of the liquid for a falling film thickness (δ) of 2.5mm on a vertical wall per metre of vertical plate (Figure 1). Flow is taking place only due to force of gravity.

Derive the expression used and write down the assumptions made in the derivation. Also, show the balances on the elemental volume.
1(b') Two immiscible, incompressible liquids are flowing in a horizontal thin slit of length ‘L’ and width ‘W’ (shown in figure 2) under the influence of horizontal pressure gradient. The fluid rates are adjusted so that the slit is half filled with fluid I (more dense phase) and half filled with fluid II (less dense phase). The fluids are flowing sufficiently slow that the interface remain exactly planar. By applying differential momentum balance obtain the momentum flux and velocity profiles for each phase and draw them also. Write down the assumptions made:

![Figure 2]

2(a) A current of 250A is passing through a stainless steel wire having a diameter of 5.08mm. The wire is 2.5m long and has a resistance of 0.0843Ω. The outer surface is held constant at 428 K. The thermal conductivity is $k = 22.5$ W/m K. Calculate the centre-line temperature of the wire at steady state.

Derive the equation used.

OR

2(a') Consider the flow of an incompressible Newtonian fluid between coaxial cylinders [figure 3 (a)]. The surfaces of outer and inner cylinders are maintained at $T = T_0$ and $T = T_b$ respectively. As the outer cylinder rotates with angular velocity $\Omega$, each cylindrical shell of fluid "rubs" against an adjacent shell of fluid, thus producing heat. Rate of heat generation due to viscous heat dissipation per unit volume is given by $S_v$. Its magnitude depends upon the local velocity gradient.

If the slit width ‘b’ is small with respect to radius ‘R’ of the outer cylinder i.e curvature effects are ignored then problem in figure3(a) can be simplified as flow between two parallel plates, one of them is stationery and other one is
moving with velocity \( V' \) [figure 3(b)]. For this modified problem the viscous heat source is given by:
\[
S_v = \mu \left( \frac{d\nu}{dx} \right)^2
\]

Find the temperature distribution for the simplified problem.

---

**Figure 3(a)**

---

**Figure 3(b)**

---

2(b) An electric current of density I ampere is flowing through an electric wire of uniform cross-section with radius 'R' and electrical conductivity \( K_e \) ohm\(^{-1}\)cm\(^{-1}\), due to electrical dissipation some electrical energy is converted into heat energy. The rate of heat energy production per unit volume is given by \( S_e = I^2 / K_e \). At the wall \( T_w \) is unknown but the heat flux at the wall is given by Newton's Law of cooling, that is at \( r = R \): \( q_{|r=R} = h(T - T_{air}) \)

Where, \( T_{air} \) is the ambient temperature, which is known. Develop the temperature profile for the above system. Assume the heat transfer coefficient and thermal conductivity both to be constant.

**OR**

2(b') A steel pipe having inside diameter of 2.067 inch and wall thickness 0.154 inch, carrying steam is insulated with 2 inch of magnesia covered in turn with 2 inch cork. Estimate the heat loss per second per meter of pipe if the inner surface of the pipe is at 121\(^\circ\)C and the outer surface of the cork is at 33\(^\circ\)C. The thermal conductivities of the substances concerned are, Steel: 45.172 \( \frac{W}{m^\circ C} \), magnesia: 0.0692 \( \frac{W}{m^\circ C} \) and cork: 0.01519 \( \frac{W}{m^\circ C} \). Derive the expression used.

3(a) A droplet of liquid 'A' of radius \( r_1 \), is evaporating in the stagnant non-

Contd... 4.
isothermal gas film 'B' surrounding the droplet having radius, $r_2$, under the conditions of constant pressure at steady state. The concentration of species A in gas phase at $r_1$ is $x_{A1}$ and $x_{A2}$ at the outer edge of the film.

Inside the gas film temperature varies with the distance as: $\left( \frac{r}{r_1} \right) = \left( \frac{r}{r_3} \right)^n$ and diffusivity varies with temperature as: $\left( \frac{D_{AB}}{D_{AB,1}} \right) = \left( \frac{T}{T_1} \right)^{3/2}$. Where $T_1$ is the temperature at $r_1$ and $D_{AB,1}$ is the diffusivity at $T_1$.

Obtain the expressions for concentration profile of species 'A' in the film and rate of evaporation of 'A'.

3(b) Derive the continuity equation for the binary system consisting of components 'A' and 'B' in terms of mass and molar units.

4(a) Show that friction factor is the function of Reynold's Number. Derive the relation of friction factor and Reynold's Number for laminar flow.

4(b) i. A cylindrical tank of radius 'R' and its drainpipe of length 'L' and diameter 'D' are completely filled with heavy oil as shown in figure 4. At time $t=0$ the valve at the bottom of the drainpipe is opened. How long will it take to drain the tank if the flow in the drainpipe is laminar?

![Figure 4](image)

ii. A cylindrical tank of inside diameter 2 m and with a water level of 4 m is to be emptied by draining through drainpipe of length 4 m and diameter 5 cm. How long will it take to remove one-half of the contents? How long will it take to empty the tank?
1. 350,000 lbm/h of a light oil is to be cooled from 240°F to 150°F using cooling water with a range of 85°F to 120°F. A maximum pressure drop of 7 psi has been specified for each stream, and fouling resistances of 0.003 h.ft².°F/Btu for the oil and 0.001 h.ft².°F/Btu for the water are required. Fluid properties are given in the table below. Design a shell-and-tube heat exchanger for this service using Kern’s method.

Data Given:

<table>
<thead>
<tr>
<th>Fluid property</th>
<th>Oil at 195°F</th>
<th>Water at 102.5°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_p ) (Btu/lbm.°F)</td>
<td>0.55</td>
<td>1.0</td>
</tr>
<tr>
<td>( k ) (Btu/h. ft.°F)</td>
<td>0.08</td>
<td>0.37</td>
</tr>
<tr>
<td>( \mu ) (cP)</td>
<td>0.68*</td>
<td>0.72</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>0.80</td>
<td>0.99</td>
</tr>
<tr>
<td>( Pr )</td>
<td>11.31</td>
<td>4.707</td>
</tr>
</tbody>
</table>

\[ \mu_{oil} \text{ (cP)} = 0.03388 \exp\left[1965.6/T (\text{°R})\right] \]

1'. Design a gasketed plate heat exchanger for the heat duty set out in Question no. 1. Specify a flow arrangement of one pass : one pass.

2. Determine the size of a Kettle Reboiler for vaporizing the bottom product of a distillation column. The bottom product is of 66°API gravity and a small boiling range at 470 K and has a flowrate of 5 kg/s. 3 kg/s of vapour is formed at an operating pressure of 200 psig. Heat is supplied by 28 °API gas oil in the range from 570 K to 530 K and 120 psig operating pressure.

A pressure drop of 10 psi is permissible.

OR

2'. Design a tubular heat exchanger for the heat duty set out in Question no. 1. Specify a flow arrangement of two passes : two passes.
2'. A 20,000 lb/hr sugar solution at 180°F is to be concentrated from 12 to 30° Brix (degrees Brix is the per cent by weight of sugar in the solution) in a double-effect, forward-feed, calandria-type evaporator. Assuming that exhaust steam from a steam engine is available at 5 psig and the vacuum in the second effect is held at 23 in. Hg, estimate (a) steam economy; (b) surface of each body, assuming $U_D$ of 500 and 200 for first and second effects, respectively, and equal surface for each effect; (c) water required for a barometric condenser, assuming that 90°F water is available and a 10°F approach to condensing temperature is permitted.

3. Design a sieve plate type continuous distillation column (Calculate Diameter and Provisional Plate Design only) to recover acetone from a 50-50 mole % acetone-water mixture available at 30°C. The feed stream flow rate is 25,000 kg/h. The top product should contain at least 95 mole% acetone and the bottom product should contain <1 % acetone by mole. Consider reboiler as equivalent to one stage. This column is operated at atmospheric pressure (top tray). Column efficiency of 60% and pressure drop per plate of 1.25 kPa may be assumed. You can take the minimum liquid flow as 70% of the maximum rate both above and below the feed plate. The vapor liquid equilibrium (VLE) data for the acetone-water system at atmospheric pressure is provided in Table 2.

Data given:
Latent heat of water = 41,360 J/mol; latent heat of acetone = 28,410 J/mol; Specific heat of water = 75.3 J/mol°C (mean); Specific heat of acetone = 128 J/mol°C (mean).
Reflux ratio, $R = 2.5 \times R_{\text{min}}$ where $R_{\text{min}} = 0.67$ for $x_D = 0.95$.
(Assuming constant molar overflow)
Molar feed flow rate, $F$ = 657.9 kmol/h;
Top product, $D$ = 346.2 kmol/h;
Vapor flow rate above feed plate, $V$ = 926.2 kmol/h;
Top section liquid flow rate, $L$ = 580 kmol/h;
Bottom product: $B$ = 311.7 kmol/h;
Liquid flow rate below feed plate, $L'$ = 1285.7 kmol/h;
Vapor flow rate below feed plate, $V'$ = 974 kmol/h;
Total number of ideal tray = 6 (above feed) + 3 (below feed) = 9;
$x$ = Mole fraction of acetone in liquid;
y = Mole fraction of acetone in vapor;
BP: Bubble point.
4(a). Glauber’s salt, Na$_2$SO$_4$·10H$_2$O, is to be produced in a Swenson–Walker crystalliser by cooling to 290 K a solution of anhydrous Na$_2$SO$_4$ which is saturated at 300 K. If cooling water enters and leaves the unit at 280 K and 290 K, respectively, and evaporation is negligible, how many sections of crystalliser, each 3 m long, will be required to process 0.25 kg/s of the product? The solubilities of anhydrous Na$_2$SO$_4$ in water are 40 and 14 kg/100 kg water at 300 K and 290 K respectively, the mean heat capacity of the liquor is 3.8 kJ/kg K and the heat of crystallisation is 230 kJ/kg. For the crystalliser, the available heat transfer area is 3 m$^2$/m length, the overall coefficient of heat transfer is 0.15 kW/m$^2$ K and the molecular weights are Na$_2$SO$_4$·10H$_2$O = 322 kg/kmol and Na$_2$SO$_4$ = 142 kg/kmol.
4(b). Ratchford and Fisher found that methylacetoxypropionate decomposes on heating to form acetic acid and methyl acrylate:

\[ CH_3\text{COOCH}(CH_3)\text{COOCH}_3 \rightarrow CH_3\text{COOH} + CH_2 = CH\text{COOCH}_3 \]

The pyrolysis closely approximates a first-order irreversible reaction with a rate constant given by:

\[ k_1 = 7.8 \times 10^9 \exp \left( \frac{-38200}{RT} \right) \text{ sec}^{-1} \]

where \( T \) is expressed in degrees Kelvin and \( R \) in calories per gram mole per degree Kelvin.

If a plug flow reactor is used to carry out the pyrolysis, calculate the volume of pipe necessary to achieve 85% conversion of the raw material to products. The raw material enters at a temperature of 555 K and a pressure of 5 atm with a flow rate of 1000 lb/hr.

If three perfectly mixed continuous stirred tank reactors of equal volume were used in series flow instead, what would the required volume be?

Note: In both cases ideal gases may be assumed. In both cases the reaction occurs at constant temperature.
2014-15
III Year B.TECH., VI SEMESTER EXAMINATION
(Chemical Engineering)
Bioprocess Engineering
CH-335

Maximum Marks: 60
Credits: 04
Duration: Three Hours

Answer all the questions.
All parts of a question should be answered in a proper sequence.
Notations used have their usual meaning.

Q.No.

1(a) Discuss the present status and future prospects of Indian bioprocess industries with suitable examples. [06]

1(b) Discuss the various functions of a bioreactor which it has to perform for an industrial bioprocess? [06]

1(c) Show that the lactic acid bacteria can behave growth wise and non growth wise as well. [03]

OR

1'(a) Define and discuss with the help of a neat diagram, exponential and stationary phases of a typical batch growth curve for an industrial bioprocess. [07]

1'(b) Discuss Deindoerfer's classification of fermentation products. Explain with the help of graphs between substrate conc. and time. [08]

2(a) Derive the rate equation for an enzyme catalysed reaction with non-competitive inhibition. Discuss the effect of conc. of substrate, inhibitor and temperature on the rate. What is industrial significance of value of $K_m$ used in the rate equation? [10]

OR

2(a') An enzyme has competitive effect on substrate. Derive the rate equation of product formation for such reaction. Explain the experimental procedure to calculate the value of $K_m$. [10]

contd. ~ 2
2(b) Differentiate between the free and immobilised enzymes. Discuss the methods of entrapment and adsorption of enzyme immobilisation.

3(a) Write short notes on any two of the following:

i) Aeration number, Na  
ii) Power number, N_p in aerobic process  
iii) Diameter, d_b and velocity V_b of air bubble

3(b) What are the merits and demerits of various bioreactors used in bioprocess industries? Explain with line diagram of the bioreactors. Also discuss one of the industrial methods of sterilized air for production of Penicillin.

3(c) How will you calculate the concentration of cell, x with the help of substrate conc. for a bioprocess? Discuss the significance of it for industrial production.

4(a) Discuss the manufacturing scheme of Lactic acid giving process flow diagram, and purification along with applications of the product. Also explain the effect of temperature, carbon, and nitrogen sources at the rate of above fermentation.

4(b) What are various methods and substrates being used for production of ethanol world wide nowadays. Explain the second generation of ethanol fermentation with the help of specific procedure. Is it good enough for Indian distillery sector? Justify your answer.
2014-15
III Year B.TECH. EXAMINATION (back log)
(CHEMICAL ENGINEERING)
BIOPROCESS ENGINEERING
CH-336 N

Maximum Marks: 60
Credits: 04
Duration: Three Hours

Answer all the questions.
All parts of a question should be answered in a proper sequence.
Notations used have their usual meaning.

Q.No.  
1(a) Discuss the merits and demerits of a Biochemical reaction with suitable examples. [06]
1(b) Discuss the composition of medium (macro and micro nutrients) for cultivation of a microorganism for a industrial bioprocess. [06]
1(c) Enumerate three industrial bioproducts fermented by three micro organisms. [3]

OR

1'(a) Define and discuss with the help of a neat diagram, two important phases of a typical batch growth curve of an industrial bioprocess. [07]
1'(b) Discuss Deindoefer's classification of fermentation products. Explain with the help of graphs (substrate conc. vs time) [08]

2(a) Derive Michaelis-Menten equation for an enzyme catalysed reaction. Discuss the effect of conc. of substrate, inhibitor and temperature on it. How will you calculate the value of \( K_m \) used in the rate equation? [10]

OR

2(a') An enzyme has competitive effect on substrate. Derive the rate equation of product formation for such reaction. [10]

2(b) Differentiate between free and immobilised cells. Discuss any two methods of cell immobilisation. [5]
3(a) Write short notes on any two of the following:

(i) Bubble aeration  (ii) Mechanical agitation, and (iii) Sterilization of medium

3(b) What is need of sterilized air in any bioprocess industry? Explain it. Also discuss one of the industrial methods of sterilized air for production of Penicillin.

3(c) How will you calculate the concentration of cell, x and dilution rate, D respectively for a bioprocess? Discuss their significance for industrial production.

4(a) Discuss the manufacturing scheme of citric acid giving process flow diagram, and purification along with applications of the product.

4(b) What are common methods of separations and increasing the concentration of fermented broth in down stream processing of bioprocess industries? Discuss any two methods to improve the concentration along with line diagram of the same.
1(a) Gaseous reactant A diffuses through a gas film and reacts on the surface of a solid according to a reversible first-order rate,

\[-r_A^\circ = k (C_{As} - C_{ Ae})\]

where \(C_{As}\) is the concentration of A in equilibrium with the solid surface. Develop an expression for the rate of reaction of A accounting for both the mass transfer and reaction steps.

1(b) Uniform sized spherical particles of \(\text{UO}_3\) are reduced to \(\text{UO}_2\) in a uniform environment with the following results:

<table>
<thead>
<tr>
<th>(t, \text{hr})</th>
<th>0.187</th>
<th>0.347</th>
<th>0.453</th>
<th>0.567</th>
<th>0.733</th>
</tr>
</thead>
<tbody>
<tr>
<td>(X_{b})</td>
<td>0.45</td>
<td>0.68</td>
<td>0.80</td>
<td>0.95</td>
<td>0.98</td>
</tr>
</tbody>
</table>

If reaction follows the shrinking core model, find the controlling mechanism and a rate equation to represent the reduction.

OR

1'(b) At high pressure \(\text{CO}_2\) is absorbed into a solution of \(\text{NaOH}\) in a packed column. The reaction is as follows:

\[\text{CO}_2 + 2\text{NaOH} \rightarrow \text{Na}_2\text{CO}_3 + \text{H}_2\text{O}, \quad \text{with} \quad -r_{AI} = kC_AC_B\]

Let \(\text{CO}_2\) and \(\text{NaOH}\) be denoted by A and B respectively. Find the rate of absorption, the controlling resistance, and what is happening in the liquid film, at a point in the column where \(p_A = 10^5\) Pa and \(C_B = 500\) mol/m\(^3\).
Data: \( k_{eq} = 10^{-4} \text{ mol/m}^2 \cdot \text{s} \), s. Pa
\( k_A = 1 \times 10^{-4} \text{ m/s} \)
\( a = 100 \text{ m}^{-1} \)
\( k = 10 \text{ m}^3 / \text{mol} \cdot \text{s} \)
\( H_A = 25000 \text{ Pa} \cdot \text{m}^3 / \text{mol} \)
\( D_A = 1.8 \times 10^{-9} \text{ m}^2 / \text{s} \)
\( D_B = 3.06 \times 10^{-9} \text{ m}^2 / \text{s} \)
\( f_l = 0.1 \)

2(a) Experimental data for the gas-phase reaction

\[ \text{A} + \text{B} \rightarrow \text{C} \]

is shown in the following table. The limiting step in the reaction is known to be irreversible, so that the overall reaction is irreversible. The reaction was carried out in a differential reactor to which all the species A, B, and C were fed.

<table>
<thead>
<tr>
<th>Run</th>
<th>( P_A ) (atm)</th>
<th>( P_B ) (atm)</th>
<th>( P_C ) (atm)</th>
<th>Reaction Rate (mol) / (g cat . s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>0.114</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>10</td>
<td>2</td>
<td>1.140</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>1</td>
<td>2</td>
<td>0.180</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>20</td>
<td>2</td>
<td>2.273</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>20</td>
<td>10</td>
<td>0.926</td>
</tr>
<tr>
<td>6</td>
<td>20</td>
<td>1</td>
<td>2</td>
<td>0.186</td>
</tr>
<tr>
<td>7</td>
<td>0.1</td>
<td>1</td>
<td>2</td>
<td>0.0243</td>
</tr>
</tbody>
</table>

(i) Sketch the reaction rate \((-r'_A)\) as a function of \( P_A \), \( P_B \), and \( P_C \) separately on a single graph (at constant partial pressure of other two species).

(ii) From your observations in part (i), which species would appear in the numerator of the rate expression, and which species in the denominator? To what power is the denominator raised? Single-site/double-site?

2(b) The chemical vapour deposition (CVD) of silica from silane (SiH\(_4\)) is believed to proceed by the following irreversible two-step mechanism (results of a new study):

\[
\text{SiH}_4 + \text{S} \rightarrow k_1 \rightarrow \text{SiH}_2 \cdot \text{S} + \text{H}_2
\]

\[
\text{SiH}_2 \cdot \text{S} \rightarrow k_2 \rightarrow \text{Si} + \text{H}_2
\]

This mechanism is somewhat different in that while SiH\(_2\) is irreversibly adsorbed, it is highly reactive. In fact, adsorbed SiH\(_2\) reacts as fast as it is formed (PSSII), so that it can...
be assumed to behave as an active intermediate. Determine if this mechanism is consistent with the following data:

\[
\begin{align*}
\text{Deposition Rate (mm/min)} & : 0.25 \quad 0.5 \quad 0.75 \quad 0.80 \\
\text{Silane Pressure (mTorr)} & : 5 \quad 15 \quad 40 \quad 60
\end{align*}
\]

OR

2(b') Gas oil is being catalytically cracked in a screw type conveyor moving-bed reactor by a 2nd order rate law. The catalyst is decaying by a 1st order kinetics. Pure feed enters in the reactor at a flow rate of \( F_{Ao} \) mole/dm\(^3\). Total weight of the catalyst at any time in the MBR is \( W \) kg and it is passing down the reactor at a velocity of \( U_s \) kg/min. Derive an equation for the conversion of the gas oil in the MBR in terms of Damköhler number \( (D_{a2}) \) and dimensionless decay time, \( \lambda \).

\[
A \rightarrow \text{Products}
\]

\[
X = D_{a2} \times (1 - \exp(-\lambda))/\lambda + D_{a2} \times (1 - \exp(-\lambda))
\]

3(a) A first-order, heterogeneous, irreversible reaction is taking place within a catalyst pore which is plated with platinum entirely along the length of the pore. The reactant concentration at the plane of symmetry (equal distance from the pore mouths) of the pore is equal to one-tenth the concentration of the pore mouth. The concentration at the pore mouth is 0.001 g mol / dm\(^3\), the pore length \( (2L) \) is 2 \times 10\(^{-3}\) cm, and the diffusion coefficient is 0.1 cm\(^2\)/s.

\[
A \rightarrow B
\]

What is the concentration of reactant at a distance of 3 \times 10\(^{-4}\) cm in from the external pellet surface? To what diameter should the pellet be reduced if the effectiveness factor is to be 0.8?

3(b) The following kinetic data on the reaction \( A \rightarrow R \) are obtained in an experimental packed bed reactor using various amounts of catalyst and a fixed feed rate \( F_{Ao} = 10 \) kmol/hr.

<table>
<thead>
<tr>
<th>( W, ) kg cat</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X_A )</td>
<td>0.12</td>
<td>0.20</td>
<td>0.27</td>
<td>0.33</td>
<td>0.37</td>
<td>0.41</td>
<td>0.44</td>
</tr>
</tbody>
</table>

(i) Find the reaction rate at 40 % conversion.

(ii) In designing a large packed bed reactor with feed rate \( F_{Ao} = 400 \) kmol/hr, how much catalyst would be needed for 40 % conversion?
4(a) Briefly explain how you can extract the rate constants of the Michaelis-Menten equation in the enzyme fermentation reaction kinetic studies.

4(b) Calculate the mass flux of reactant A to a single catalyst pellet 1 cm in diameter suspended in a large body of liquid. The reactant is present in dilute concentrations, and the reaction is considered to take place instantaneously at the external pellet surface ($C_{A_{in}} = 0$). The bulk concentration of the reactant is 1.0M, and the free-system liquid velocity is 0.1 m/s. The kinematic viscosity is 0.5 centistoke (cS; 1 centistoke = $10^{-6}$ m$^2$/s), and the liquid diffusivity of A is $10^{-10}$ m$^2$/s. Under the circumstances of this system, mass transfer coefficient for single spheres can be calculated from the Frossling correlation.

OR

What is the significance of Thoenes & Kramers correlation in the study of external resistance to mass transfer in heterogeneous catalytic reactions?

A spherical mono-dispersed solid particle is dissolving in an excess liquid solvent. The rate of dissolution is first order in the solvent concentration, C. Show that the following conversion-time relationships hold.

<table>
<thead>
<tr>
<th>Rate-Limiting Regime</th>
<th>Conversion Time relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface reaction</td>
<td>$1 - (1 - X)^{1/3} = \alpha t / D_i$</td>
</tr>
<tr>
<td>Mass transfer</td>
<td>$D_i / 2D^* \left[ 1 - (1 - X)^{2/3} \right] = \alpha t / D_i$</td>
</tr>
<tr>
<td>Mixed</td>
<td>$\left[ 1 - (1 - X)^{1/3} \right] + D_i / 2D^* \left[ 1 - (1 - X)^{2/3} \right] = \alpha t / D_i$</td>
</tr>
</tbody>
</table>

Pharmacokinetic analysis of the dissolution process has given the following diameter-time relationship:

$$D_i - D + (1/2 D^*) [D_i^2 - D^2] = \alpha t$$

Where,

$$k_c = 2 D_e / D, \quad D^* = 2 D_e / k_r, \quad \alpha = 2 k_r C_A / \rho$$