A co-current shell and tube heat exchanger at steady state is shown in fig. I. The hot stream is following through the tube side where as the cold fluid is flowing through the shell side. Assume that the heat transfer between the fluids across the tube is governed by an overall heat transfer coefficient $u$ and across the perimeter $P$.

(i) Writing the appropriate equations regarding energy balance reduce the equations to vector form.
(ii) Show that this problem in an Initial Value Problem.

OR

1'. Single-phase first order reaction shown below is taking place in a batch reactor.

\[
\begin{array}{c}
A \\
\downarrow \quad k_2 \\
B \quad k_1 \\
\downarrow \quad D \\
C \\
\end{array}
\]

The reactor is assumed to be isothermal. The rate constants $k_1$, $k_2$ and $k_3$ are constants.

(i) Writing the appropriate balance equations for species $C_A$, $C_B$, $C_C$ and $C_D$ reduce the equations to vector form.
(ii) Show that it is an Initial Value Problem.

2. Along with the appropriate diagrams, explain the following terms:

(i) METRICS
(ii) NORM
(iii) INNER PRODUCTS

OR

2'. Linear dependence plays a pivotal role in determining the state of a chemical plant. A particulate state of the chemical plant is shown by the following metric form. Analyse the problem in terms of linear dependence of the variables involved.
3. Solve the following P faftian differential equation:

\[
\begin{bmatrix}
-1 & -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & -1 & -1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & -1 & -1 & 0 & 0 \\
0 & 1 & 0 & 0 & -1 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & -1
\end{bmatrix} \begin{bmatrix}
F_1 \\
F_2 \\
F_3 \\
F_4 \\
F_5 \\
F_6 \\
F_7 \\
F_8 \\
F_9
\end{bmatrix} = 0
\]

4. Initially a tank contains 100 litres of fluid A with a concentration of 5 kg/litre. Within the tank, A decomposes by a second order reaction. Reaction rate constant \( k = 0.1 \) litre per gmole per sec. Develop an expression to relate the outlet concentration as a function of time for the following cases.

(i) A stream of inerts flows into the tank at a rate of 10 litres/min.

(ii) A fluid of concentration 1 kg/litre flows into the tank at a rate of 10 litre per min.

(iii) Reduce the equation obtained into Bernoulli's equation and Riccati's equations.

Fig 1: Shell & Tube Heat Exchanger
2011 – 2012
M.TECH. (I SEMESTER) EXAMINATION
(CHEMICAL ENGINEERING)
CHEMICAL REACTOR ANALYSIS AND DESIGN
(CH – 613)

Maximum Marks : 60
Duration : Three Hours

"Students governed by the old ordinances will be examined out of 75 marks and their obtained marks shall be proportionately raised."

1. (a) Show that the greatest possible value of $X$ is the least positive value of 
\[
\frac{N_b}{(-\alpha)_{\alpha}}
\]
[03]

(b) At constant Pressure, a reacting ideal gas mixture changes volume both by a change in the total numbers of moles and by a change in temperature proportional to the extent. If the latter is linear, $T = T_0 + Jx$,
Show that:
\[
\frac{d\ln V}{dt} = \left(\frac{\alpha}{C} + \frac{NJ \cdot R}{P}\right) r
\]
Here $R$ is the gas constant.
[06]

(c) How many of the following reactions are independent? Show by Matrix analysis:
[06]

(i) 
\[
\begin{align*}
2\text{NaCl} + \text{H}_2\text{SO}_4 &= \text{Na}_2 \text{SO}_4 + 2\text{HCl} \\
\text{Na}_2\text{SO}_4 + 4\text{C} &= \text{Na}_2\text{S} + 4\text{CO} \\
\text{Na}_2\text{S} + \text{CaCO}_3 &= \text{Na}_2\text{CO}_3 + \text{CaS}
\end{align*}
\]

(ii) 
\[
\begin{align*}
4\text{NH}_3 + 5\text{O}_2 &= 4\text{NO} + 6\text{H}_2\text{O} \\
4\text{NH}_3 + 3\text{O}_2 &= 2\text{N}_2 + 6\text{H}_2\text{O} \\
4\text{NH}_3 + 6\text{NO} &= 5\text{N}_2 + 6\text{H}_2\text{O} \\
2\text{NO} + \text{O}_2 &= 2\text{NO}_2 \\
2\text{NO} &= \text{N}_2 + \text{O}_2 \\
\text{N}_2 + 2\text{O}_2 &= 2\text{NO}_2
\end{align*}
\]

2. (a) The catalytic dehydration of methanol (ME) to form dimethyl ether (DME) and Water was carried out over an ion exchange catalyst [K. Klusacek, collection Czech. Chem. Commun. 49, 170 (1984)]. The packed bed was initially filled with nitrogen and at $t = 0$, a feed of pure methanol vapour entered the reactor at 413 K, 100 kPa and 0.2 cm$^3$/s. The following partial pressures were recorded at the exit to the differential reactor containing 1.0 gm of catalyst in 4.5 cm$^3$ of reactor volume.
[09]

Contd.....2
<table>
<thead>
<tr>
<th>t(s)</th>
<th>0</th>
<th>10</th>
<th>50</th>
<th>100</th>
<th>150</th>
<th>200</th>
<th>300</th>
</tr>
</thead>
<tbody>
<tr>
<td>P_{N_2} (kPa)</td>
<td>100</td>
<td>50</td>
<td>10</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>P_{ME} (kPa)</td>
<td>0</td>
<td>2</td>
<td>15</td>
<td>23</td>
<td>25</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>P_{H_2O} (kPa)</td>
<td>0</td>
<td>10</td>
<td>15</td>
<td>30</td>
<td>35</td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td>P_{DME} (kPa)</td>
<td>0</td>
<td>38</td>
<td>60</td>
<td>45</td>
<td>40</td>
<td>37</td>
<td>37</td>
</tr>
</tbody>
</table>

Discuss the implications of these data.

(b) Write a brief note on straight – through transport Reactors.

OR

2'. (a) A recent study of the chemical vapour deposition of silica from silane (SiH₄) is believed to proceed by the following irreversible two step mechanism:

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

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

This mechanism is somewhat different in that while SiH₂ is irreversibly adsorbed, it is highly reactive. Infact, adsorbed SiH₂ reacts as fast as it is formed, so that it can be assumed to behave as an active intermediate. Determine if this mechanism is consistent with the following data:

<table>
<thead>
<tr>
<th>Deposition (mm/min)</th>
<th>0.25</th>
<th>0.5</th>
<th>0.75</th>
<th>0.80</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silane Pressure (morr)</td>
<td>5</td>
<td>15</td>
<td>40</td>
<td>60</td>
</tr>
</tbody>
</table>

(b) Discuss Langmuir-Hinshelwood kinetics with the help of a suitable example?

3. Deduce the expression:

\[ \eta = \frac{3}{\Phi_1^2} (\Phi_1 \coth \Phi_1 - 1) \]

for a first order reaction in a spherical catalyst pellet, where

\[ \Phi_1 = \text{Thiele Modulus} \]

\[ \eta = \text{internal effectiveness factor}. \]

Also, discuss how the effectiveness factor is affected by thiele modulus?

OR

3'. (a) What are Multiphase Reactors? List the industrial application of multiphase rectors along with examples.

(b) Dilute A diffuses through a stagnant liquid film onto a plane surface consisting of B, reacts there to produce R which diffuses back into the mainstream. Develop the overall rate expression for the liquid-solid reaction.

\[ A(\ell) + B(s) \rightarrow R(\ell) \]

\[ r_a^* = k_s C_A \]

using standard notations.
4. (a) What are the factors that must be considered in the selection and design of contactors for fluid-fluid reactions? [05]

(b) Gaseous A absorbs and reacts with B in liquid according to

\[ A(g \rightarrow \ell) + B(\ell) \rightarrow R(\ell) \ ; \ -r_A = kC_A C_B \]

in a packed bed under conditions where

\[
K_{Ag} a = 0.1 \text{ mol / hr.m}^2 \text{ reactor.Pa} \\
K_{Al} \alpha = 100 \text{ m}^3 \text{ liquid/m}^3 \text{ reactor.hr} \ , \ \alpha = 100 \text{ m}^2/\text{m}^3 \text{ reactor} \\
f = 0.01 \text{ m}^3 \text{ liquid/m}^3 \text{ reactor.} \ D_{A\ell} + D_{B\ell} = 10^{-6} \text{ m}^2/\text{hr.}
\]

At a point in the reactor where \( P_A = 100 \text{ Pa} \) and \( C_B = 100 \text{ mol / m}^3 \text{ liquid} \)
\[ K = 10 \text{ m}^3 \text{ liquid / mol.hr} \ , \ H_A = 10^3 \text{ Pa.m}^3 \text{ liquid / mol} \]

(i) Locate the resistance to reaction?

(ii) Determine the behaviour in the liquid film?

(iii) Locate the reaction zone?

(iv) Calculate the rate of reaction in mol / hr.m\(^3\) of reactor?

See Figure 1 for \( M_H \) and \( E \).

[ Figure enclosed ]

Contd......4
If $E_i > 5M_H$ we then have pseudo first order reaction by the $G/L$ interface in which case 
\[ E \equiv M_H \]
More precisely 
\[ E = M_H \left(1 - \frac{M_H - 1}{2E_i}\right) + \ldots \]

**Figure 1**

\[ M_H = \sqrt{D_A k_C B} \]

If $E_i < \frac{M_H}{5}$ then we have instantaneos reaction at a plane on the $L$ film in which case 
\[ E \equiv E_i \]
More precisely: 
\[ E \equiv E_i + \frac{E_i^2(E_i - 1)}{M_H^2} + \ldots \]
Note: Answer all the questions.

1. (a) Derive an expression to determine the thickness of thermal boundary layer, \( \delta_t \) when the liquid is flowing in a horizontal pipe and heated from outside. [10]

OR

(a') (i) Discuss various regions of flow if vapour and liquid phases are flowing in a vertical tube. [06]

(ii) Define an discuss the physical significance of Nusselt No., Nu and Schmidt No., Sc in the study of heat and mass transfer operations. [04]

(b) What do you understand by Euler's equations? Discuss it's significance in the study of momentum transfer operations. [05]

2. (a) Discuss with the help of a neat diagram, the boiling curve and Rohsenow's correlation to calculate the heat transfer coefficient for nucleate pool boiling. [06]

(b) What are recent techniques of enhancement of boiling heat transfer? Discuss any two methods for the same. Also discuss the mechanism of enhanced boiling heat transfer. [09]

OR

2'. (a) What are important properties of a fin that affect its efficiency? Derive an expression to evaluate the efficiency of a straight fin of uniform cross section and an adiabatic fin. [06]

(b) A steel tube is fitted with straight fins of following specifications:

(i) Tube = 0.0 = 54.0 mm (ii) Fin dia. = 72.0 mm (iii) Fin thickness = 2.84 mm

(iv) No. of fins = 245/m. Determine the heat loss per unit length of the tube when the surface temperature is 375 K and the surrounding temperature is 285 K. The heat transfer coefficient between the fin and gas is 32 w/m²K and thermal conductivity is 42 w/m.k. [09]

3. (a) Define the critical thickness of insulation. Derive an equation to explain the same. [05]
(b) What are merits and demerits of compact heat exchangers? Explain them with the help of a simple diagram of plate and frame heat exchanger.

(c) Derive an equation to calculate the time of heating of some liquid in a Jacketed vessel.

OR

(c') Hydrogen gas is maintained at 3 bars and 1 bar on opposite sides of a plastic membrane which is 0.3 mm thick. The temperature is 25°C and the binary diffusion coefficient of hydrogen in the plastic is $8.7 \times 10^{-8}$ m²/s. The solubility of hydrogen in the membrane is $1.5 \times 10^{-3}$ k mol/m³ – bar. What is the mass diffusive flux of hydrogen through the membrane?

4. (a) What are important parameters which affect the performance of a fluidised bed for heat transfer studies? How will you calculate heat transfer coefficient and pressure drop with the help of correlations?

(b) To maintain a pressure close to one atm. an industrial pipeline containing NH₃ gas is vented to ambient air. It is achieved by tapping the pipe and inserting a 3 mm dia. tube which extends for 20 m into atmosphere. With the entire system operating at 25°C, determine the mass rate of NH₃ lost to the atmosphere and the mass rate of contamination of the pipe with air.

Date: For NH₃-air at 25°C, $D_{AB} = 0.28 \times 10^{-4}$ m²/s.
2011-2012
M.TECH. (I SEMESTER) EXAMINATION
(CHEMICAL ENGINEERING)
PROCESS INTEGRATION
(CH-616)

Maximum Marks: 60
Duration: Three Hours

"Students governed by the old ordinances will be examined out of 75 marks and their obtained marks shall be proportionately raised."

Note: Use of Steam Table is allowed. Assume any missing data with proper justification.

1. (a) Write down the procedure for Unit targeting, Shell targeting, and Pre-design Optimization of $\Delta T_{\text{min}}$. (04)

OR

(a') Discuss the appropriate placement of heat pumps and engines relative to pinch. (04)

(b) Determine the minimum utility requirements, pinch temperature, and counterflow area target for the data of Table 1 at $\Delta T_{\text{min}} = 13$ K. (12)

<table>
<thead>
<tr>
<th>$T_{\text{in}}$(K)</th>
<th>$T_{\text{out}}$(K)</th>
<th>$MC_P$(kW/K)</th>
<th>$h$(kW/m$^2$°C)</th>
<th>Stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>175</td>
<td>45</td>
<td>10</td>
<td>0.2</td>
<td>H1</td>
</tr>
<tr>
<td>125</td>
<td>65</td>
<td>40</td>
<td>0.2</td>
<td>H2</td>
</tr>
<tr>
<td>20</td>
<td>155</td>
<td>20</td>
<td>0.2</td>
<td>C3</td>
</tr>
<tr>
<td>40</td>
<td>112</td>
<td>15</td>
<td>0.2</td>
<td>C4</td>
</tr>
<tr>
<td>180</td>
<td>179</td>
<td>0</td>
<td>0.2</td>
<td>HU</td>
</tr>
<tr>
<td>15</td>
<td>25</td>
<td>0</td>
<td>0.2</td>
<td>CU</td>
</tr>
</tbody>
</table>

2. Write in brief about Continuous Targeting Algorithm, Topology Traps, and Sensitivity Threshold. Consider the stream data in Table 1 with the following modification: the $MC_P$ value of stream H2 is 15 kW/°C (and not 40 kW/°C). Determine how the hot utility requirements and pinch temperature vary with $\Delta T_{\text{min}}$. Indicate clearly the sensitivity threshold and multiple pinches (including topology traps), if any exist. (16)

OR
For the stream data in Table 1, Design three MER networks for a $\Delta T_{\text{min}}$ of 13°C using the pinch design method.

Obtain the total site profiles from the two sets of GCC data given in Table 2. Take the global $\Delta T_{\text{min}} = 20$°C. Consider the utility system with two steam mains for servicing the process. The central utility system generates very high pressure (VHP) steam at 475°C in a boiler. The VHP steam is supplied to steam turbines to generate power as well as intermediate pressure (IP) steam at 205°C and low pressure (LP) steam at 145°C. Assume cooling water is available at 25°C. For this total site, obtain targets for VHP, IP, and LP steams, as well as for fuel and cogeneration (power). Given: $\Delta T_{\text{min}} = 20$°C, site power demand = 1000 kW, ambient temperature = 25°C, theoretical flame temperature = 1500°C.

### Table 2:

<table>
<thead>
<tr>
<th>GCC1</th>
<th>$T_{\text{in}}$ °C</th>
<th>$Q$ (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>165</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td>605</td>
<td>175</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GCC2</th>
<th>$T_{\text{in}}$ °C</th>
<th>$Q$ (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>195</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>700</td>
<td>400</td>
</tr>
</tbody>
</table>

Synthesize a minimum utility cost mass exchange network for recovering zinc chloride from spent pickle liquor (rich stream R1) and rinse wastewater (rich stream R2) for $e = 0.0001$, using the stream data given in Table 3. Two mass exchange operations, solvent extraction and ion exchange, are to be utilized to effect the recovery. Five lean streams (MSAs) are available: the three solvents are tributyl phosphate (S1 costing 0.02 $/kg$), triisooctyl amine (S2 costing 0.11 $/kg$), and di-2-ethyl hexyl phosphoric acid (S3 costing 0.04 $/kg$) whereas the two ion exchange resins are a strong base resin (S4 costing 0.05 $/kg$) and a weak base resin (S5 costing 0.13 $/kg$). The equilibrium relationships for zinc chloride in each of the lean streams are as follows: $y = 0.845x_1, y = 1.134x_2 + 0.01, y = 0.632x_3 + 0.02, y = 0.376x_4 + 0.0001$, and $y = 0.362x_5 + 0.002$. Also, the target compositions for the lean streams may truly be regarded as upper bounds.

### Table 3:

<table>
<thead>
<tr>
<th>Stream</th>
<th>$y_{\text{in}}$</th>
<th>$y_{\text{out}}$</th>
<th>$G$ (kg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>0.08</td>
<td>0.020</td>
<td>0.2</td>
</tr>
<tr>
<td>R2</td>
<td>0.03</td>
<td>0.001</td>
<td>0.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stream</th>
<th>$x_{\text{in}}$</th>
<th>$x_{\text{out}}$</th>
<th>$L$ (kg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>0.0060</td>
<td>0.060</td>
<td>$\infty$</td>
</tr>
<tr>
<td>S2</td>
<td>0.0100</td>
<td>0.020</td>
<td>$\infty$</td>
</tr>
<tr>
<td>S3</td>
<td>0.0090</td>
<td>0.050</td>
<td>$\infty$</td>
</tr>
<tr>
<td>S4</td>
<td>0.0001</td>
<td>0.010</td>
<td>$\infty$</td>
</tr>
<tr>
<td>S5</td>
<td>0.0040</td>
<td>0.015</td>
<td>$\infty$</td>
</tr>
</tbody>
</table>