SECTION - A

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

1. (a) Using 0.7-V-drop model, find the values of I and V in the circuit shown in Fig. for Q. 1(a).

\[ V = 10V \]
\[ R = 10k\Omega \]
\[ D_1 \]
\[ D_2 \]
\[ I \]
\[ 5k\Omega \]
\[ -10V \]  
Fig. for Q. 1(a)

(b) Draw the input-output characteristics of the circuit shown in Fig. for Q. 1(b). Assume the diodes to be ideal.
2. (a) Design a circuit with op-amps so that it can perform following operation.

\[ V_0 = -2V_1 + 3V_2 + 4 \frac{dV_2}{dt} - 5 \int_0^t V_1 \, dt \]

where \( V_1 \) and \( V_2 \) are inputs and \( V_0 \) is output.

(b) Find the expression of \( V_0 \) in terms of the inputs \( V_1 \) and \( V_2 \) for the circuit shown in Fig. for Q. 2(b). Also, write the condition under which it acts as a difference amplifier.

3. (a) What is a 'Transducer'? Write the classification of Transducers.

(b) Describe briefly how you can measure force and strain using piezoelectric transducers.

(c) Write the operating principle of an ultrasonic flow meter for flow measurement.

4. (a) Describe the working principle of an SCR by using "Two Transistor Model".

(b) Determine all the node voltages and branch currents in the circuit shown in Fig. for Q. 4(b). Assume that \( \beta \) is specified to be 100.

(c) Write the conditions and models for the operation of the npn-BJT in various modes.
5. (a) A three phase system with line to line voltage 480 V is driving a 40 KVA, 0.98 pf leading Δ-Connected load.

Find:
   (i) Branch impedance of the load. Draw the circuit of the system.
   (ii) Line current and phase current.
   (iii) Real power and reactive power consumed by the circuit.

(b) Two single phase transformers $T_1$ and $T_2$ are operating in parallel as shown in Fig. for Q 5(b). The transformers are rated at 250 KVA, 33 kV/13 kV. The resistances of the transformers referred to primary are 10.02 Ω and 9.82 Ω, respectively. Similarly, the reactances referred to primary are 30.29 Ω and 29.88 Ω, respectively. This configuration is being used to run a 370 KVA, 13 kV, 0.92 pf (lagging) load. Compute the currents $I_1$ and $I_2$ of the transformers when the source $V_1$ is 33 kV. Also find the power delivered by each of the transformers.

6. (a) A 15 KVA, 2300/230-V transformer is to be tested to determine its excitation branch components, its series impedances, and its voltage regulation. The following test data has been taken from the primary side of the transformer:

<table>
<thead>
<tr>
<th>Test Condition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Circuit Test</td>
<td></td>
</tr>
<tr>
<td>$V_{OC}$ = 2300 V</td>
<td></td>
</tr>
<tr>
<td>$I_{OC}$ = 0.21 A</td>
<td></td>
</tr>
<tr>
<td>$P_{OC}$ = 50 W</td>
<td></td>
</tr>
<tr>
<td>Short Circuit Test</td>
<td></td>
</tr>
<tr>
<td>$V_{SC}$ = 47 V</td>
<td></td>
</tr>
<tr>
<td>$I_{SC}$ = 6 A</td>
<td></td>
</tr>
<tr>
<td>$P_{SC}$ = 160 W</td>
<td></td>
</tr>
</tbody>
</table>

Find the equivalent circuit of the transformer referred to the high voltage side.
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Contd... Q. No. 6

(b) In the configuration given in Fig. for Q 6(b) the turns ratios of two single phase transformers A and B are 2:1 and 1:1 respectively. The magnetizing branch impedances are 100 $\Omega$ and 50 $\Omega$, respectively. The configuration is driving an inductor of 5 $\Omega$. Compute the voltages $e_{11}$ and $e_{21}$ in terms of voltage $E$.  

![Diagram](image)

7. (a) A 120 V cumulatively compounded DC generator has the following characteristics:

$R_A + R_S = 0.21 \Omega$, $R_F = 20 \Omega$, $R_{adj} = 0$ to $30 \Omega$, set to $10 \Omega$

$N_F = 1000$, $N_{SE} = 20$, $n_m = 1800$ r/min

The equivalent circuit is shown in Fig. for Q 7(a)-1 and the magnetization curve of the machine is given in Fig. for Q 7(a)-2. Assume no armature reaction and answer the following questions:

(i) Terminal voltage at no load.
(ii) Terminal voltage when armature current is 20 A.
(iii) Terminal voltage when armature current is 40 A.
(iv) Plot the approximate terminal characteristics of the machine.

![Diagram](image)
8. (a) Derive the terminal characteristics of a Shunt DC Motor. (15)
(b) Explain different methods of Speed Control of Shunt DC Motors. (20)

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(b) Derive the terminal characteristics of a series DC generator. (10)
(c) What kind of DC generator is used for arc welding? What is the terminal characteristic of such DC generator? (5)
SECTION – A
There are FOUR questions in this section. Answer any THREE.

1. (a) Starting from first principles, derive the Maxwell equations. (10)
(b) Show that
\[ \Delta U = \frac{r_1}{r_2} \int_C \frac{dP}{P} + \int_{r_2}^{r_1} \tau \left( \frac{\partial P}{\partial T} \right)_V - P \, dv \] (13)
(c) Derive the Clapeyron-Clausius equation. What is its usage? (12)

2. (a) Describe the working principle of a simple gas-turbine power cycle. Derive an expression for the thermal efficiency. (12)
(b) Discuss the modifications that are used over the simple gas-turbine to improve the thermal efficiency. Elaborate your answer by using P-v and T-s diagrams. (13)
(c) Thermal efficiency of an air-standard Otto cycle increases if the compression ratio is increased. But the compression ratio cannot be increased beyond a certain limit — elaborate on this statement. (10)

3. (a) Discuss the different ways of improving the efficiency of a simple steam power plant running on basic Rankine cycle (without changing the basic cycle or hardware). Also discuss the main factors that limit the efficiency improvement by the above mentioned methods. (23)
(b) What is cogeneration? Discuss its importance in chemical process plants. Draw the schematics of a cogeneration plant that can handle variable loads. (12)

4. (a) In a cold country the outside temperature is -5°C. A 3-kW electric heater is used to maintain the inside temperature of a room at 24°C.
   (i) What is the first-law efficiency of the heating process? (2)
   (ii) What is the second-law efficiency? (7)
   (iii) If the 3-kW heater is removed and a 2-kW electric heater is used to maintain the inside temperature at 15°C, what are the first and second law efficiencies. (6)
(b) Write a short note on Joule-Thomson effect. (10)
(c) What is combined-cycle power generation? Draw simple schematics and thermodynamic diagrams and describe the cycle. (10)
5. (a) Explain how Zeroth Law of thermodynamics serves as a basis for the validity of temperature measurement. (5)
(b) Distinguish between the concepts of 'system' and 'control volume'. (4)
(c) Briefly discuss the forms in which energy can be transferred 'to' or 'from' a system. (6)
(d) Draw and state the key features of P-V and P-T diagram for pure substance. (12)
(e) Make a comparison between van der Walls and Virial equation of state. (8)

6. (a) Derive the general expression for work done in a polytropic process. (10)
(b) Describe the working principle of a simple vapor-compressor refrigeration cycle. Explain how refrigeration is obtained in the above cycle using proper thermodynamic diagrams. (10)
(c) The power output of an adiabatic steam turbine is 5 MW, and the inlet and the exit conditions of the steam are indicated below:

\[ P_i = 2 \text{ MPa}, \quad T_i = 400^\circ\text{C}, \quad v_i = 50 \text{ m}^3/\text{kg}, \quad z_i = 10 \text{ m} \]

\[ P_e = 15 \text{ kPa}, \quad z_e = 50\%, \quad v_e = 180 \text{ m}^3/\text{kg}, \quad z_e = 6 \text{ m} \]

(i) Compare the magnitude of \( \Delta h \), \( \Delta K_e \), and \( \Delta P_e \).
(ii) Determine the work done per unit mass of the steam flowing through the turbine.
(iii) Calculate the mass flow-rate of the steam.
7. (a) Write short notes on
   (i) Perpetual-motion machine
   (ii) Carnot heat engine
   (iii) Heat pump
   (iv) Energy has quality as well as quantity
   (v) Entropy from molecular viewpoint.
   
   (b) During winter, a house is expected to lose heat at a rate of 120,000 kJ/h when the outside temperature drops to -6°C. A heat pump is required to heat the house. Determine the minimum power required to drive this heat pump to maintain the inside temperature of the house at 22°C.

8. (a) How does reversible work differ from useful work? Explain with examples.
   (b) What is the second-law efficiency? How does it differ from the first-law efficiency?
   (c) Derive the first Tds, or Gibbs, equation which is Tds = du + Pdv.
   (d) The food compartment of a refrigerator is maintained at 4°C by removing heat from it at a rate of 360 kJ/min. If the required power input to the refrigerator is 2 kW, determine the rate of heat rejection to the room that houses refrigerator.
1. (a) Show that the three vectors \( \mathbf{A} = 2\mathbf{i} + \mathbf{j} - 3\mathbf{k}, \mathbf{B} = \mathbf{i} - 4\mathbf{k} \) and \( \mathbf{C} = 4\mathbf{i} + 3\mathbf{j} - \mathbf{k} \) are linearly dependent. Determine a relation among them and hence show that the terminal points are collinear.

(b) If \( \mathbf{a}, \mathbf{b}, \mathbf{c} \) are non-coplanar vectors then prove that the following four points are coplanar:

\[ -\mathbf{a} + 4\mathbf{b} - 3\mathbf{c}, 3\mathbf{a} + 2\mathbf{b} - 5\mathbf{c}, -3\mathbf{a} + 8\mathbf{b} - 5\mathbf{c}, -3\mathbf{a} + 2\mathbf{b} + \mathbf{c}. \]

(c) A force of 10 units acts through the point \( A (4, -2, 3) \) in the direction of the vector \( (6, -7, 5) \). Find its moment about the point \( B (2, -3, 4) \) and the moment about axes through that point parallel to the co-ordinate axes.

2. (a) If \( \mathbf{a}, \mathbf{b}, \mathbf{c} \) and \( \mathbf{a}', \mathbf{b}', \mathbf{c}' \) are reciprocal system of vectors, then find

\[ (i) \quad \langle \mathbf{a}.\mathbf{a}' \rangle + \langle \mathbf{b}.\mathbf{b}' \rangle + \langle \mathbf{c}.\mathbf{c}' \rangle \]

\[ (ii) \quad \mathbf{a}' \times \mathbf{b}' + \mathbf{b}' \times \mathbf{c}' + \mathbf{c}' \times \mathbf{a}' \]

(b) If \( \mathbf{P} = A \cos kt + B \sin kt \), where \( A \) and \( B \) are constant vectors and \( k \), a constant scalar, then find \( \frac{d}{dt} \left( \mathbf{P} \times \frac{d\mathbf{P}}{dt} \right) \).

(c) Find \( \nabla^2 (r^2 \mathbf{r}) \) where \( \mathbf{r} \) is the position vector.

3. (a) Find the equations of the tangent plane and the normal line to the surface \( 3z = x^2 - y^2 \) at the point \( (4, 1, 5) \).

(b) Show that the gradient of a scalar function \( f \) is a vector along the normal to the level surface whose magnitude is the greatest rate of change of \( f \).

(c) Is the vector field \( \mathbf{F} = \left( x^3 z - 2xyz \right) \mathbf{i} + \left( xy - 3x^2 yz \right) \mathbf{j} + \left( yz^2 - xz \right) \mathbf{k} \) solenoidal? If so, find a vector function \( \mathbf{V} \) such that \( \mathbf{F} = \nabla \times \mathbf{V} \).
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4. (a) Use the Gauss Divergence Theorem to find the flux of \( \mathbf{F} \) across the surface \( S \) with outward orientation where 
\[
\mathbf{F}(x,y) = x^2y \mathbf{i} - x^2y \mathbf{j} + (z + 2)k
\]
; \( S \) is the surface of the solid bounded above by the plane \( z = 2x \) and below by the paraboloid \( z = x^2 + y^2 \).

(b) Find curl of \( \mathbf{F} \) where 
\[
\mathbf{F} = (x^2 - y^2 + 2xz)\mathbf{i} + (xz - xy + yz)\mathbf{j} + (z^2 + x^2)k
\]. Also show that the vectors given by curl \( \mathbf{F} \) at the points \( P(1,2,-3) \) and \( Q(2,3,12) \) are orthogonal.

SECTION – B

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

5. (a) Using only elementary row transformations, find the inverse of \( A \) when 
\[
A = \begin{bmatrix}
1 & 2 & 3 & 4 \\
2 & 3 & 4 & 6 \\
3 & 4 & 5 & 7 \\
4 & 5 & 5 & 7
\end{bmatrix}
\]

(b) For the matrix 
\[
A = \begin{bmatrix}
1 & 3 & -1 & 3 \\
3 & 4 & -3 & 4 \\
1 & 3 & 1 & 2
\end{bmatrix}
\]
find the non-singular matrices \( P \) and \( Q \) such that \( PAQ \) is in the normal form.

(c) Determine the values of \( \alpha \) so that following system in unknown \( x, y, z \) has: (i) no solution (ii) more than one solution (iii) a unique solution:
\[
\begin{align*}
x + y - z &= 1 \\
2x + 3y + \alpha z &= 3 \\
x + \alpha y + 3z &= 2
\end{align*}
\]

6. (a) Show that the quadratic form:
\[
g = 5x_1^2 + 4x_2^2 + 15x_3^2 + 14x_2x_3 + 16x_3x_1 + 6x_1x_2
\]
is positive semi-definite and find a non-trivial set of values \( x_1, x_2, x_3 \) which makes the form zero.

(b) Verify Cayley-Hamilton theorem for the matrix 
\[
A = \begin{bmatrix}
1 & 2 & 3 \\
2 & -1 & 1 \\
3 & 1 & 1
\end{bmatrix}
\]

(c) Find all eigen values and corresponding eigen vectors of the matrix,
\[
A = \begin{bmatrix}
1 & 2 & -1 \\
0 & -2 & 0 \\
0 & -5 & 2
\end{bmatrix}
\]

Contd .......... P/3
7. (a) State and prove 2nd shifting property for Laplace Transformation. Find
\[ L\{f(t)\} \text{ when } f(t) = \begin{cases} (t-\pi)e^{-\pi t} \cos(3t-\pi), & t > \pi \\ 0, & t < \pi \end{cases} \]
(b) Find
\[(i) \quad L\left\{ \frac{2}{\sqrt{\pi}} e^{-u^2} du \right\} \quad (ii) \quad L^{-1}\left\{ \frac{1}{(s^2 + 2s + 5)^{\frac{3}{2}}} \right\} \]
(c) Use Laplace Transformation to evaluate the integral:
\[ \int_{0}^{\infty} \cos x^2 dx \]

8. (a) Find \( L^{-1}\left\{ \frac{s^2 - 3}{(s + 2)(s - 3)(s^2 + 2s + 5)} \right\} \).
(b) Solve the system of differential equations using Laplace Transformation:
\[
\begin{align*}
x'' + x' + 3x &= 15e^{-t} \\
y'' - 4y' + 3y &= 15\sin 2t
\end{align*}
\]
with \( x(0) = 35, \ x'(0) = -48, \ y(0) = 27, \ y'(0) = -55. \)
(c) Prove that \( \int_{0}^{\pi} \cos(t \cos \theta) \, d\theta = J_0(t) \) (using Laplace Transform).
1. (a) Draw the typical regions of a one component phase diagram. Explain why the coexistence of four phases in equilibrium is forbidden. 

(b) A binary hypothetical solution of A in water (70% by mass of water) boils unchanged at 110°C. How would you explain this effect? Explain with a temperature-composition diagram. Can you separate these two by fractional distillation? Justify your answer. 

(c) It is found that the boiling point of a binary solution of A and B with $X_A = 0.6589$ is 88°C. At this temperature the vapor pressure of pure A and B are 127.6 kPa and 50.60 kPa, respectively. (i) Is this solution ideal? (ii) What is the initial composition of the vapor above the solution?

2. (a) Draw a graph showing the decay of the reactant in a first order reaction. What will happen to the rate of the decay if the rate constant, $K$ increases or decreases? 

(b) The initial rate of a reaction is dependent on concentrations of a substance "j" As follows: 

$$ \frac{[J]_0}{(mmol \ dm^{-3})} \quad 5.0 \quad 8.2 \quad 17 \quad 30 
$$

$$ \frac{V_0}{(10^{-7} \ mol \ dm^{-3} \ s^{-1})} \quad 3.6 \quad 9.6 \quad 41 \quad 130 $$

Determine the order of the reaction with respect to J and calculate the rate constant.

(c) What are the two steps in Michaelis-Menten mechanism of enzyme catalysis? According to this mechanism, the rate of product formation?

$$ V = \frac{k_1[E]}{1 + K_m / [S]_0} $$

(i) Draw a graph to show the variation of the rate of enzyme catalyzed reaction with substrate concentration. Explain at what conditions the rate of the reaction reaches its maximum?

(ii) What is the catalytic efficiency of an enzyme in Michaelis-Menten mechanism? How it is related to the rate constant of the two steps in the mechanism? When does the efficiency reach its maximum value?
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3. (a) How does the electronic transition from the ground electronic state to its excited state take place? Draw a diagram. (10)
   (b) "All molecules having a permanent dipole moment are said to be microwave active"- Explain the statement citing an example. (10)
   (c) Explain how the width of spectral lines depends on the life time of an excited electronic state is usually $10^{-8}$s. What can be inferred from this? (5)
   (d) Why do the consecutive rotational spectral lines always appear with a constant difference $2B$ ($B$ is rotational constant) for a rigid diatomic molecule? (10)

4. (a) What are the differences in chemisorption and physisorption? How do you explain the rate of adsorption using the term sticking probability? (8+4=12)
   (b) Draw a graph showing how the sticking probability generally changes with the increase of surface coverage. (5)
   (c) Draw a schematic diagram of a catalytic converter for automobile. (8)
   (d) Ozone layer depletion is the consequence of production of free radical acting as a catalyst.
      (i) What is homogeneous catalysis?
      (ii) Show the homogeneous catalysis process of ozone decomposition of oxygen. (10)

SECTION – B
There are FOUR questions in this section. Answer any THREE.
Assume reasonable values for any missing data.

5. (a) Define specific conductance. Establish the relationship between specific conductance and equivalent conductance. Explain how the equivalent conductance of strong and weak electrolytes vary with concentration. (13)
   (b) Define ionic mobility show that the ionic mobility of an ion is directly proportional to its ion conductance. (12)
   (c) In a particular cell a 0.01 N solution of potassium chloride gave a resistance of 150.00 ohm at 25°C while a 0.01N solution of HCl gave a resistance of 51.40 ohm at the same temperature. If the specific conductance of 0.01N potassium chloride is $0.0014088 \text{ ohm}^{-1}\text{cm}^{-1}$, calculate the equivalent conductance of HCl solution. (10)

Contd .......... P/3
6. (a) State and explain Ostwald dilution law. With the help of equivalence conductance measurement explain how you can determine the values of $\alpha$, $K_a$ and $\Lambda_o$ of a weak acid. (13)
(b) What is ionic atmosphere? Explain how the motion of an ion in an ionic atmosphere is retarded due to asymmetric effect and electrophoretic effect. (12)
(c) The specific conductance of a 0.01N solution of acetic acid at 25°C is $1.63 \times 10^{-4}$ ohm$^{-1}$ cm$^{-1}$ and the ionic conductance at infinite dilution at the same temperature for H$^+$ and CH$_3$COO$^-$ are 349.8 and 40.9 ohm$^{-1}$cm$^2$ equiv$^{-1}$, respectively. Calculate the dissociation constant of acetic acid at 25°C. (10)

7. (a) Define activity and activity coefficient. Establish the relationship between them for an electrolyte of general formula $M_xA_y$. (13)
(b) What is ionic strength? How does ionic strength of strong electrolytes affect the activity coefficient? Show that the solubility of a sparingly soluble salt increases with increasing the ionic strength of an added electrolyte having no common ion. (12)
(c) Calculate the mean activity coefficient of Na$_2$SO$_4$ at a molality of 0.001 in aqueous solution at 25°C. (10)

8. (a) What are concentration cells? How are they classified? Consider the cell: H$_2$(1 atm) | HCl (a) | AgCl(s) | Ag. From cell emf measurement explain how you can determine the value of $E^{o}_{Ag/AgCl}$ of the cell. (13)
(b) What is meant by standard hydrogen electrode? Explain why hydrogen electrode is not convenient for routine work. (12)
(c) Predict whether zinc and silver react with 1 N sulphuric acid solution to give out hydrogen or not. Given that the standard reduction potentials of zinc and silver are $-0.76$ volt and $0.80$ volt. (10)
L-2/T-1/CHE

Date: 05/08/2017

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA


Sub: CHE 201 (Materials and Energy Balance)

Full Marks: 210  Time: 3 Hours

USE SEPARATE SCRIPTS FOR EACH SECTION

The figures in the margin indicate full marks

A Data Booklet containing all relevant data is supplied.

SECTION – A

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

1. (a) Methanol is produced in the reaction of carbon dioxide and hydrogen:

\[ \text{CO}_2 + 3\text{H}_2 \rightarrow \text{CH}_3\text{OH} + \text{H}_2\text{O} \]

The fresh feed to the process contains hydrogen, carbon dioxide and 0.40 mole percent inerts (I). The reactor effluent passes to a condenser that removes essentially all of the methanol and water formed and none of the reactants or inerts. The latter substances are recycled to the reactor. To avoid buildup of the inerts in the system, a purge stream is withdrawn from the recycle. The feed to the reactor contains 28.0 mole% CO\textsubscript{2}, 70 mole% H\textsubscript{2} and 2% inerts. The single pass conversion of H\textsubscript{2} is 50%. Draw the Process Flow Diagram (PFD), label it completely and carry out and complete degrees of freedom (DOF) analysis. Based on the results of DOF analysis, outline a procedure to solve the problem (A complete solution is NOT required).

(b) Define the heating value of a fuel? What is the difference between Higher Heating Value (HHV) and Lower Heating Value of a fuel? Explain.

2. Hydrogen is produced in the steam reforming of propane:

\[ \text{C}_3\text{H}_8(g) + 3\text{H}_2\text{O}(v) \rightarrow 3\text{CO}(g) + 7\text{H}_2(g) \]

Water-gas shift reaction also takes place in the reactor, leading to the formation of additional hydrogen:

\[ \text{CO}(g) + 3\text{H}_2\text{O}(v) \rightarrow \text{CO}_2(g) + \text{H}_2(g) \]

The reaction is carried out over a nickel catalyst in the tubes of a shell-and-tube reactor. The feed to the reactor contains steam and propane in a 6:1 molar ratio at 125°C, and the products emerge at 800°C. Excess steam in the feed assures essentially complete consumption of the propane. Heat is added to the reaction mixture by passing a hot gas over the outside of the tubes that contain the catalyst (See Figure: Q2). The heating gas is fed at 5 m\textsuperscript{3}/mol C\textsubscript{3}H\textsubscript{8}, entering the unit at 1400°C, entering the unit at 1400°C and 1 atm and leaving at 900°C. The unit may be considered adiabatic. Calculate the molar composition of the product gas assuming that the heat capacity of the heating gas is 0.045 kJ/(mol°C).

Contd .......... P/2
3. (a) Ethanol is produced commercially by the hydration of ethylene:

\[ \text{C}_2\text{H}_4 + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_5\text{OH} \]

Some of the product is converted to diethyl ether in the side reaction

\[ 2\text{C}_2\text{H}_5\text{OH} \rightarrow (\text{C}_2\text{H}_5)_2\text{O} + \text{H}_2\text{O} \]

The feed to the reactor contains ethylene, steam and an inert gas. A sample of the reactor effluent gas is analyzed and found to contain 42 mole% ethylene, 3% mole ethanol, 0.15 mole% ether, 10 mole% inert and the balance water.

(i) Draw and label the process flow chart.

(ii) Calculate the molar composition of the reactor feed, the percentage conversion of ethylene, the fractional yield of ethanol and the selectivity of ethanol production relative to ether production.

(iii) If the percentage conversion of ethylene calculated in part (ii) is very low, what may be the reason for maintaining low conversion in the reactor. What additional processing steps are likely to take place downstream from the reactor?

(b) Water is added to a storage tank at a rate of 1000 kg/h and is simultaneously withdrawn at a rate of \( m_w(t) \) (kg/h) that increases linearly with time, \( t \). At \( t = 0 \), the tank contains 500 kg water and \( m_w = 500 \) kg/h. Five hours later \( m_w = 750 \) kg/h.

Calculate an expression for \( m_w(t) \) and incorporate it into a differential mass balance equation for the system. Find the expression for mass of water in the tank at any time \( t \).

What will be the maximum amount of water in the tank?
4. (a) Natural gas having composition 92 mol% methane and the balance ethane is burned in an adiabatic furnace with 25% excess air. What will be the adiabatic flame temperature in the furnace? Assume the inlet temperatures of both natural gas and air are 35°C. (25)

(b) Instead of burning the natural gas in part (a) with air, if it were to be burned with theoretical oxygen, would the adiabatic flame term increase or decrease. Justify your answer. (10)

SECTION – B

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

5. (a) Liquid methyl ethyl ketone (MEK) is introduced into a vessel containing air. The system temperature is increased to 55°C, and the vessel contents reach equilibrium with some MEK remaining in the liquid state. The equilibrium pressure is 1200 mm Hg.

(i) Use the Gibbs phase rule to determine how many degrees of freedom exist for the system at equilibrium. (15)

(ii) Mixtures of MEK vapor and air the contain between 1.8 mole% MEK and 11.5 mole% MEK can ignite and burn explosively if exposed to a flame or spark. Determine whether or not the given vessel constitutes an explosion hazard.

(b) Sulfur trioxide (SO₃) dissolves in and reacts with water to form an aqueous solution of sulfuric acid (H₂SO₄). The vapor in equilibrium with the solution contains both SO₃ and H₂O. If enough SO₃ is added, all of the water reacts and the solution becomes pure H₂SO₄. If still more SO₃ is added, it dissolves to form a solution of SO₃ in H₂SO₄, called Oleum or fuming sulfuric acid. The vapor in equilibrium with oleum is pure SO₃. Based on this information, (20)

(i) Prove that a 15.0% oleum contains 84.4% SO₃.

(ii) Suppose a gas stream at 40°C and 1.2 atm containing 90 mole% SO₃ and 10% N₂ contacts a liquid stream of 98 wt% H₂SO₄ (aq), producing 15% oleum at the tower outlet. Tabulated equilibrium data indicate that the partial pressure of SO₃ in equilibrium with this oleum is 1.15 mm Hg. Calculate the mole fraction of SO₃ in the outlet gas if this gas is in equilibrium with the liquid product at 40°C and 1 atm, and the ratio (m³ gas feed)/(kg liquid feed).
6. (a) Saturated steam at 300°C is used to heat a countercurrently flowing stream of methanol vapor from 65°C to 260°C in an adiabatic heat exchanger. The flow rate of the methanol is 5500 standard liters per minute, and the steam condenses and leaves the heat exchanger as liquid water at 90°C.

(i) Calculate the required flow rate of the entering steam in m³/min.

(ii) Calculate the rate of heat transfer from the water to the methanol (kW).

(b) An NH₃–H₂O mixture containing 60 wt% NH₃ is brought to equilibrium in a closed container at 140°F. The total mass of the mixture is 250 g. Use figure for question no. 6(b) to determine the masses of ammonia and of water in each phase of the system.

7. (a) The air in a building is to be maintained at 25°C and 55% relative humidity by passing outside air through a water spray. The air enters the spray chamber at 32°C and 70% relative humidity, leaves the chamber cooled and saturated with water vapor, and is then reheated to 25°C. Estimate the temperature of the air leaving the spray chamber and the water (kg) added to or removed from (specify which) each kilogram of dry air processed.
(b) A mixture of propane and butane is burned with air. Partial analysis of the stack gas produces the following dry-basis volume percentages:

0.0527\% C_3H_8, 0.0527\% C_4H_{10}, 1.48\% CO, and 7.12\% CO_2.

The stack gas is at an absolute pressure of 780 mm Hg and the dew point of the gas is 46.5°C. Calculate the molar composition of the fuel.

8. Wet solids pass through a continuous dryer. Hot dry air enters the dryer at a rate of 400 kg/min and picks up the water that evaporates from the solids. Humid air leaves the dryer at 50°C containing 2.44 wt\% water vapor and passes through a condenser in which it is cooled to 10°C. The pressure is constant at 1 atm throughout the system.

(i) At what rate (kg/min) is water evaporating in the dryer?

(ii) Use the psychrometric chart to estimate the wet-bulb temperature, relative humidity, dew point, and specific enthalpy of the air leaving the dryer.

(iii) Use the psychrometric chart to estimate the absolute humidity and specific enthalpy of the air leaving the condenser.

(iv) Use the results of parts (b) and (c) to calculate the rate of condensation of water (kg/min) and the rate at which heat must be transferred from the condenser (kW).

(v) If the dryer operates adiabatically, what can you conclude about the temperature of the entering air? Briefly explain your reasoning. What additional information would you need to calculate this temperature?