CHEMICAL ENGINEERING

SECTION A

(80 Marks)

1. Fill in the blanks :
   a. The steps involved in the manufacture of phenol by chlorobenzene caustic process are chlorination of benzene, _____ and _____. The process is competitive when low cost chlorine is available. This means that the process must be coupled to a _____ plant.
   b. For manufacture of styrene the major raw materials are _____ and _____. One important copolymer of styrene is _____ which is widely used in the manufacture of automobile tyres.
   c. Select the appropriate name from the right hand column, against the processes mentioned :
   - (I) H_2 from light petroleum stock
   - (II)   High octane gasoline from naptha
   - (III)   Gasoline from gas oil
   - (IV)   Petroleum coke from residue
   - (A)   Pyrolysis
   - (B)   Catalytic cracking
   - (C)   Platforming
   - (D)   Steam reforming of naptha
   d. An electrostatic precipitator is normally used for separating particles from gases when
   - (A)   Particle size is greater than 1 mm
   - (B)   Particle size is less than 1 micron
   - (C)   Gases contain high concentration of carbon monoxide
   - (D)   Gases contain very high concentration of solids.

2. Fill in the blanks :
   a. It is desired to make 100 kg of a solution containing 40% salt by mixing solution A containing 25% salt and solution B containing 50° % salt. The mass in kg of solution A. required is _____.
   b. 1.2 g atoms of carbon and 1.5 g moles of oxygen are reacted to give 1 g mole of carbon dioxide. The limiting reactant is _____. The per

cent excess reactant supplied is _____.
   c. A gaseous reaction A → 2B + C takes place isothermally in a constant pressure reactor. Starting with a gaseous mixture containing 50% ^{o}A (rest inerts), the ratio of final to initial volume is found to he 1.6. The percentage conversion of A is
   - (A)   30
   - (B)   50
   - (C)   60
   - (D)   74
   d. A multiple effect evaporator has a capacity to process 4000 kg of solid caustic soda per day when it is concentrating Iron. 10% to 25% solids. The water evaporated in kg per day is
   - (A)   600
   - (B)   24,000
   - (C)   60,000
   - (D)   48,000

3. Choose the correct alternate :
   a. The mechanical energy equation
   $$\left(\frac{V^2}{2} + gz + \frac{p}{\rho}\right)_2 = \left(\frac{V^2}{2} + gz + \frac{p}{\rho}\right)_1 - \frac{dW_s}{dm} - \frac{dW_t}{dm}$$
   has been obtained under which of the following assumptions
   - (A)   the flaw is steady
   - (B)   the flow is incompressible
   - (C)   no viscous work is being done
   - (D)   points 2 and 1 are on the same streamline.
   b. A spherical particle is falling slowly in a viscous liquid such that Reynolds number is less than 1. Which statement is correct for this situation?
   - (A)   Inertial and drag forces are important
   - (B)   Drag, gravitational and buoyancy forces are important
   - (C)   Drag force and gravitational forces are important
   - (D)   None of the above.
   c. As the velocity V and thus the Reynolds number of a flow past a sphere increases from very low values, the drag force for Re << 1
   - (A)   increases linearly withV

2 of 6

(B)   decreases linearly with V

(C)   decreases as V^2

(D)   none of these.

d. The Weber number can be used to estimate

(A)   ratio of inertial and surface tension forces

(B)   ratio of inertia and compressibility forces

(C)   ratio of inertial and centrifugal bites

(C)   ratio of pressure and surface tension forces.

4.   Choose the correct alternate :

a. A particle A of diameter 10 microns settles in an oil of specific gravity 0.9 and viscosity 10 poise under Stokes Law. A particle B with diameter 20 microns settling in the same oil will have a settling velocity

(A)   same as that of A

(B)   one-fourth as that of A

(C)   twice as that of A

(D)   four-times as that of A.

b. Write equations for :

(A)   Baud's law of size reduction

(B)   Filtration under constant pressure

c. Match the following :

(I)   Cut diameter

(II)   Specific cake resistance

(III)   Size Reduction Ratio

(IV)   Angle of Internal Friction

(A)   Filtration

(B)   Cyclone separators

(C)   Storage of solids

(D)   Kick's law

d. During washing of filter at the end of constant pressure filtration, the rate of washing equals the

(A)   rate of filtration at time zero

(B)   rate of filtration at the end of filtration

(C)   rate of filtration when half the filtrate has been obtained

(D)   rate of filtration at the end of filtration, but decreases with time subsequently.

5.   Choose the correct alternate :

a. In a heat exchanger with steam outside the tubes, a liquid gets heated to 45°C when its flow velocity in the tubes is 2 m/s. If the flow velocity is reduced to 1 m/s, other things remaining the same,

the temperature of the exit liquid will be

(A)   less than 45°C

(B)   equal to 45°C

(C)   greater than 45°C

(D)   Initially decreases and remains constant thereafter.

b. Indirect contact heat exchanger are preferred over direct heat exchangers because

(A)   heat transfer coefficients are high

(B)   there is no risk of contamination

(C)   there is no mist formation

(D)   cost of equipment is lower

c. To initiate boiling of a liquid, the temperature of the heated surface, if smooth will be _____ (higher/lower) than for a commercial or a roughened surface.

d. The advantage of backward-feed multiple-effect evaporators over forward-feed units is that

(A)   heat sensitive materials can be handled

(B)   there is no additional cost of pumping

(C)   most concentrated liquor is at highest temperature

(D)   equal heat transfer coefficients exist in various effects.

6.   Fill in the blanks :

a. In drying a solid containing moisture above the critical moisture content, the number of degrees of freedom is _____.

b. In the McCabe-Thiele diagram for binary distillation, vertical feed line represents _____ feed and horizontal feed line represents _____ feed.

c. _____number in mass transfer corresponds to Nusselt number in heat transfer and _____ number to Prandtl number.

d. In small columns local efficiency is _____ Murphree efficiency; in large columns local efficiency is _____ Murphree efficiency.

7.   Choose the correct alternate :

a. Write expressions for

(A)   Van't Hoff equation

(B)   Van der Waals equation of State

b. During Joule-Thom expansion of gases,

(A) Enthalpy remains constant
(B) Entropy remains constant
(C) Temperature remains constant
(D) None of the above

c. The necessary and sufficient condition for equilibrium between two phases is
(A) concentration of each component should be same in the two phases
(B) the temperature of each phase should be same
(C) the pressure should be same in the two phases
(D) the chemical potential of each component should be same in the two phases.

d. For a single component, two-phase mixture the number of independent variable properties are
(A) two
(B) one
(C) zero
(D) three

8. Choose the correct alternate :
a. The conversion of a reactant, undergoing a first-order reaction, at a time equal to three- times the half life of the reaction is
(A) 0.875
(B) 0.5
(C) 0.425
(D) not possible to calculate because of insufficient data.

b. The units of frequency factor in Arrhenius equation
(A) are the same as those of the rate constant
(B) depend on the order of the reaction
(C) depend on temperature, pressure etc. of the reaction
(D) are cycles per unit time.

c. Fill in the blanks:
Transition state theory approaches the problem of calculating reaction rates by concentrating on the idea of_____.

d. Fill in the blanks:
In a first-order reaction
    A $\rightarrow$ Products
the reaction becomes slower as it proceeds, because the concentration of A _____, and the rate is _____.

9. Choose the right answer:
a. When a bare thermocouple is covered by a protective sheath, the response- becomes:

(A) Faster and oscillatory
(B) Faster and non-oscillatory
(C) Slower and oscillatory
(D) Slower and non-oscillatory.

b. Rearrange into an equivalent unity feedback diagram :
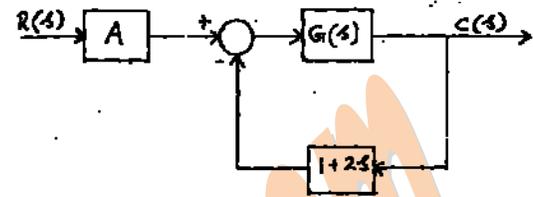
c. An integrating process [l/T_is] is controlled by a proportional controller [K_c] . The measuring instrument and the final control element respond instantaneously. Find the offset following a unit step change in load.

d. State whether the following systems are stable or unstable :
(i) $\angle G(j\omega) = -210^\circ$ when $|G(j\omega)| = 1$
(ii) $\angle G(j\omega) = -180^\circ$ when $|G(j\omega)|=0.588$.

10. Give the answers of the following :
a. Indicate the most appropriate material for the handling of the chemicals as given below :
Chemicals
(I) Dilute Sulphuric
(II) Concentrated Hydrochloric Add
(III) Wet chlorine
(IV) Concentrated Caustic Soda
Materials
(A) Karbate
(E) Nickel
(C) Lead
(D) Titanium

b. For pipe lines handling fluid under pressure, circumferential stiffening rings are used for withstanding higher internal pressure. (True or False).

c. In the. layout plan; for, a vacuum distillation unit, operating at 60 mm Hg, supported by a barometric condenser, the appropriate place for the location of vacuum drum for collecting the distillate will be
(A) at ground level
(B) 2 m above ground
(C) 5 m above ground
(D) 10 m above ground.

d. Match the following :
(I) Capitalized cost
(II) Unamortized value
(Ill) Payout period

(IV)   Cost index
(A)   Comparing alternative investment choices
(B)   Updating cost data of equipment
(C)   Profitability evaluation
(D)   Cost accounting
(F)   Replacement decisions

(F)   Working capital

SECTION B
(120 Marks)

11.   The concentration of SO_2 in the flue gases from a boiler was found to be 0.2 kg/m^3 at N.T.P. Determine the concentration of SO_2 in parts per million by volume, at N.T.P. Assume that the gases are perfect.

12.   Answer the following questions :
   a.   The analysis of the gas entering the secondary converter in a contact sulphuric acid plant is 4% SO_2, 13% O_2, and 83% N, (volume %). In the converter SO_2 is oxidised to SO_3. The gases leaving the converter contain 0.45% SO_2 on an SO_3^- free basis (volume %). Calculate the percent conversion of SO_2.
   b.   Dry methane is burned with dry air. Both are at 25°C initially. The flame temperature is 1300°C. If complete combustion is assumed how much excess air is being used? The reaction is

   $$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O.$$
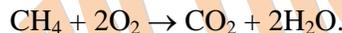
   Standard heat of reaction = -8.028×10^5 J/g mole of CH_4 reacted. Mean molal specific heats of gases between 25°C and 1300°C are in J/(g. mole) (°K) :
   $CO_2 = 51.88$
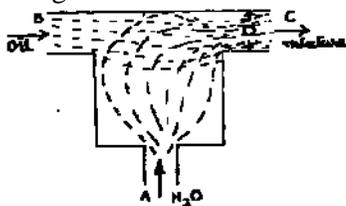 $H_2O = 40.45$
   $O_2 = 34.01$
   $N_2 = 32.21$

13.   Answer the following :
   a.   Water is forced into the device shown in figure below at the rate of

   0.15 m^3/sec through pipe A, while oil of specific gravity 0.8 forced in at the rate of 0.05 m^3/sec through pipe B. If the liquids are incompressible and form a homogeneous mixture of oil globules in water, what is the average velocity and density of the mixture leaving through pipe C having a diameter of $\sqrt{7/22}$ m.
   b.   For flow over a flat plate wherein a laminar boundary layer is present for the case of a zero pressure gradient, the parabolic profile for velocity u is given by

   $$u = a_1y + a_2 y^2 \quad \text{for } y \leq \delta$$
   $$u = V_0 \quad \text{for } y \geq \delta$$
   Find a_1 and a_2.
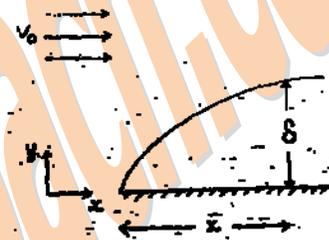
14.   Answer the following :
   a.   Particles of average feed size 25×10^4m are crushed to an average product size of 5×10^{-4} m at the rate of 15 tons per hour. At this rate the crusher consumes 32 kW of power of which 2 kW are required for running the mil1 empty. What would be the power & consumption if 40 tons per hour of this product is further crushed to 1×10^{-4} m size in the same mill? Assume that Rittinger's law is applicable.
   b.   A filter press contains 20 frames, each of 0.6 m. by 0.6 m inside dimension The frames are 0.025 m thick. The press is equipped with 1 and 3-button plates for washing. The volume of wash water used is 10% of the filtrate per cycle. The time required for filtering, at constant pressure, is 2 hours by which time the frames are full. Washing is done at the same pressure as filtering and the viscosity of wash water is nearly the same as that of the filtrate. What is the time for washing? There is 0.05 m^3 of final cake per m^3 of filtrate. Neglect the resistance of the filter medium.

15.   Answer the following questions :

a. Consider three infinite parallel plates. Plate 1 is maintained at 1227°C and plate 3 is maintained at –173°C. Emissivities are equal to that of a black body. Plate 2 is placed between plates 1 and 3; and receives no heat from external sources. What is the temperature of plate 2 ?

b. A nickel steel rod 8 cm OD originally at a temperature of 300°C is suddenly immersed in a liquid at 100°C for which the convective heat transfer coefficient is 100 W/m². K. Determine the time required for the rod to teach a-temperature of 150°C. (Hint: Calculate the Blot number and make the necessary assumption).

Properties of nickel steel :

$K = 80$ W/m. K ;

$\rho = 8000$ kg/m³ ;

$C_p = 0.5$ J/kg. K.

16. Answer the following questions :

a. Equilibrium relationship for the system heptane-oil-air is given by $Y = 2X$ (Y and X are kg-heptane/kg.air and kg-heptane/kg-oil respectively). Oil containing 0.005 kg-heptane/kg-oil is being used as solvent for reducing the heptane content of air from 0.10 to 0.02 kg-heptane/kg-air in a continuous counter-current packed bed absorber. What column height is required to treat 1400 kg/(hr) (m² of empty tower cross section) of pure air containing heptane if the overall gas mass transfer coefficient is 320 kg/(hr) (m³) per unit gradient of Y. The oil rate employed is 3100 kg/(hr) (m²).

Solve analytically.

b. The following information is available from the records of a binary fractionating column:

Feed = 180 kg-mole/hr and 60% vaporised;

Distillate = 100 kg-mole/hr with 0.98 mole fraction of the more volatile component;

Reboiler steam demand = 420 kg/hr;

Latent heat of column liquid = 3×10^4 J/g mole; and

Latent heat of steam used in reboiler = 2200 J/g.

Calculate

(i) the operating reflex ratio and

(ii) the composition of vapor entering that plate from which liquid overflow contains 0.7 mole fraction of the more volatile component.

c. Sheet material 0.5 cm thick containing 800 kg of dry stock/m³ of original wet stock is to be dried at constant drying conditions. The initial drying rate is 4 kg/(hr) (m²) at the initial moisture content of 33%. The final drying rate is 1 kg/(hr) (m²) at 6% final moisture content. The equilibrium moisture content is negligible. If drying is from the two large surfaces only, and if the drying rate in the falling rate period is proportional to the free moisture content, calculate the total drying time. All moisture contents are on the dry basis.

TWO, THREE & SIX MARKS QUESTIONS (17-20)

17. Answer the following :

a. 10^6 Joules of heat are transferred from a reservoir at 327°C to an engine that operates on the Carnot cycle. The engine rejects heat to a reservoir at 27°C. Determine the thermal efficiency of the cycle and the work done by the engine.   (3 marks)

b. An inventor claims to have developed a refrigeration unit which maintains the refrigerated space at –3°C while operating in a room where the temperature is 27°C, and which has a coefficient of performance of 9.5. How do you evaluate his claim?   (3 marks)

c. Consider the compression of air from 10^5 Pa at 27°C to 3×10^6 Pa in an ideal two-stage compressor with intercooling. Assume that the temperature of the air leaving the intercooler is also 27°C, and that the optimum interstage pressure is used. The compressor is water-jacketed and the polytropic exponent ii is 1.30 for both stages. Determine the work of compression per kg of air.   (6 marks)

18. Answer the following :

a. Explain in one or two sentences why the following statements are incorrect:

(i) The steady-state approximation in a

radical chain mechanism involves the assumption that since the concentration of any particular atomic or radical species is so small that it can be taken to be zero. (2 marks)

(ii) Coal forms an inexplosive mixture with air at ordinary temperatures when it is in finely divided form. (2 marks)

(iii) Inhibition is the process where the rate-of reaction is decreased by lowering the temperature. (3 marks)

b. A homogeneous liquid phase reaction

$$A \rightarrow R; \qquad -r_A = kC_A^2$$

takes place with 50% conversion in a well mixed reactor operating isothermally. What will be the conversion it the reactor is replaced by a plug flow type of equal size all else remaining the same? (3 marks)

c. Consider the set -of elementary reactions

$$A \xrightarrow{k_1} B$$
$$A + B \xrightarrow{k_2} C$$
$$A + D \xrightarrow{k_3} 2E$$
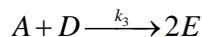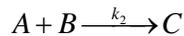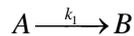
At time t = 0, a batch reactor is filled with a mixture of A and D. What is the relation between the concentrations of B and D after a time t? (3 marks)

19. Answer the following questions :

a. A thermometer follows first-order dynamics with a time constant 0.2 min. It is placed in a temperature bath at 100°C and is allowed to reach steady state. It is suddenly transferred to another bath at 150°C at time t = 0 and is left there for 0.2 min. It is immediately returned to the original bath at 100°C.
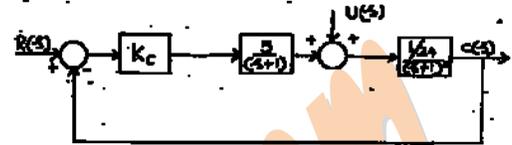Calculate its readings at :

(i) t = 0.l min
(ii) t = 0.4 min. (6 marks)

b. Determine :
(i) The maximum gain for stable operation.
(ii) The corresponding frequency of oscillation.

(6 marks)

20. Answer the following :

a. Give the expressions for the two principal stresses for a cylindrical pressure vessel closed at both ends. (2 marks)

b. For a gas cylinder, designed on the "Thin Cylinder Principle", calculate the thickness of a seamless cylinder under the following conditions :
Pressure of N_2 gas in the cylinder $= 100 \times 10^5$ N/m^2.
Tensile stress permissible $= 1200 \times 10^5$ N/m^2.
Internal diameter of cylinder = 25 cm. (4 marks)

c. The plant of a chemical company has an initial worth of Rs. 50 lakhs, and an estimated salvage value of Rs. 2 lakhs in a service life of 8 years.
(i) Given a choice between the straight-line and declining-balance methods of depreciation. Which method would you recommend to save tax and why? (3 marks)
(ii) Estimate the book value of the plant at the end of 4 years for each of the two methods of depreciation. (3marks)