MPSC

Forest Service

(Mains)

Previous Year Paper

(Chemical Engineering)

10 May, 2025

महाराष्ट्र वन सेवा मुख्य परीक्षा-2024 दिनांक - 90 मे, 2024

2024

V19

BOOKLET NO.
120026

Forest Services

Chemical Engineering

Time Allowed : Three Hours **Maximum Marks : 200**

Medium : English **Type of Paper : Conventional**

Question Paper Specific Instructions

Please read each of the following instructions carefully before attempting questions :

1. There are **EIGHT** questions divided in two Sections, out of which **FIVE** are to be attempted.
2. Questions no. 1 and 5 are compulsory. Out of the remaining questions, THREE are to be attempted choosing at least ONE question from each Section.
3. The number of marks carried by a question/sub question is indicated against it.
4. Keep in mind the word limit indicated in the question if any.
5. Wherever option has been given, only the required number of responses in the serial order attempted shall be assessed. Unless struck off, attempt of a question shall be counted even if attempted partly. Excess responses shall not be assessed and shall be ignored.
6. Candidates are expected to answer all the sub-questions of a question together. If sub-question of a question is attempted elsewhere (after leaving a few page or after attempting another question) the later sub-question shall be overlooked.
7. Any page or portion of the page left blank in the Answer Booklet must be clearly struck off.
8. Unless otherwise mentioned, symbol and notation have their usual standard meanings. Assume suitable data, if necessary and indicate the same clearly.
9. Neat sketches may be drawn, wherever required.
10. The medium of answer should be mentioned on the answer book as claimed in the application and printed on admission card. The answers written in medium other than the authorized medium will not be assessed and no marks will be assigned to them.

Note : Candidates will be allowed to use Scientific (Non-programmable type) calculators.

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SECTION – A

Q1. Solve **any five** out of seven : **(8×5=40)**

(a) I) What is Newton's law of viscosity ? Define Newtonian and non-Newtonian fluids.

II) Define Kinematic viscosity. Derive the equation for S.I. unit of Kinematic viscosity.

III) State whether the following statements are TRUE or FALSE.

i) The viscosity increases with increasing temperature, for gasses at low density.

ii) For liquids the viscosity usually decreases with increasing temperature.

IV) Draw the graph for shear stress versus shear rate for Newtonian, dilatant, pseudoplastic and bingham plastic fluid.

(b) I) Write down the Fick's first law for the diffusivity DAB of constituent A in solution of B, for the 'Z' direction. Also write Fick's first law in terms of mole fraction of A.

II) State whether the following statements are TRUE or FALSE.

i) The diffusivity is a measure of its diffusive mobility, but it is not the ratio of its concentration gradient to its flux.

ii) Diffusion co-efficient, D is not a property of the system dependent upon temperature, pressure and the nature of the component.

III) Define gas hold-up and superficial gas velocity.

IV) If the liquid flow upward in vertical pipe co-currently with the gas, write the equation for slip velocity (Vs).

(c) I) Write the short note on mean temperature difference for co-current flow.

II) Write the short note on mean temperature difference for counter current flow.

III) Write the short note on natural convection and forced convection.

IV) Define emissivity and state Kirchhoff's law of emissivity.

(d) I) Define stiffness and creep in relation to the mechanical properties of materials.

II) Define pitting corrosion and erosion corrosion of the material.

III) List out the commonly used materials in the construction of chemical plant.

IV) List out the commonly used plastics as materials of construction for chemical plant.

(e) I) Define absolute humidity (y′) and molal absolute humidity (y). Write down the relation between absolute humidity and molal absolute humidity.

II) Define the relative volatility in the case of distillation. Write the formula for relative volatility (α).

III) Define the two types of adsorptions. Write the differences between them.

IV) What is bound moisture and unbound moisture in case of drying operation.

(f) I) Define total emissive power and state 'Stefan-Boltzmann law.

II) In assessing the performance of heat exchanger, define effectiveness and number of transfer unit.

III) Write down the equation which represent heat transfer operation. How is the heat transfer coefficient related to thermal resistance ?

IV) Write down the equation for heat flow (Q) for a composite wall made up of three materials with thermal conductivities K_1, K_2, K_3 with thickness x_1, x_2, x_3 and with temperatures T_1, T_2, T_3 and T_4 at the faces.

(g) I) What is fixed operating cost and variable operating cost ?

II) Draw the chemical project cash flow graph.

III) What is piping and instrumentation diagram (P & ID) ?

IV) Define tensile strength and toughness of material used in plant.

(7.5×2=15)

Q2. (a) I) Define the continuity equation in the fluid mechanics. Derive the continuity equation for an incompressible fluid in three-dimensional Cartesian coordinates.

II) What pressure gradient is required to cause diethylaniline $C_6H_5N(C_2H_5)_2$, to flow in a horizontal, smooth, circular tube of inside diameter D = 3 cm at a mass rate of 1028 g/s at 20°C. At this temperature the density of diethylaniline is $\rho = 0.935$ g/cm^3 and its viscosity is $\mu = 1.95$ cp friction factor for turbulent flow in smooth tube can be estimated using, $f = 0.0791/R^{1/4}$?

(7.5×2=15)

(b) I) Derive the equation relating the friction factor to the pressure gradient for flow in a circular tube with an inside diameter D and length L.

II) Water is flowing at a velocity of 7 ft/s in both 1 in. and 2 in. Internal diameter pipes, which are joined together and fed into a 3 in. internal diameter pipe. Determine the water velocity in the 3 in. pipe at the outlet.

(5×2=10)

(c) I) What are the different types of corrosion encounter in chemical plants ? Suggest methods to prevent them.

II) Discuss the key properties that should be considered while selecting a material for chemical plant equipment.

(7.5×2=15)

Q3. (a) I) Ethanol (A) is diffusing through air (B) under steady state condition with air non-diffusing, at temperature 313 K and pressure 101.3 KPa. The partial pressure of ethanol at two planes 5 mm apart are 8 KPa and 4 KPa. The diffusivity of ethanol in air is $1.45\times10^{-5}\ \frac{m^2}{s}$, calculate

a) The rate of diffusion of ethanol per unit area of the planes.

b) The mole fractions of ethanol as a function of the distance along the direction of diffusion.

c) Use the result to evaluate the mole fraction at the centre of the diffusion path.

II) Ninty percent of the n-pentane is to be recovered by simple distillation from a mixture containing 20 mol% n-pentane and 80 mol% n-hexane. Determine

a) the amount of hexane distilled.

b) the composition of the residue.

Solve analytically using an average relative volatility α, value of 2.5g. (Assume basis of 100 Kmol of feed).

P.T.O.

(7.5×2=15)

(b) I) Derive the equation for McCabe -Thiele method for determining the number of theoretical stages in a binary distillation column. How does relative volatility influence the separation efficiency in plate column ?

II) In a gas-liquid contactor, a pure gas is absorbed in a solvent and the penetration theory provides a reasonable model by which to describe the transfer mechanism. As fresh solvent is exposed to the gas, the transfer rate is initially limited by the rate at which the gas molecules can reach the surface. If at 293 K and pressure of 1 bar the maximum possible rate of transfer of gas is 50 m^3/m^2s, express this as an equivalent resistance, when the gas solubility is 0.04 $Kmol/m^3$.
If the diffusivity in the liquid phase is 1.8×10^{-9} m^2/s at what time after the initial exposure will the resistance attributed to access of gas be equal to about 10% of the total resistance to transfer ?

(5×2=10)

(c) I) A pipeline constructed of carbon steel failed after 3 years of operation, on examination it was found that the wall thickness has been reduced by corrosion to about half the original value. The pipeline was constructed of nominal 304.8 mm (12 in) Schedule 40, pipe inside diameter 102.3 mm (4.026 in), outside diameter 114.3 mm (4.5 in). Estimate the rate of corrosion in inch per year and mm per year. Density of carbon steel is 490 lb/ft^3.

II) A chemical processing company is selecting a material for a new pressure vessel. The following three materials are under consideration :

Sr. No.	Material	Cost per Unit mass (Rs./Kg)	Density Kg/m^3	Max. allowable stress (N/mm^2)
1	Carbon Steel	200	7850	250
2	Stainless Steel	480	800	310
3	Titanium alloy	1250	4500	900

Determine which material is the most cost-effective based on the cost rating.

(7.5×2=15)

Q4. (a) I) A counter flow double pipe heat exchanger using super heated steam is used to heat water at the rate of 10500 kg/hr. The steam enters the heat exchanger at 180°C and leaves at 130°C. The inlet and exit temperature of water are 30°C and 80°C respectively. If the overall heat transfer coefficient from steam to water is 814 $w/m^2.k$. Calculate the heat transfer area. What would be the increase in area, if the fluid flow were parallel ?

The specific heat of water is 4.187×10^3 J/Kg.°C.

P.T.O.

II) A spherical container of negligible thickness holding a hot fluid at 140°C and having an outer diameter of 0.4 m is insulated with three layers of each 50 mm thick insulation of K_1= 0.02 W/m.k ; K_2 = 0.06 W/m.k; K_3 = 0.16 W/m.k (starting from inside).

The outside surface temperature is 30°C. Determine

i) The heat loss and

ii) Interface temperature of insulating layers.

(7.5×2=15)

(b) I) Consider a long cylindrical wire of radius R carrying an electric current. Due to the resistance of the material heat is generated internally at the uniform rate of Q per unit volume. The wire is in thermal equilibrium meaning that the heat generate is conducted radially outward and dissipated at the surface. The temperature at the surface of the wire is maintained at To.

a) Derive the temperature distribution T(r) within the wire.

b) Find the maximum temperature in the wire.

II) Demonstrate mathematically why counter-current heat exchangers are more preferred over co-current heat exchangers.

(5×2=10)

(c) I) Discuss in detail the various types of vessel supports used in chemical plants. Explain the factors influencing the selection of a particular type of support, including mechanical stability, thermal expansion and load distribution.

II) Provide example of an industry or process where vertical, horizontal and spherical type of storage vessel is used, explaining the reasons behind the choice.

SECTION – B

Q5. Write short notes on **any five** from seven : **(8×5=40)**

(a) Explain direct and indirect sensing methods for measurement of level.

(b) Describe with applications of Bypass and Recycle operations in chemical process industries.

(c) State and explain the First and Second law of thermodynamics.

(d) Explain preparation of wood pulp and paper by sulphate process.

(e) Explain heat of combustion and it's significance in energy balance calculation.

(f) What are CSTR and plug flow reactors ? Explain their operations and applications.

(g) Explain methanol manufacturing process via synthesis gas route.

Q6. (a) Explain waveforms of PID Action and give use of PID controllers for different types of applications like pressure, level, flow and temperature control. **15**

(b) Explain a control system and block diagram for a stirred tank heater. **15**

(c) Describe penicillin production process by fermentation. **10**

Q7. (a) Carbon monoxide and hydrogen react to give methanol. **15**

$CO + 2H_2 \rightarrow CH_3OH$

The conversion of CO entering the reactor is only 20%. A feed stream consisting of 33% CO, 66.5% H_2 and 0.5% CH_4 is mixed with a recycle stream and fed to a reactor. Methanol leaving the reactor is separated and the unconverted gases are recycled. To prevent the accumulation of CH_4 and keep its concentration in the recycle stream at 3%, a portion of the recycled stream is blown off for 100 moles of fresh feed. Determine

i) The moles of recycle stream.

ii) The moles of purge stream.

iii) The composition of the purge stream.

iv) The moles of methanol produced.

(b) An ideal gas is undergoing a series of three operations as follows : **15**

The gas is heated at constant volume from 300 K and 1 bar to a pressure of 2 bar. It is expanded in a reversible adiabatic process to a pressure of 1 bar. It is cooled at a constant pressure of 1 bar to 300 K. Determine the heat and work effects for each step.

Assume $C_P = 29.3 kJ/kmole\ K$, $\gamma = 1.4$, heat capacity ratio for adiabatic process PV^{γ} = constant.

(c) Explain domestic waste water treatment process. **10**

Q8. (a) Determine the enthalpy and entropy changes of liquid water for a change of state from 1 bar and 25°C to 1000 bar and 50°C. Use the following data : **15**

t/°C	P/bar	C_p/Jmole^{-1}k^{-1}	V/cm^{3}mole^{-1}	B/k^{-1}
25	1	75.305	18.071	256×10^{-6}
25	1000	–	18.012	366×10^{-6}
50	1	75.314	18.234	458×10^{-6}
50	1000	–	18.174	568×10^{-6}

For P = 1 bar, C_p = 75.310 Jmole^{-1}k^{-1}

For t = 50°C (V) = 18.204 cm^{3}mole^{-1}

$(\beta) = 513\times10^{-6}k^{-1}$

(b) The homogeneous gas decomposition of phosphine **15**

$4PH_{3(g)} \rightarrow P_{4(g)} + 6H_2$

Proceeds at 649°C with the first order rate

$-\gamma_{PH_3} = (10/hr)\, C_{PH_3}$

What size of plug flow reactor operating at 649°C and 460 kPa can produce 80% conversion of a feed consisting of 40 mole of pure phosphine per hour ?

ε_A = Expansion factor is 0.75.

(c) Explain factors responsible for Green house effect and give control strategies to reduce their impact. **10**

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