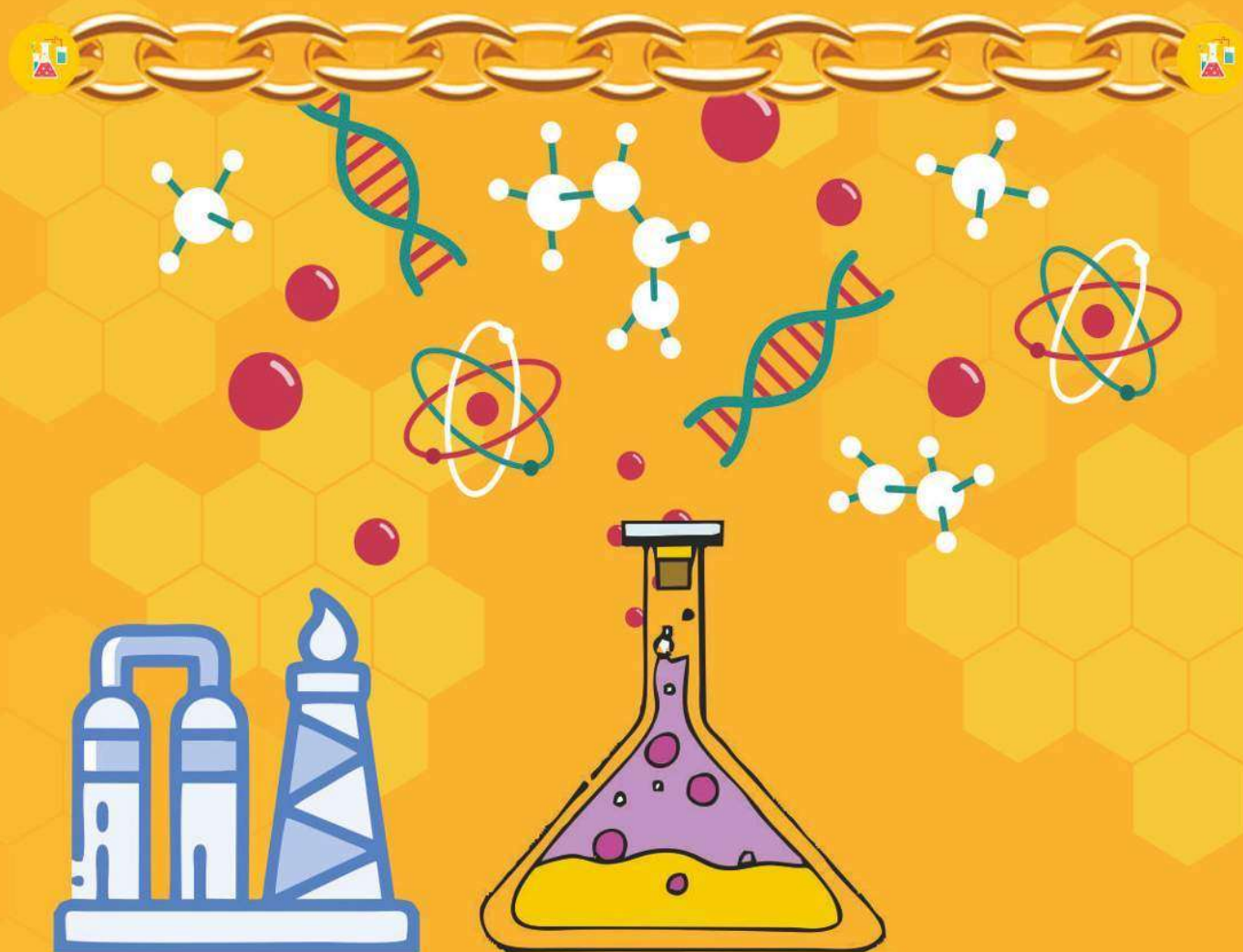


GATE

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Words of Guidance



Success in the GATE exam isn't just about understanding concepts — it's about mastering problem-solving with speed and precision under time pressure. With 65 questions to solve in just 180 minutes, aspirants must develop not only subject knowledge but also the **ability to approach, solve, and verify answers quickly and accurately.**

This book, a comprehensive compilation of **GATE Chemical Engineering Solved Papers**, is designed with that exact purpose. Questions are carefully **classified subject-wise** to help you target your weak areas and revise systematically. Every solution is presented in a **simple and easy-to-understand format**, with alternate solving methods wherever applicable, to strengthen your grasp of the concepts and problem-solving approach.

Practicing with real GATE questions gives you valuable exposure to the **latest trends**, types of questions asked, and helps build the **exam temperament** needed to perform under pressure. These papers serve not just as practice tools but also as an **insightful guide to GATE's evolving pattern.**

We strongly recommend aspirants to use this book as a **core part of their preparation**, and stay connected with us for access to **All India Mock Tests & Pre-GATE exams**, which are trusted by toppers for their **quality, accuracy, and exam-like experience.**

Special thanks to all our dedicated mentors and our loving students, whose remarkable success in GATE and PSUs continues to inspire us to deliver excellence every year.

Let this book be your constant companion in your GATE journey. Practice well, analyze smartly, and aim high.

R.K. Rajesh

Director

Engineers Institute of India

GATE SYLLABUS FOR CHEMICAL ENGINEERING (CH)

ENGINEERING MATHEMATICS

Linear Algebra: Matrix algebra, Systems of linear equations, Eigen values and eigenvectors.

Calculus: Functions of single variable, Limit, continuity and differentiability, Taylor series, Mean value theorems, Evaluation of definite and improper integrals, Partial derivatives, Total derivative, Maxima and minima, Gradient, Divergence and Curl, Vector identities, Directional derivatives, Line, Surface and Volume integrals, Stokes, Gauss and Green's theorems.

Differential equations: First order equations (linear and nonlinear), Higher order linear differential equations with constant coefficients, Cauchy's and Euler's equations, Initial and boundary value problems, Laplace transforms, Solutions of one dimensional heat and wave equations and Laplace equation.

Complex variables: Complex number, polar form of complex number, triangle inequality.

Probability and Statistics: Definitions of probability and sampling theorems, Conditional probability, Mean, median, mode and standard deviation, Random variables, Poisson, Normal and Binomial distributions, linear regression analysis.

Numerical Methods: Numerical solutions of linear and non-linear algebraic equations. Integration by trapezoidal and Simpson's rule. Single and multi-step methods for numerical solution of differential equations.

CHEMICAL ENGINEERING

Process Calculations and Thermodynamics: Steady and unsteady state mass and energy balances including multiphase, multicomponent, reacting and non-reacting systems. Use of tie components; recycle, bypass and purge calculations; Gibb's phase rule and degree of freedom analysis.

First and Second laws of thermodynamics. Applications of first law to close and open systems. Second law and Entropy. Thermodynamic properties of pure substances: Equation of State and residual properties, properties of mixtures: partial molar properties, fugacity, excess properties and activity coefficients; phase equilibria: predicting VLE of systems; chemical reaction equilibrium.

Fluid Mechanics and Mechanical Operations:

Fluid statics, Newtonian and non-Newtonian fluids, shell-balances including differential form of Bernoulli equation and energy balance, Macroscopic friction factors, dimensional analysis and similitude, flow through pipeline systems, flow meters, pumps and compressors,

elementary boundary layer theory, flow past immersed bodies including packed and fluidized beds, Turbulent flow: fluctuating velocity, universal velocity profile and pressure drop.

Particle size and shape, particle size distribution, size reduction and classification of solid particles; free and hindered settling; centrifuge and cyclones; thickening and classification, filtration, agitation and mixing; conveying of solids.

Heat Transfer: Steady and unsteady heat conduction, convection and radiation, thermal boundary layer and heat transfer coefficients, boiling, condensation and evaporation; types of heat exchangers and evaporators and their process calculations. Design of double pipe, shell and tube heat exchangers, and single and multiple effect evaporators.

Mass Transfer: Fick's laws, molecular diffusion in fluids, mass transfer coefficients, film, penetration and surface renewal theories; momentum, heat and mass transfer analogies; stage-wise and continuous contacting and stage efficiencies; HTU & NTU concepts; design and operation of equipment for distillation, absorption, leaching, liquid-liquid extraction, drying, humidification, dehumidification and adsorption.

Chemical Reaction Engineering: Theories of reaction rates; kinetics of homogeneous reactions, interpretation of kinetic data, single and multiple reactions in ideal reactors, non-ideal reactors; residence time distribution, single parameter model; non-isothermal reactors; kinetics of heterogeneous catalytic reactions; diffusion effects in catalysis.

Instrumentation and Process Control: Measurement of process variables; sensors, transducers and their dynamics, process modelling and linearization, transfer functions and dynamic responses of various systems, systems with inverse response, process reaction curve, controller modes (P, PI, and PID); control valves; analysis of closed loop systems including stability, frequency response, controller tuning, cascade and feed forward control.

Plant Design and Economics: Principles of process economics and cost estimation including depreciation and total annualized cost, cost indices, rate of return, payback period, discounted cash flow, optimization in process design and sizing of chemical engineering equipments such as compressors, heat exchangers, multistage contactors.

Chemical Technology: Inorganic chemical industries (sulphuric acid, phosphoric acid, chlor-alkali industry), fertilizers (Ammonia, Urea, SSP and TSP); natural products industries (Pulp and Paper, Sugar, Oil, and Fats); petroleum refining and petrochemicals; polymerization industries (polyethylene, polypropylene, PVC and polyester synthetic fibres).

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This booklet is designed exclusively for practicing and understanding previous years' GATE questions. Since the syllabus and pattern change very little, past questions offer valuable insight into topic weightage and difficulty level.

Solving these questions helps predict the nature of upcoming exam problems.

Practice each question seriously, analyze your mistakes, and work toward mastery.

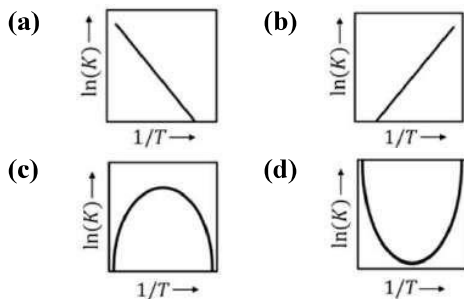
We also welcome your suggestions and feedback to improve future editions.

For any errors or corrections, kindly report them at eii.rkrajesh@gmail.com

1. CHEMICAL REACTION ENGINEERING
(GATE Previous Papers)

GATE-2023

1. For a reversible endothermic chemical reaction with constant heat of reaction over the operating temperature range, K is the thermodynamic equilibrium constant. Which one of the following figures shows the CORRECT dependence of K on temperature T ? **(1-Mark)**



2. CO and H_2 participate in a catalytic reaction. The partial pressures (in atm) of the reacting species CO and H_2 in the feed stream are p_{CO} and p_{H_2} , respectively. While CO undergoes molecular adsorption, H_2 adsorbs via dissociative adsorption, that is, as hydrogen atoms. The equilibrium constants (in atm^{-1}) corresponding to adsorption of CO and H_2 to the catalyst sites are K_{CO} and K_{H_2} , respectively. Total molar concentration of active sites per unit mass of the catalyst is C_t (in $\text{mol} \cdot (\text{g cat})^{-1}$). Both the adsorption steps are at equilibrium. Which one of the following expressions is the CORRECT ratio of the concentration of catalyst sites occupied by CO to that by hydrogen atoms? **(2-Marks)**

- (A) $\frac{K_{CO} p_{CO}}{\sqrt{K_{H_2} p_{H_2}}}$ (B) $\frac{K_{CO}}{\sqrt{K_{H_2}}}$
(C) $\frac{p_{CO}}{\sqrt{p_{H_2}}}$ (D) $\frac{K_{CO} p_{CO}}{K_{H_2} p_{H_2}}$

3. Fresh catalyst is loaded into a reactor before the start of the following catalytic reaction.
A → products

The catalyst gets deactivated over time. The instantaneous activity $a(t)$, at time t , is defined as the ratio of the rate of reaction $-r_A'(t) (\text{mol} \cdot (\text{g cat})^{-1} \text{hr}^{-1})$ to the rate of reaction with fresh catalyst. Controlled experimental measurements led to an empirical correlation $-r_A'(t) = 0.5t + 10$

where t is in hours. The activity of the catalyst at $t = 10$ hr is _____ (rounded off to one decimal place). **(2-Marks)**

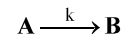
4. A unimolecular, irreversible liquid-phase reaction **(2-Marks)**



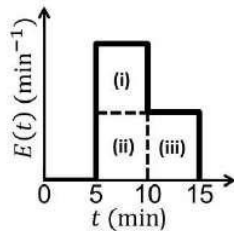
was carried out in an ideal batch reactor at temperature T . The rate of the reaction ($-r_A$) measured at different conversions X_A is given in the table below. This reaction is also carried out in an ideal continuous stirred tank reactor (CSTR) at the same temperature T with a feed concentration of $1 \text{ mol} \cdot \text{m}^{-3}$, under steady-state conditions. For a conversion 0.8, the space-time (ins) of the CSTR is _____ (in integer).

X_A	0	0.1	0.2	0.4	0.6	0.8
$-r_A$ ($\text{mol} \cdot \text{m}^{-3} \text{s}^{-1}$)	0.45	0.35	0.31	0.18	0.11	0.05

5. An irreversible liquid-phase second-order reaction **(2-Marks)**



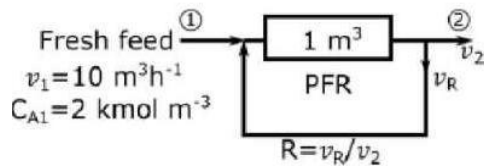
with rate constant $k = 0.2 \text{ liter} \cdot \text{mol}^{-1} \text{min}^{-1}$, is carried out in an isothermal non-ideal reactor. A tracer experiment conducted on this reactor resulted in a residence time distribution (E-curve) as shown in the figure below. The areas of the rectangles (i), (ii), and (iii) are equal. Pure A at a concentration of $1.5 \text{ mol} \cdot \text{liter}^{-1}$ is fed to the reactor. The segregated model mimics the non-ideality of this reactor. The percentage conversion of A at the exit of the reactor is _____ (rounded off to the nearest integer).



GATE-2022

6. An elementary irreversible liquid-phase reaction, $2A \rightarrow B$, is carried out under isothermal conditions in a 1 m^3 ideal plug flow reactor (PFR) as shown in the figure. The volumetric flow rate of fresh A, $v_1 = 10\text{ m}^3\text{ h}^{-1}$, and its concentration $C_{A1} = 2\text{ kmol m}^{-3}$. For a recycle ratio $R = 0$, the conversion of A at location 2 with respect to the fresh feed (location 1) is 50%. For $R \rightarrow \infty$, the corresponding conversion of A is _____ % (rounded off to one decimal place)

(1-Mark)



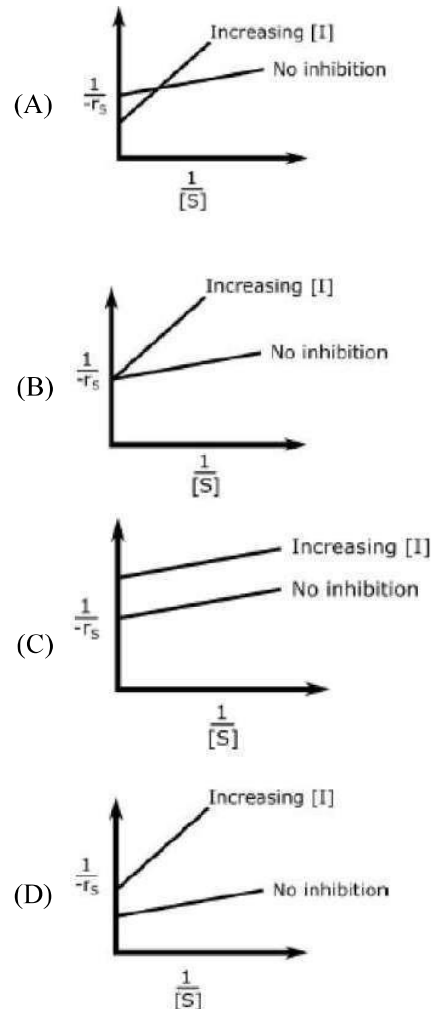
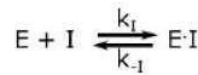
7. The reaction $A \rightarrow B$ is carried out isothermally on a porous catalyst. The intrinsic reaction rate is kC_A^2 , where k is the rate constant and C_A is the concentration of A. If the reaction is strongly pore-diffusion controlled, the observed order of the reaction is:

(1-Mark)

- (A) 1 (B) 3/2
(C) $\sqrt{2}$ (D) 2

8. In an enzymatic reaction, an inhibitor (I) competes with the substrate (S) to bind with the enzyme (E), thereby reducing the rate of product (P) formation. The competitive inhibition follows the reaction mechanism shown below. Let $[S]$ and $[I]$ be the concentration of S and I, respectively, and r_s be the rate of consumption of S. Assuming pseudo-steady state, the correct plot of $\frac{1}{-r_s}$ vs $\frac{1}{[S]}$ is

(1-Mark)

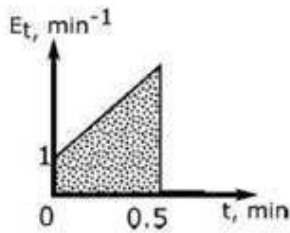


9. A compressor with a life of 10 years costs Rs 10 lakhs. Its yearly operating cost is Rs 0.5 lakh. If the annual compound interest rate is 8%, the amount needed at present to fund perpetual operation of the compressor is Rs _____ lakhs (rounded to first decimal place).

(2-Mark)

10. An elementary irreversible liquid-phase reaction, $2P \xrightarrow{k} Q$, where the rate constant $k = 2\text{ L}^{-1}\text{ min}^{-1}$, takes place in an isothermal non-ideal reactor. The E-curve in a tracer experiment is shown in the figure. Pure P (2 mol L^{-1}) is fed to the reactor. Using the segregated model, the percentage conversion of P at the exit of the reactor is _____ % (rounded off to the nearest integer).

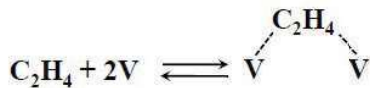
(2-Mark)



11.....An elementary irreversible gas-phase reaction $A \rightarrow B+C$, is carried out at fixed temperature and pressure in two separate ideal reactors: (i) a 10m^3 plug flow reactor (PFR), (ii) a 10m^3 continuous-stirred tank reactor (CSTR). If pure A is fed at $5\text{m}^3\text{h}^{-1}$ the PFR operating at 400 K, the conversion is 80%. If a mixture of 50 mol% of A and 50 mol% of an inert is fed at $5\text{m}^3\text{h}^{-1}$ to the CSTR operating at 425 K, the conversion is 80%. The universal gas constant $R = 8.314\text{J mol}^{-1}\text{K}^{-1}$. Assuming the Arrhenius rate law, the estimated activation energy is _____ kJ mol^{-1} (rounded off to one decimal place).

GATE-2021

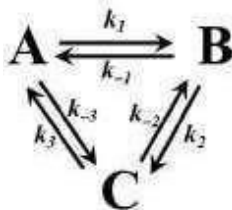
12. Ethylene adsorbs on the vacant active sites V of a transition metal catalyst according to the following mechanism.



If N_T, N_V and $N_{\text{C}_2\text{H}_4}$ denote the total number of active sites, number of vacant active sites and number of adsorbed C_2H_4 molecules, respectively, the balance on the total number of active sites is given by (1-Mark)

- (A) $N_T = N_V + N_{\text{C}_2\text{H}_4}$
- (B) $N_T = N_V + 2N_{\text{C}_2\text{H}_4}$
- (C) $N_T = 2N_V + N_{\text{C}_2\text{H}_4}$
- (D) $N_T = N_V + 0.5N_{\text{C}_2\text{H}_4}$

13. The following homogeneous liquid phase reactions are at equilibrium.



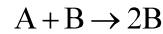
The values of rate constants are given by:

$$k_1 = 0.1\text{s}^{-1}, k_{-1} = 0.2\text{s}^{-1}, k_2 = 1\text{s}^{-1},$$

$$k_{-2} = 10\text{s}^{-1}, k_3 = 10\text{s}^{-1}.$$

The value of rate constant k_{-3} is _____ s^{-1} (round off to 1 decimal place). (1-Mark)

14. The following isothermal autocatalytic reaction,



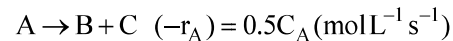
$$(-r_A) = 0.1C_A C_B (\text{mol L}^{-1} \text{s}^{-1})$$

is carried out in an ideal continuous stirred tank reactor (CSTR) operating at steady state. Pure A at 1mol L^{-1} is fed, and 90% of A is converted in the CSTR. The space time of the CSTR is _____ seconds. (2-Marks)

15. Reactant A decomposes to products B and C in the presence of an enzyme in a well-stirred batch reactor. The kinetic rate expression is given by $-r_A = \frac{0.01C_A}{0.05 + C_A} (\text{mol L}^{-1} \text{min}^{-1})$

If the initial concentration of A is 0.02mol L^{-1} , the time taken to achieve 50% conversion of A is _____ min (round off to 2 decimal places). (2-Marks)

16. The following homogeneous, irreversible reaction involving ideal gases,



is carried out in a steady state ideal plug flow reactor (PFR) operating at isothermal and isobaric conditions. The feed stream consists of pure A, entering at 2m s^{-1} . In order to achieve 50% conversion of A, the required length of the PFR is _____ meter (round off to 2 decimal places). (2-Marks)

GATE-2020

17. The decomposition of acetaldehyde (X) to methane and carbon monoxide follows four-step free radical mechanism. The overall rate of decomposition of X is

$$-r_X = k_2 \left(\frac{k_1}{2k_3} \right)^{1/2} C_X^{3/2} = k_{\text{overall}} C_X^{3/2}$$

where, k_1, k_2 and k_3 denote the rate constants of the elementary steps, with corresponding activation energies (in kJ mol^{-1}) of 320, 40, and 0, respectively. The temperature dependency of the rate constants is described by Arrhenius equation.

(A)
$$\frac{kK_A p_A p_B}{[1 + K_A p_A + K_B p_B]}$$

(B)
$$\frac{kK_B p_A p_B}{[1 + K_A p_A + K_B p_B]}$$

(C)
$$\frac{kK_A K_B p_A p_B}{[1 + K_A p_A + K_B p_B + K_C p_C]}$$

(D)
$$\frac{kK_A K_B p_A p_B}{[1 + K_A p_A + K_B p_B + K_C p_C]^2}$$



ANSWER KEY

1	2	3	4	5	6	7	8	9	10
A	A	0.5	16	72	37.2-39.2	B	B	24.878	50
11	12	13	14	15	16	17	18	19	20
45.5-49.5	B	0.5	100	4.44-4.51	3.49-3.61	199-201	D	C	0.75
21	22	23	24	25	26	27	28	29	30
2.866	2	0.5	0.5	C	D	64.64	855.7	67	133.27
31	32	33	34	35	36	37	38	39	40
A	C	0.816	50	6	0.035	0.40	A	B	C
41	42	43	44	45	46	47	48	49	50
0.60	1	0.8	4	20.4	2	C	28.6	0.26671	8
51	52	53	54	55	56	57	58	59	60
B	0.25	B	A	B	A	C	0.801	A	D
61	62	63	64	65	66	67	68	69	70
B	C	D	0.5	0.32	0.50	1.0	51.7	20.0	90
71	72	73	74	75	76	77	78	79	80
D	D	B	B	C	B	C	A	B	A
81	82	83	84	85	86	87	88	89	90
B	C	B	D	A	A	B	C	A	C
91	92	93	94	95	96	97	98	99	100
C	C	D	B	B	A	C	A	C	D
101	102	103	104	105	106	107	108	109	110
B	A	C	C	B	C	B	C	B	A
111	112	113	114	115	116	117	118	119	120
B	B	A	A	A	C	D	A	B	D
121	122	123	124	125	126	127	128	129	130
C	D	B	D	A	C	A	B	D	A
131	132	133	134	135	136	137	138	139	140
C	A	C	A	B	A	D	C	C	D
141	142	143	144	145	146	147	148	149	150
C	C	A	B	B	D	B	D	A	B
151	152	153	154	155	156	157	158	159	160
C	D	C	D	D	A	B	D	B	D
161	162	163	164	165	166	167	168	169	170
B	C	B	B	B	A	A	C	A	C
171	172	173	174	175	176	177			
A	C	B	C	A	C	D			

SOLUTIONS

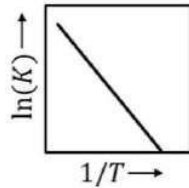
GATE-2023

1. A

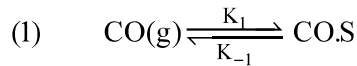
From Van't Hoff equations on integration

$$\frac{d(\ln K)}{dT} = \frac{\Delta H_{rxn}^{\circ}}{RT^2}$$

$$\Rightarrow \ln K = -\frac{\Delta H_{rxn}^{\circ}}{RT} + C$$

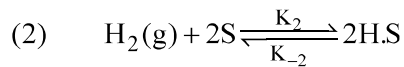


2. A



$$\therefore K_{co} = \frac{K_1}{K_{-1}} = \frac{[CO.S]}{[S]p_{co}}$$

$$\Rightarrow [CO.S] = K_{co} \cdot p_{co}[S] \dots(1)$$



$$K_{H_2} = \frac{K_2}{K_{-2}} = \frac{[H.S]^2}{p_{H_2} \cdot [S]^2}$$

$$\Rightarrow [H.S]^2 = K_{H_2} \cdot p_{H_2} [S]^2$$

$$\Rightarrow [H.S] = \sqrt{K_H p_{H_2}} [S] \dots(2)$$

Acc. to question form (1) and (2)

$$\frac{[CO.S]}{[H.S]} = \frac{K_{co} p_{co} [S]}{\sqrt{k_H p_{H_2}} [S]} = \frac{k_{co} p_{co}}{\sqrt{k_H p_{H_2}}}$$

3. 0.5

$$\text{Activity } a = \frac{-r'_A}{-r_A}$$

$$\text{Given, } -r'_A = -0.5t + 10$$

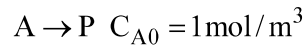
Rate of reaction with fresh catalyst i.e. $t = 0$

$$\therefore -r_A = -(0.5)0 + 10 = 10$$

Then activity at $t = 10$ hr

$$a|_{t=10hr} = \frac{-0.5(10) + 10}{10} = 0.5$$

4. 16



$$X_A = 0.8 \frac{V}{F_{A0}} = \frac{X_A}{-r_A}$$

$$\frac{\tau}{C_{A0}} = \frac{X_A}{-r_A} = \frac{0.8}{0.05}$$

$$\tau = \frac{0.8}{0.05} \times 1 = 16 \text{ s}$$

5. 72

As, area under E-curve

$$\int_0^{\infty} E(t) dt = 1$$

$$\Rightarrow A_1 + A_2 + A_3 = 1$$

$$(\because A_1 = A_2 = A_3 = A) \therefore 3A = 1$$

$$\Rightarrow A = \frac{1}{3} \text{ i.e. area rectangle } (\ell \times b)$$

$$\Rightarrow \ell \times 5 = \frac{1}{3} \Rightarrow \ell = \frac{1}{15} \therefore 2\ell = \frac{2}{15}$$

For $n = 2$

$$tk C_{A0} = \frac{X_A}{1 - X_A}$$

$$\text{or } X_A = \frac{tk C_{A0}}{1 + tk C_{A0}}$$

$$\text{Given, } k = 0.2, C_{A0} = 1.5$$

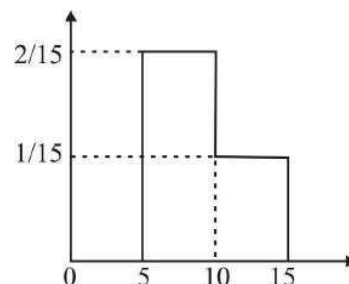
$$X_A = \frac{0.3t}{1 + 0.3t}$$

Now, mean conversion

$$\bar{X}_A = \int_0^{\infty} X(t) E(t) dt$$

$$\bar{X}_A = \int_5^{10} \frac{0.3t}{1 + 0.3t} E_1(t) dt + \int_{10}^{15} \frac{0.3t}{1 + 0.3t} E_2(t) dt$$

$$E_1(t) = \frac{2}{15}, \quad E_2(t) = \frac{1}{15}$$



$$= \int_5^{10} \frac{kC_{A0}t}{1+kC_0t} \times \frac{2}{15} dt + \int_{10}^{15} \frac{kC_{A0}t}{1+kC_{A0}t} \frac{1}{15} dt$$

$$= \frac{2}{15} \int_5^{10} \frac{0.3t}{1+0.3t} dt + \frac{1}{15} \int_{10}^{15} \frac{0.3t}{1+0.3t} dt = 0.72$$

X = 72%

GATE-2022

6. 37.2- 39.2

For PFR, $\frac{X_A}{1-X_A} = kC_{A0}\tau_P$

(when recycle ratio is zero.)

$$\frac{0.50}{0.50} = k \times 2 \times \frac{1}{10} \Rightarrow k = 5 \frac{m^3}{kmol.hr}$$

When Recycle ratio goes to infinity. PFR behaves as a CSTR.

Now, $\frac{1}{10C_{A0}} = \frac{X_A}{kC_{A0}^2(1-X_A)^2}$

$$\Rightarrow X_A^2 - 3X_A + 1 = 0$$

$$X_A = 38.2\%$$

7. B

The reaction $A \rightarrow B$ is carried out isothermally in porous catalyst given rate of reaction $r_A = kC_A^2$

In case of strongly pore diffusion for given

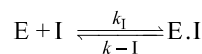
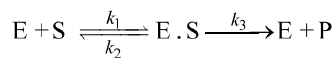
rate of reaction $r_A = kC_A^n$

$$\text{Observed order} = \frac{n+1}{2}$$

Here n = 2, So observed rate of reaction

$$= \frac{2+1}{2} = \frac{3}{2}$$

8. B



Rate with inhibition, $-r_{S1} = \frac{k_3[E]_0[S]}{[S] + C_M([I] + [E])}$

Rate without inhibition, $-r_{S2} = \frac{k_3[E]_0[S]}{[S] + C_M}$

At high [S], $-r_{S1} = k_3[E]_0$ $-r_{S2} = k_3[E]_0$

i.e., at high [S] \Rightarrow low $\frac{1}{[S]}$, $-r_{S1}$ and $-r_{S2}$ are equal.

At low [S], $-r_{S1} = \frac{k_3[E]_0[S]}{C_M([I] + [E]_0)}$

$$\Rightarrow \frac{-1}{r_{S1}} = \frac{C_M([I] + [E]_0)}{k_3[E]_0} \cdot \frac{1}{[S]}$$

$$\Rightarrow \text{Slope} = \frac{C_M}{k_3[E]_0} ([I] + [E]_0)$$

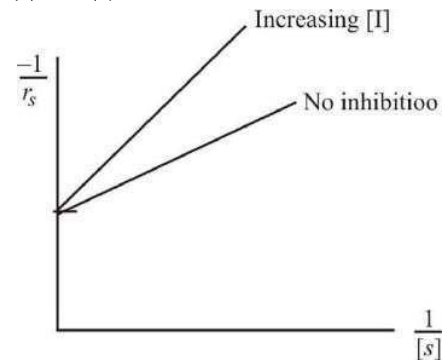
$$-r_{S2} = \frac{k_3[E]_0[S]}{C_M} \Rightarrow \frac{-1}{r_{S2}} = \frac{C_M}{k_3[E]_0} \cdot \frac{1}{[S]}$$

$$\text{Slope} = \frac{C_M}{k_3[E]_0}$$

Slope with inhibition > Slope without inhibition

at low [S] \Rightarrow high $\frac{1}{[S]}$... (2)

From (1) and (2)



Option (B) is correct.

9. 24.878

Total capitalized cost of perpetuity

$$K = \text{Initial cost of equipment} + \frac{\text{Replacement cost}}{(1+i)^n - 1}$$

$$+ \frac{\text{Operating cost per year}}{i}$$

$$K = V_0 + \frac{(V_0 - V_s)}{(1+i)^n - 1} + \frac{\text{Operating cost per year}}{i}$$

From given data Salvage value $V_s = 0$

$$V_0 = 10 \text{ lac } i = 0.08, n = 10 \text{ years}$$

Operating cost/year = 0.5 lac

$$K = 10 + \frac{(10 - 0)}{(1 + 0.08)^{10} - 1} + \frac{0.5}{0.08}$$

$$K = 10 + 8.628 + 6.25 = 24.878 \text{ lac}$$

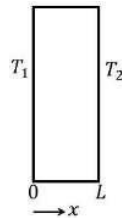
10. 50

Area of E curve

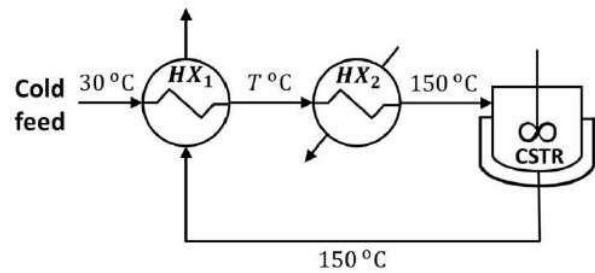
2. HEAT TRANSFER
(GATE Previous Papers)

GATE-2023

1. A slab of thickness L , as shown in the figure below, has cross-sectional area A and constant thermal conductivity k . T_1 and T_2 are the temperatures at $x=0$ and $x=L$, respectively. Which one of the following options is the CORRECT expression of the thermal resistance for steady-state one-dimensional heat conduction? **(1-Mark)**



- (A) $\frac{L}{kA}$ (B) $\frac{k}{LA}$
 (C) $\frac{kA(T_1 - T_2)}{L}$ (D) $\frac{A}{Lk}$
2. Spray dryers have many advantages. Which one of the following is NOT an advantage of a typical spray dryer? **(1-Mark)**
- (A) Has short drying time
 (B) Produces hollow spherical particles
 (C) Has high heat efficiency
 (D) Is suitable for heat sensitive materials
3. An isothermal jacketed continuous stirred tank reactor (CSTR) operating at 150°C is shown in the figure below. The cold feed entering the system at 30°C is preheated to a temperature T ($T < 150^\circ\text{C}$) using a heat exchanger HX_1 . This preheated feed is further heated to 150°C using the utility heater HX_2 . The mass flow rate and heat capacity are same for all the process streams, and the overall heat transfer coefficient is independent of temperature. Which one of the following statements is the CORRECT action to take if it is desired to increase the value of T ? **(1-Mark)**



- (A) Increase both heat transfer area of HX_1 and heat duty of HX_2 .
 (B) Decrease both heat transfer area of HX_1 and heat duty of HX_2 .
 (C) Increase the heat transfer area of HX_1 and decrease the heat duty of HX_2 .
 (D) Decrease the heat transfer area of HX_1 and increase the heat duty of HX_2 .

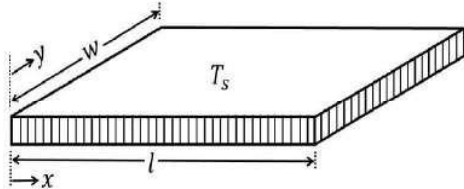
4. Given that E (in $\text{W}\cdot\text{m}^{-2}$) is the total hemispherical emissive power of a surface maintained at a certain temperature, which of the following statements is/are CORRECT?

(1-Mark)

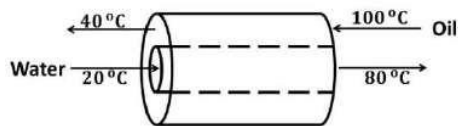
- (A) E does not depend on the direction of the emission.
 (B) E depends on the view factor.
 (C) E depends on the wavelength of the emission.
 (D) E does not depend on the frequency of the emission.

5. A fluid is flowing steadily under laminar conditions over a thin rectangular plate at temperature T_s as shown in the figure below. The velocity and temperature of the free stream are u_∞ and T_∞ , respectively. When the fluid flow is only in the x -direction, h_x is the local heat transfer coefficient. Similarly, when the fluid flow is only in the y -direction, h_y is the corresponding local heat transfer coefficient. Use the correlation $Nu = 0.332 (Re)^{1/2} (Pr)^{1/3}$ for the local heat transfer coefficient, where, Nu , Re , and Pr , respectively are the appropriate Nusselt, Reynolds and Prandtl numbers. The

average heat transfer coefficients are defined as $\bar{h}_l = \frac{1}{l} \int_0^l h_x dx$ and $\bar{h}_w = \frac{1}{w} \int_0^w h_y dy$. If $w = 1\text{m}$ and $l = 4\text{m}$, the value of the ratio of \bar{h}_w to \bar{h}_l is ____ (in integer). (2-Marks)



6. A perfectly insulated, concentric tube counter current heat exchanger is used to cool lubricating oil using water as a coolant (see figure below). Oil enters the outer annulus at a mass flow rate of 2 kg.s^{-1} with a temperature of 100°C and leaves at 40°C . Water enters the inner tube at a mass flow rate of 1 kg.s^{-1} with a temperature of 20°C and leaves at 80°C . Use specific heats of oil and water as $2089\text{ J.kg}^{-1}\text{K}^{-1}$ and $4178\text{ J.kg}^{-1}\text{K}^{-1}$, respectively. There is no phase change in both the streams. Under steady-state conditions, the number of transfer units (NTU) is ____ (in integer). (2-Marks)



GATE-2022

7. A single-effect evaporator with a heat transfer area of 70m^2 concentrates a salt solution using steam. The salt solution feed rate and temperature are 10000 kg h^{-1} and 40°C , respectively. The saturated steam feed rate and temperature are 7500 kg h^{-1} and 150°C , respectively. The boiling temperature of the solution in the evaporator is 80°C . The average specific heat of the solution is $0.8\text{ kcal kg}^{-1}\text{K}^{-1}$. The latent heat of vaporization is 500 kcal kg^{-1} . If the steam-economy is 0.8, the overall heat transfer coefficient is ____

$\text{kcal h}^{-1}\text{m}^{-2}\text{K}^{-1}$ (rounded off to the nearest integer). (2-Mark)

8. A cylindrical fin of diameter 24 mm is attached horizontally to a vertical planar wall. The heat transfer rate from the fin to the surrounding air is 60% of the heat transfer rate if the entire fin were at the wall temperature. If the fin effectiveness is 10, its length is ____ mm (rounded off to the nearest integer). (1-Mark)

9. Consider a bare long copper wire of 1 mm diameter. Its surface temperature is T_s and the ambient temperature is T_a ($T_s > T_a$). The wire is to be coated with a 2 mm thick insulation. The convective heat transfer coefficient is $20\text{ W m}^{-2}\text{K}^{-1}$. Assume that T_s and T_a remain unchanged. To reduce heat loss from the wire, the maximum allowed thermal conductivity of the insulating material, in $\text{W m}^{-1}\text{K}^{-1}$, rounded off to two decimal places, is (2-Mark)

- (A) 0.02 (B) 0.10
(C) 0.04 (D) 0.01

10. Two large parallel planar walls are maintained at 1000 K and 500 K. Parallel radiation shields are to be installed between the two walls. Assume that the emissivities of the walls and the shields are equal. If the melting temperature of the shields is 900 K, the maximum number of shields (s) that can be installed between the walls is (are) (1-Mark)

- (A) 0 (B) 2 (C) 3 (D) 1

11. Saturated steam condenses on a vertical plate maintained at a constant wall temperature. If x is the vertical distance from the top edge of the plate, then the local heat transfer coefficient $h(x) = \Gamma(x)^{-1/3}$, where $\Gamma(x)$ is the local mass flow rate of the condensate per unit plate width. The ratio of the average heat transfer coefficient over the entire plate to the heat transfer coefficient at the bottom of the plate is (2-Mark)

- (A) 4/3 (B) 3/4
(C) 4 (D) 3

12. A perfectly insulated double pipe heat exchanger is operating at steady state. Saturated steam enters the inner pipe at 100°C and leaves as saturated water at 100°C . Cooling water enters the outer pipe at 75°C and exits at 95°C .

ANSWER KEY

1	2	3	4	5	6	7	8	9	10
A	C	C	A, C	2	3	677.55	94	A	D
11	12	13	14	15	16	17	18	19	20
A	0.14	B	B	C	42-44	89-91	362-363	A	C
21	22	23	24	25	26	27	28	29	30
34.76	D	100.57	1.77	A	B	D	902.68	0.305	800
31	32	33	34	35	36	37	38	39	40
C	B	13.06	28.2	0.52	27.0	B	300	C	C
41	42	43	44	45	46	47	48	49	50
B	3.9	C	D	B	A	0.25	A	A	250.9
51	52	53	54	55	56	57	58	59	60
C	C	A	D	17.14	3.85	271.07	D	D	5.67
61	62	63	64	65	66	67	68	69	70
C	D	D	B	D	A	B	B	B	A
71	72	73	74	75	76	77	78	79	80
B	A	A	A	B	A	A	D	B	A
81	82	83	84	85	86	87	88	89	90
B	B	C	B	A	D	D	B	B	D
91	92	93	94	95	96	97	98	99	100
B	B	D	C	B	B	A	D	B	A
101	102	103	104	105	106	107	108	109	110
C	D	B	A	D	D	A	D	B	B
111	112	113	114	115	116	117	118	119	120
C	D	B	C	A	C	A	C	B	A
121	122	123	124	125	126	127	128	129	130
A	D	D	A	A	B	A	B	D	A
131	132	133	134	135	136	137	138	139	140
A	D	B	B	D	D	A	D	C	B
141	142	143	144	145	146	147	148		
B	B	C	C	D	A	D	C		

SOLUTIONS

GATE-2023

1. A

$$Q = \frac{KA\Delta T}{x}$$

$$(\text{rate}) = \frac{\text{driving force}}{\text{resistance}} = \frac{\Delta T}{\frac{x}{kA}} = \frac{T_2 - T_1}{\frac{(L-0)}{kA}} = \frac{T_2 - T_1}{\frac{L}{kA}}$$

$$\text{Resistance} = \frac{L}{kA}$$

2. C

Spray drying is a kind of unit operation with high energy consumption and relatively low energy utilization.

$$\mu = \left\{ \frac{\text{Heat of material} + \text{Heat of water evaporation}}{\text{Heat input}} \right\} \times 100$$

3. C

To increase the value of T , we need more heat exchange at HX_1 and now as T is increased, to maintain outlet Temperature at 150°C , we need to decrease heat duty of HX_2 . To improve Heat exchange at HX_1 we need to increase Heat Transfer Area of HX_1 .

4. A, C

$$E = \int_0^\infty E_\lambda d\lambda$$

So, E depends on wavelength and frequency.

E does not depend on direction of emission and view factor.

5. 2

$$\text{Velocity} = u_\infty \quad \text{Temperature} = T_\infty$$

$$Nu = 0.332(Re)^{1/2}(Pr)^{1/3}$$

$$\Rightarrow \frac{h_x \cdot x}{K} = 0.332 \left(\frac{\rho u_\infty x}{\mu} \right)^{1/2} (Pr)^{1/3}$$

$$h_x \propto (x)^{-1/2} \frac{h_y \cdot y}{K} = 0.332 \left(\frac{\rho u_\infty y}{\mu} \right)^{1/2} (Pr)^{1/3}$$

$$\Rightarrow h_y \propto (y)^{-1/2}$$

$$\text{Now, } \bar{h}_\ell \propto \frac{1}{\ell} \int_0^\ell (x)^{-1/2} dx$$

$$\propto \frac{1}{\ell} \cdot \frac{(x)^{-\frac{1}{2}+1}}{1-\frac{1}{2}} \Big|_0^\ell \Rightarrow \propto \frac{1}{\ell} \cdot \frac{\sqrt{x}}{(1/2)} \Big|_0^\ell \Rightarrow \propto \frac{2}{\ell} \cdot \sqrt{\ell}$$

$$\bar{h}_\ell \propto \frac{2}{\sqrt{\ell}} \Rightarrow \bar{h}_w \propto \frac{1}{w} \int_0^w (y)^{-1/2} dy$$

$$\propto \frac{1}{w} \cdot \frac{(y)^{-\frac{1}{2}+1}}{1-\frac{1}{2}} \Big|_0^w \Rightarrow \propto \frac{1}{w} \cdot \frac{\sqrt{y}}{1/2} \Big|_0^w$$

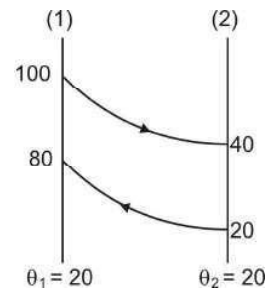
$$\Rightarrow \bar{h}_w \propto \frac{2}{w} \sqrt{w} \Rightarrow \bar{h}_w \propto \frac{2}{\sqrt{w}}$$

$$\Rightarrow \frac{\bar{h}_w}{\bar{h}_\ell} = \frac{2/\sqrt{w}}{2/\sqrt{\ell}} = \frac{\sqrt{\ell}}{\sqrt{w}} = \frac{\sqrt{4}}{\sqrt{1}} = 2$$

6. 3

$$\dot{m}_h = 2 \text{ kg/sec} \quad \Rightarrow \quad \dot{m}_c = 1 \text{ kg/sec}$$

$$C_{Ph} = 2089 \frac{\text{J}}{\text{kg K}} \quad \Rightarrow \quad C_{Pc} = 4178 \frac{\text{J}}{\text{kg K}}$$



$$\therefore \theta_1 = \theta_2 = \theta_m (\dot{m}_h C_{Ph} = \dot{m}_c C_{Pc})$$

$$\varepsilon = \frac{\text{actual heat transfer}}{\text{maximum heat transfer}}$$

$$\varepsilon = \frac{\dot{m}_h C_{Ph} (100 - 40)}{\dot{m}_h C_{Ph} (100 - 20)} = \frac{60}{80}$$

$$\varepsilon = \left(\frac{3}{4} \right) = 0.75 \quad R = \frac{C_{\min}}{C_{\max}} = 1$$

$$\Rightarrow \varepsilon = \frac{NTU}{1 + NTU}$$

$$\Rightarrow \frac{3}{4} = \frac{NTU}{1 + NTU} \quad \Rightarrow \quad NTU = 3$$

GATE-2022

7. 677.55

Steam Economy =

$$\frac{\text{Vapor flow rate}}{\text{steam rate fed to the evaporator}}$$

$$0.8 = \frac{V}{7500} \Rightarrow V = 6000 \text{ kg/hr}$$

Using energy balance around evaporator

$$Q = FC_p(T - T_F) + V\lambda_v$$

$$Q = 10000 \times 0.8(80 - 40) + 6000 \times 500$$

$$Q = 3.32 \times 10^6 \frac{\text{Kcal}}{\text{hr}}$$

Overall heat transfer coefficient using 70m^2 heat transfer area

$$Q = UA\Delta T$$

$$3.32 \times 10^6 \text{ kcal} = U \times 70 \times (T_{\text{steam}} - T_{\text{solution}})$$

$$U = \frac{3.32 \times 10^6}{70\text{m}^2 \times (150 - 80)\text{K}} = 677.55 \frac{\text{kcal}}{\text{h m}^2\text{K}}$$

8. 94

$$D = 0.024\text{m}$$

$Q_{\text{actual}} = 0.6 Q_{\text{Entire fin at base temperature}}$
& Effectiveness (ξ) = 10

$$\text{So, } \eta = \frac{Q_{\text{actual}}}{Q_{\text{entire fin at base temperature}}} = 0.6$$

&

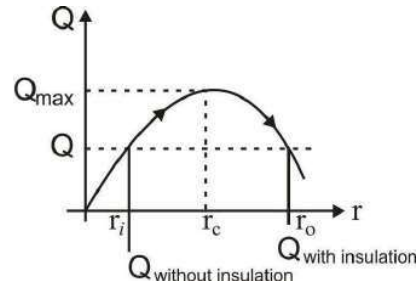
$$\frac{\xi}{\eta} = \frac{A_s(\text{surface area of fin})}{A_c(\text{cross sectional of fin})}$$

$$\frac{\xi}{\eta} = \frac{10}{0.6} = \frac{Pl + A_c}{A_c} = \frac{\pi D l + \frac{\pi}{4} D^2}{\frac{\pi}{4} D^2}$$

$$\frac{100}{6} = \frac{\pi \times 0.024 \times l + \frac{\pi}{4} \times (0.024)^2}{\frac{\pi}{4} (0.024)^2} =$$

$$= \frac{l}{\frac{0.024}{4}} + \frac{1}{\frac{1}{4}} = 94\text{mm}$$

9. A



$$d_i = 1\text{mm} = 1 \times 10^{-3}\text{m} \quad d_o = 5 \times 10^{-3}\text{m}$$

$$h = 20 \text{ W/m}^2\text{K} \quad d_o = d_i + 2t$$

t → thickness of insulation

$$Q_{\text{without insulation}} = Q_{\text{with insulation}}$$

$$hA_i(T_s - T_a) = \frac{(T_s - T_a)}{\ln \frac{r_o}{r_i} + \frac{1}{2\pi Lk} + \frac{1}{hA_o}}$$

$$20 \times 2\pi \times r_i(AT) = \frac{\Delta T}{\ln \frac{r_o}{r_i} + \frac{1}{20 \times 2\pi \times r_o}}$$

$$20 \times 0.5 \times 10^{-3} = \frac{1}{\ln \frac{2.5 \times 10^{-3}}{0.5 \times 10^{-3}} + \frac{1}{20 \times 2.5 \times 10^{-3}}}$$

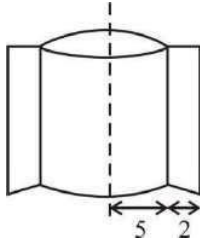
$$\Rightarrow 0.01 = \frac{1}{\frac{1.609}{k} + \frac{1}{0.05}}$$

$$r_{cr} = \frac{k}{h} = \frac{0.6}{8} = 0.075 \text{ m} = 7.5 \text{ cm}$$

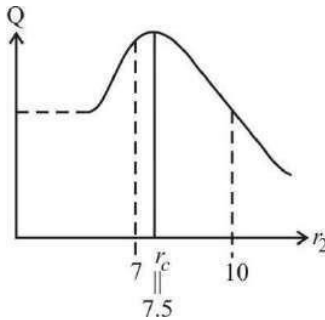
Insulation thickness = 2 cm

$$r_2 = 5 + 2 = 7 \text{ cm}$$

$$r_2 < r_{cr}$$



Heat loss increases upto $r_2 = 7.5 \text{ cm}$ and thereafter it will decrease.



So, at $r_2 = 7 \text{ cm}$, heat loss from the pipe will be greater than that of an un-insulated steam pipe.

If the thickness of insulation = 5 cm,
 $r_2 = 5 + 5 = 10 \text{ cm}$.

⇒ Heat loss from a 2 cm thick insulated pipe will be greater than heat loss from a steam pipe with 5 cm insulation.

138. D

$$\frac{T_f - T_\infty}{T_i - T_\infty} = \exp\left[\frac{-hA}{mC_p} t\right]$$

$$\frac{120 - 150}{30 - 150} = \exp\left[-\frac{1000 \times 4000}{1500 \times 1.2} \times t\right]$$

$$t = 3080.65 \text{ sec} = 51.34 \text{ min}$$

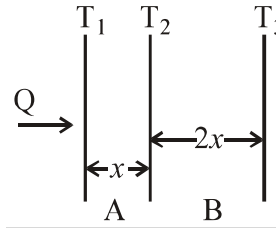
139. C

At steady state heat fluxes across both plates A and B are equal

$$Q_A = Q_B \frac{K_A \Delta T_A}{x} = \frac{K_B \Delta T_B}{2x} \frac{2K_A}{K_B} = \frac{\Delta T_B}{\Delta T_A}$$

Given $\Delta T_A > \Delta T_B \therefore \frac{\Delta T_B}{\Delta T_A} < 1$

So, $\frac{2K_A}{K_B} < 1 \quad K_A < 0.5K_B$



GATE-2001

140. B

By painting the surface white it reduces its absorptivity as well as emissivity.

141. B

For natural convection

$$Nu = f(G_r, Pr) \quad \frac{hL}{k} = f\left[\frac{L^3 g \beta \Delta T}{\mu}, \frac{C_p \mu}{k}\right]$$

$$\therefore h \propto \beta \text{ (Thermal expansion coefficient)}$$

142. B

Sieder-Tate correlation for heat transfer

$$St = 0.023 Re^{-0.2} Pr^{\frac{2}{3}} \left(\frac{\mu_b}{\mu_w}\right)^{0.14}$$

$$\frac{Nu}{Re Pr} = 0.023 Re^{-0.2} Pr^{\frac{2}{3}} \left(\frac{\mu_b}{\mu_w}\right)^{0.14}$$

$$\therefore Nu = 0.023 Re^{0.8} Pr^{1/3} \left(\frac{\mu_b}{\mu_w}\right)^{0.14}$$

$$Nu \propto Re^{0.8} \frac{hD}{K} \propto \left(\frac{\rho V D}{\mu}\right)^{0.8} \therefore h \propto D^{-0.2}$$

143. C

$$\frac{1}{U} = \frac{1}{U_o} + \frac{1}{h_{d_o}}$$

where, U – Overall heat transfer coefficient with fouling factor

U_o – Clean surface heat transfer coefficient

U_{d_o} – Fouling factor

$$\therefore \frac{1}{U} = \frac{1}{400} + \frac{1}{2000}$$

$$U = 333 \text{ W/m}^2 \cdot \text{K}$$

144. C

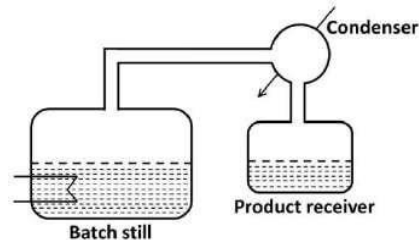
Heat flux $\frac{q}{A} = K \frac{\Delta T}{\Delta x}$ Put given data

$$10 = 0.04 \times \frac{T_o - (-5)}{0.16}$$

3. MASS TRANSFER (GATE Previous Papers)

GATE-2023

1. A packed distillation column, with vapor having an average molecular weight of 45 kg.kmol^{-1} , density of 2 kg.m^{-3} and a molar flow rate of 0.1 kmol.s^{-1} , has a flooding velocity of 0.15 m.s^{-1} . The column is designed to operate at 60 % of the flooding velocity. Which one of the following is the CORRECT value for the column diameter (in m)? **(1-Mark)**
- (A) $\frac{5}{\sqrt{\pi}}$ (B) $5\sqrt{\pi}$
(C) 4π (D) $\frac{10}{\sqrt{\pi}}$
2. A liquid L containing a dissolved gas S is stripped in a counter current operation using a pure carrier gas V. The liquid phase inlet and outlet mole fractions of S are 0.1 and 0.01, respectively. The equilibrium distribution of S between V and L is governed by $y_e = x_e$, where y_e and x_e are the mole fractions of S in V and L, respectively. The molar feed rate of the carrier gas stream is twice as that of the liquid stream. Under dilute solution conditions, the minimum number of ideal stages required is _____ (in integer). **(1-Mark)**
3. In a binary gas-liquid system, $N_{A,EMD}$ is the molar flux of a gas A for equimolar counter diffusion with a liquid B. $N_{A,UMD}$ is the molar flux of A for steady one-component diffusion through stagnant B. Using the mole fraction of A in the bulk of the gas phase as 0.2 and that at the gas-liquid interface as 0.1 for both the modes of diffusion, the ratio of $N_{A,UMD}$ to $N_{A,EMD}$ is equal to _____ (rounded off to two decimal places). **(1-Mark)**
4. Which one of the following represents the CORRECT effects of concentration polarization in a reverse osmosis process?
(A) Reduced water flux and reduced solute rejection
(B) Increased water flux and increased solute rejection
(C) Reduced water flux and increased solute rejection
(D) Increased water flux and reduced solute rejection **(2-Marks)**
5. Partially saturated air at 1 bar and 50°C is contacted with water in an adiabatic saturator. The air is cooled and humidified to saturation, and exits at 25°C with an absolute humidity of $0.02 \text{ kg water per kg dry air}$. Use latent heat of vaporization of water as 2450 kJ.kg^{-1} , and average specific heat capacity for dry air and water, respectively as $1.01 \text{ kJ.kg}^{-1}\text{K}^{-1}$ and $4.18 \text{ kJ.kg}^{-1}\text{K}^{-1}$. If the absolute humidity of air entering the adiabatic saturator is $H \times 10^{-3} \text{ kg water per kg dry air}$, the value of H is _____ (rounded off to two decimal places). **(2-Marks)**
6. Distillation of a non-reactive binary mixture with components A and B is carried out in a batch still as shown in the figure below. The initial charge of the mixture in the still is 1 kmol. The initial and final amounts of A in the still are 0.1 kmol and 0.01 kmol, respectively. Use a constant relative volatility of 4.5. The mole fraction of B remaining in the vessel is _____ (rounded off to three decimal places). **(2-Marks)**



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7. A simple distillation column is designed to separate an ideal binary mixture to specified distillate and bottoms purities at a given column pressure. If RR_{\min} is the minimum reflux ratio for this separation, select the statement that is NOT CORRECT with regard to the variation in the total annualized cost (TAC) of the column with reflux ratio (RR).
- (A) The sharpest decrease in TAC occurs as RR approaches RR_{\min} from above.
- (B) The sharpest rise in TAC occurs as RR approaches RR_{\min} from above.
- (C) TAC increase with RR for $RR \gg RR_{\min}$
- (D) TAC has a minimum with respect to RR **(1-Mark)**
8. A wet solid containing 20% (w/w) moisture (based on mass of bone-dry solid) is dried in a tray-dryer. The critical moisture content of the solid is 10% (w/w). The drying rate ($\text{kg m}^{-2}\text{s}^{-1}$) is constant for the first 4 hours, and then decreases linearly to half the initial value in the next 1 hour. At the end of 5 hours of drying, the percentage moisture content of the solid is _____ % (w/w) (rounded off to one decimal place). **(2-Marks)**
9. An equimolar binary mixture is to be separated in a simple tray-distillation column. The feed rate is 50 kmol min^{-1} . The mole fractions of the more volatile component in the top and bottom products are 0.90 and 0.01, respectively. The feed as well as the reflux stream are saturated liquids. On application of the McCabe-Thiele method, the operating line for the stripping section is obtained as $y = 1.5x - 0.005$ where y and x are the mole fractions of the more volatile component in the vapor and liquid phases, respectively. The reflux ratio is _____ (rounded off to two decimal places). **(2-Marks)**

10. The dry-bulb temperature of air in a room is 30°C . The Antoine equation for water is given as

$$\ln P^{\text{sat}} = 12.00 - \frac{4000}{T - 40}$$

where T is the temperature in K and P^{sat} is the saturation vapor pressure in bar. The latent heat of vaporization of water is 2000 kJ kg^{-1} , the humid heat is $1.0 \text{ kJ kg}^{-1} \text{ K}^{-1}$, and the molecular weights of air and water are 28 kg kmol^{-1} and 18 kg kmol^{-1} , respectively. If the absolute humidity of air is Y' kg moisture per kg dry air, then for a wet-bulb depression of 9°C , $1000 \times Y' =$ _____ (rounded off to one decimal place). **(2-Marks)**

11. Consider steady-state diffusion in a binary A-B liquid at constant temperature and pressure. The mole-fraction of A at two different locations is 0.8 and 0.1. Let N_{A1} be the diffusive flux of A calculated assuming B to be non-diffusing, and N_{A2} be the diffusive flux of A calculated assuming equimolar counter-diffusion. The quantity $\frac{(N_{A2} - N_{A1})}{N_{A1}} \times 100$ is _____ (rounded off to one decimal place). **(1-Marks)**
12. Consider interphase mass transfer of a species S between two immiscible liquids A and B. The interfacial mass transfer coefficient of S in liquid A is twice of that in liquid B. The equilibrium distribution of S between the liquids is given by $y_S^A = 0.5y_S^B$, where y_S^A and y_S^B are the mole-fractions of S in A and B, respectively. The bulk phase mole-fraction of S in A and B is 0.10 and 0.02, respectively. If the steady-state flux of S is estimated to be $10 \text{ kmol h}^{-1} \text{ m}^{-2}$, the mass transfer coefficient of S in A is _____ $\text{kmol h}^{-1} \text{ m}^{-2}$ (rounded off to one decimal place). **(2-Marks)**

ANSWER KEY

1	2	3	4	5	6	7	8	9	10
D	3	1.17	A	9.3	0.982	A	8	27.53	10 to 12
11	12	13	14	15	16	17	18	19	20
53.45	222.22	B	D	A, C, D	A	0.63-0.65	34- 35	0.24-0.26	C
21	22	23	24	25	26	27	28	29	30
C	0.03	D	C	176	2	A	A	C	B
31	32	33	34	35	36	37	38	39	40
0.01	C	8	0.005	1.647	D	B	D	3.84	0.67
41	42	43	44	45	46	47	48	49	50
11.11	1	124.25	D	120	B	0.897	B	4	13.33
51	52	53	54	55	56	57	58	59	60
0.396	C	1	C	C	B	D	1.1	1.02	C
61	62	63	64	65	66	67	68	69	70
B	0.22	1.4	6.4	D	C	A	B	B	1.21
71	72	73	74	75	76	77	78	79	80
3.75	B	D	66.85	A	1.14	A	C	B	B
81	82	83	84	85	86	87	88	89	90
C	C	B	B	A	D	B	D	D	B
91	92	93	94	95	96	97	98	99	100
D	A	A	A	C	D	A	D	C	C
101	102	103	104	105	106	107	108	109	110
D	B	A	A	A	B	B	D	A	A
111	112	113	114	115	116	117	118	119	120
A	C	C	B	B	B	B	B	C	C
121	122	123	124	125	126	127	128	129	130
A	A	A	C	B	D	C	C	A	A
131	132	133	134	135	136	137	138	139	140
A	B	C	D	A	D	C	A	D	A
141	142	143	144	145	146	147	148	149	150
C	B	D	C	B	C	C	D	D	C
151	152	153	154	155	156	157	158	159	160
D	B	B	A	B	C	D	D	B	D
161	162	163	164	165	166	167	168	169	170
C	A	C	C	C	A	C	B	C	B
171	172	173	174	175	176				
A	B	B	C	D	C				