Q. No. 1 – 25 Carry One Mark Each

1. Consider the following set of linear algebraic equations

$$x_1 + 2x_2 + 3x_3 = 2$$
$$x_2 + x_3 = -1$$
$$2x_2 + 2x_3 = 0$$

The system has

(A) A unique solution (B) No solution

(C) An infinite number of solutions (D) Only the trivial solution

Answer:- (B)

Exp:- $\left[\begin{array}{ccc|c} 1 & 2 & 3 & 2 \\ 0 & 1 & 1 & -1 \\ 0 & 2 & 2 & 0 \end{array}\right] \xrightarrow{R_3-2R_2} \left[\begin{array}{ccc|c} 1 & 2 & 3 & 2 \\ 0 & 1 & 1 & -1 \\ 0 & 0 & 0 & 2 \end{array}\right]$

$\text{rank}(A) = \ \text{rank}(A/B) = 3$

So system is inconsistent and has no solution

2. If a and b are arbitrary constants, then the solution to the ordinary differential equation $\frac{d^2y}{dx^2} - 4y = 0$ is

(A) y= ax+b (B) $y = ae^{-x}$

(C) $y = a\sin 2x + b\cos 2x$ (D) $y = a\cosh 2x + b\sinh 2x$

Answer:- (D)

Exp:- Let us solve it from the options

$\frac{d^2y}{dx^2} - 4y = 0;\ d(\sinh x) = \text{coh}x;\ d(\cosh x) = \sinh x$

Consider option (D), $y = a\cosh 2x + b\sinh 2x;\ \frac{dy}{dx} = 2a\sinh 2x + 2b\cosh 2x;$

$\frac{d^2y}{dx^2} = 4a\cosh 2x + 4b\sinh 2x = 4y$

3. For the function $f(t) = e^{-t/\tau}$; the Taylor series approximation for $t << \tau$ is

(A) $1 + \frac{t}{\tau}$ (B) $1 - \frac{t}{\tau}$ (C) $1 - \frac{t}{2\tau^2}$ (D) $1 + t$

Answer:- (B)

Exp:- $f(t) = e^{-t/\tau}$; By Taylor's expansion, $e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \ldots$

$e^{-t/\tau} = 1 - \frac{t}{\tau} + \frac{t^2}{2\tau^2} - \frac{t^3}{6\tau^2} + \ldots\ldots t << \tau$

$e^{-t/\tau} = 1 - \frac{t}{\tau}$, as all higher expressions of τ can be ignored

4. A box containing 10 identical compartments has 6 red balls and 2 blue balls. If each compartment can hold only one ball, then the numbers of different possible arrangements are

(A) 1026 (B) 1062 (C) 1260 (D) 1620

Answer:- (C)

Exp:-

1	2	3	4	5	6	7	8	9	10

Total 8 balls and 10 places.

Possible arrangements are $\frac{{}^{10}P_8}{6!2!} = \frac{10!}{6!2!} = 1260$

5. Consider the following (2×2) matrix

$$\begin{pmatrix} 4 & 0 \\ 0 & 4 \end{pmatrix}$$

Which one of the following vectors is NOT a valid eigen vector of the above matrix?

(A) $\begin{pmatrix} 1 \\ 0 \end{pmatrix}$ (B) $\begin{pmatrix} -2 \\ 1 \end{pmatrix}$ (C) $\begin{pmatrix} 4 \\ -3 \end{pmatrix}$ (D) $\begin{pmatrix} 0 \\ 0 \end{pmatrix}$

Answer:- (D)

Exp:- Let us solve this question from options

Option (A) : $\begin{pmatrix} 4 & 0 \\ 0 & 4 \end{pmatrix}\begin{pmatrix} 1 \\ 0 \end{pmatrix} = \begin{pmatrix} 4 \\ 0 \end{pmatrix} = 4\begin{pmatrix} 1 \\ 0 \end{pmatrix}$ is an eigen vector

Option (B) : $\begin{pmatrix} 4 & 0 \\ 0 & 4 \end{pmatrix}\begin{pmatrix} -2 \\ 1 \end{pmatrix} = \begin{pmatrix} -8 \\ 4 \end{pmatrix} = 4\begin{pmatrix} -2 \\ 1 \end{pmatrix}$ is an eigen vector

Option (C) : $\begin{pmatrix} 4 & 0 \\ 0 & 4 \end{pmatrix}\begin{pmatrix} 4 \\ -3 \end{pmatrix} = \begin{pmatrix} 16 \\ -12 \end{pmatrix} = 4\begin{pmatrix} 4 \\ -3 \end{pmatrix}$ is an eigen vector

Option (D) : $\begin{pmatrix} 4 & 0 \\ 0 & 4 \end{pmatrix}\begin{pmatrix} 0 \\ 0 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} = 4\begin{pmatrix} 0 \\ 0 \end{pmatrix}$ not an eigen vector, since eigen vector should be a non-zero vector, eigen values of A are 4,4

6. In a throttling process, the pressure of an ideal gas reduces by 50%. If C_p and C_v are the heat capacities at constant pressure and constant volume, respectively $\left(\gamma = \frac{C_p}{C_\gamma}\right)$, the specific volume will change by a factor of

(A) 2 (B) $2^{\frac{1}{\gamma}}$ (C) $2^{\frac{\gamma-1}{\gamma}}$ (D) 0.5

Answer:- (A)

7. If the temperature of saturated water is increased infinitesimally at constant entropy, the resulting state of water will be

(A) Liquid (B) Liquid-vapour coexistence

(C) Saturated vapour (D) Solid

Answer:- (B)

8. In a parallel flow heat exchanger operating under steady state, hot liquid enters at a temperature $T_{h,in}$ and leaves at a temperature $T_{h,out}$. Cold liquid enters at a temperature $T_{c,in}$ and leaves at a temperature $T_{c,out}$. Neglect any heat loss from the heat exchanger to the surrounding. If $T_{h,in} >> T_{c,in}$, then for a given time interval, which ONE of the following statements is true?

(A) Entropy gained by cold stream is GREATER than entropy lost by hot stream

(B) Entropy gained by cold stream is EQUAL than entropy lost by hot stream

(C) Entropy gained by cold stream is LESS than entropy lost by hot stream

(D) Entropy gained by cold stream is ZERO

Answer:- (A)

9. For an exothermic reversible reaction, which one of the following correctly describes the dependence of the equilibrium constant (K) with temperature (T) and pressure (P)?

(A) K is independent of T and P

(B) K increases with an increase in T and P

(C) K increases with T and decreases with P

(D) K decreases with an increase T and is independent of P

Answer:- (D)

10. Water is flowing under laminar conditions in a pipe of length L. If the diameter of the pipe is doubled, for a constant volumetric flow rate, the pressure drop across the pipe

(A) Decreases 2 times (B) Decreases 16 times

(C) Increases 2 times (D) Increases 16 times

Answer:- (B)

Exp:- For laminar flow, $\Delta\rho = \dfrac{32\mu VL}{D^2} = \dfrac{32,\left(\dfrac{4Q}{\pi D^2}\right)^2}{D^2} = \dfrac{128\,\mu QL}{\pi D^4}$

$$\left(V = \frac{\text{Volumetric flow rate}}{\text{Cross sec tional area of pipe}} = \frac{Q}{\frac{\pi D^2}{4}} = \frac{4Q}{\pi D^2}\right)$$

$\Rightarrow \Delta p \;\alpha\; \dfrac{1}{D^4}$ (for const flow rate)

$$\therefore \quad \Delta p_2 = \Delta p_1 \left(\frac{D_1}{D_2}\right)^4 = \Delta p_1 \left(\frac{D}{2D}\right)^4 = \frac{\Delta p_1}{16}$$

11. The local velocity of a fluid along a streamline can be measured by

(A) Pitot tube (B) Venturi meter (C) Rotameter (D) Orifice meter

Answer:- (A)

12. For uniform laminar flow (in the x-direction) past a flat plate at high Reynolds number, the local boundary layer thickness (δ) varies with the distance along the plate (x) as

(A) $\delta \propto x^{1/4}$ (B) $\delta \propto x^{1/3}$ (C) $\delta \propto x^{1/2}$ (D) $\delta \propto x$

Answer:- (C)

Exp:- For a flow over a flat plate, the local boundary layer thickness (δ) varies with

$x^{0.5}$ for laminar flow

$x^{0.8}$ for fully developed turbulent flow

13. In a mixing tank operating at very Reynolds number $\left(>10^4\right)$, if the diameter of the impeller is doubled (other conditions remaining constant), the power required increases by a factor of

(A) 1/32 (B) 1/4 (C) 4 (D) 32

Answer:- (D)

Exp:- For mixing tank,

Power required, $P = k_T n^3 D^5.\rho \Rightarrow P_2 = (P_1)\dfrac{D_2^5}{D_1^5} = (P_1)\left[\dfrac{(2D)}{(D)}\right]^5 = 32P_1$

14. For heat transfer across a solid fluid interface, which one of the following statements is NOT true when the Biot number is very small compared to 1?

(A) Condition resistance in the solid is very small compared to convection resistance in the fluid

(B) Temperature profile within the solid is nearly uniform

(C) Temperature drop in the fluid is significant

(D) Temperature drop in the solid is significant

Answer:- (D)

Exp:- Bioit number $= \dfrac{hD}{k} \rightarrow$ characteristic length

$= \dfrac{\text{Conductive resistance in solid}}{\text{Convective resistance in fluid}}$

Of Biot number (z), conductive resistance is small.

$\therefore$ Temperature drop in solid is not significant.

15. A solid sphere with an initial temperature T_i is immersed in a large thermal reservoir of temperature T_o. The sphere reaches a steady temperature after a certain time t_1. If the radius of the sphere is doubled, the time required to reach steady state will be

(A) $\dfrac{t_1}{4}$ (B) $\dfrac{t_1}{2}$ (C) $2t_1$ (D) $4t_1$

Answer:- (C)

Exp:- We know,

$$\frac{T - T_o}{T_\infty - T_o} = \exp\left(-\frac{hA}{mc_p}t\right)$$

Here $A = u\pi r^2$: $m = \rho v = \rho\frac{4}{3}\pi(r)^3$

$\because$ The final steady state temperature is same for both the cases,

$$\exp\left(-\frac{hA_{01}\,t_1}{m_1 c_p}\right) = \exp\left(-\frac{hA_2 t_2}{m_2 c_p}\right)$$

$$\Rightarrow \frac{A_1 t_1}{m_1} = \frac{A_2 t_2}{m_2} \Rightarrow \frac{4\pi r_1^2}{\left(\frac{4}{3}\pi r_1^3\right)\rho}t_1 = \frac{4\times r_2^2}{\left(\frac{4}{3}\pi r_2^3\right)\rho}t_2$$

$$\Rightarrow \frac{t_1}{r_1} = \frac{t_2}{r_2} \Rightarrow t_2 = (t_1)\frac{r_2}{r_1} = (t_1)\left(\frac{2r}{r}\right) = 2t_1 \Rightarrow t_2 = 2t_1$$

16. If the Nusselt number (Nu) for heat transfer in a pipe varies with Reynolds number (Re) as $Nu \propto Re^{0.8}$, then for constant average velocity in the pipe, the heat transfer coefficient varies with the pipe diameter D as

(A) $D^{-1.8}$ (B) $D^{-0.2}$ (C) $D^{0.2}$ (D) $D^{1.8}$

Answer:- (B)

Exp:- $Nu\,\alpha\,Re^{0.8} \Rightarrow \frac{hD}{K}\,\alpha\,\left(\frac{V\rho D}{\mu}\right)^{0.8}$

$$\Rightarrow \frac{hD}{K}\,\alpha\,\frac{V^{0.8}\rho^{0.8}D^{0.8}}{\mu^{0.8}} \Rightarrow h\,\alpha\,V^{0.8}\,\rho^{0.8}\,D^{-0.2}\,K$$

$\therefore$ For constant average velocity, $h\,\alpha\,D^{-0.2}$

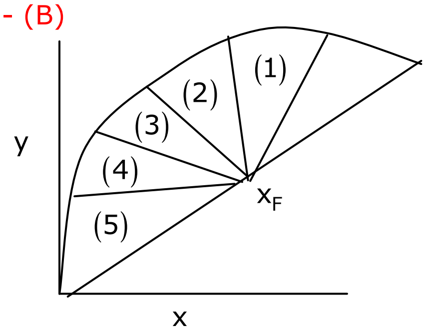
17. In the Mc-Cabe-Thiele diagram, if the x-coordinate of the point of intersection of the q-line and the vapour-liquid equilibrium curve is greater than the x-coordinate of the feed point, then the quality of the feed is

(A) Superheated vapour (B) Liquid below bubble point

(C) Saturated vapour (D) Saturated liquid

Answer:- (B)

Exp:-



(1) = Liquid below bubble point

(2) = Saturated liquid

(3) = Mixture of vapor and liquid

Vapor and liquid

(4) = Saturated vapor

(5) = Super heated vapor

$\therefore$ The present case falls under the case of (1)

18. For which of the following combinations, does the absorption operation become gas-film controlled?

P. The solubility of gas in the liquid is very high

Q. The solubility of gas in the liquid is very low

R. The liquid-side mass transfer coefficient is much higher than the gas-side mass transfer coefficient

S. The liquid-side mass transfer coefficient is much lower than the gas-side mass transfer coefficient

(A) P & Q (B) P & R (C) P & S (D) Q & R

Answer:- (B)

19. The half-life of an n^{th} order reaction in a batch reactor depends on

(A) Only the rate constant

(B) Only the rate constant and the order of the reaction

(C) Only the rate constant and initial reactant concentration

(D) The rate constant, initial reactant concentration and the order of the reaction

Answer:- (D)

Exp:- For an n^{th} order reaction, $-\frac{dcA}{dt} = kC_A^n$

$$\Rightarrow -\frac{dc_A}{c_A^n} = kdt \Rightarrow \int_{C_{AO}}^{C_A} \frac{-dc_A}{c_A^n} = \int_0^t kdt \Rightarrow \frac{1}{c_A^{1+n}} - \frac{1}{C_{A_0}^{t+n}} = (k)\ (1-n)$$

For half life, $t = t_{1/2}$ and $C_A = \frac{C_{AO}}{2}$

$$\Rightarrow \frac{1}{\left(\frac{C_{Ao}}{2}\right)^{-1+n}} - \frac{1}{C_A^{-1+n}} = kt_{\frac{1}{2}}\ (1+n) \Rightarrow \frac{1}{C_{Ao}^{1+n}}\left[2^{1-n} - 1\right] = Kt_{\frac{1}{2}}\ (1+n)$$

$$\Rightarrow t_{\frac{1}{2}} = \frac{\left(0.5^{n-1} - 1\right)\ C_{Ao}^{1-n}}{K\,(n-1)}$$

$$t_{\frac{1}{2}} = \frac{\left(0.5^{n-1} - 1\right)\ C_{Ao}^{1-n}}{k\,(n-1)}$$

20. Consider the reaction scheme shown below:

$$A \xrightarrow{k_1} B \xrightarrow{k_2} C$$

Both the reactions are first-order. The activation energies for k_1 and k_2 are 80 and 20kJ/mol, respectively. To maximize the yield of B, it is preferable to use

(A) CSTR and high temperature (B) PFR and high temperature

(C) CSTR and low temperature (D) PFR and low temperature

Answer:- (B)

Exp:- For given reactions,

$$\frac{dC_B}{dt} = K_1C_A - K_2C_B \qquad A \xrightarrow{K_1} B \xrightarrow{K_2} C$$

$$= K_{10}\, e^{-\frac{80\times10^3}{8.314\times T}} C_A - K_{20}\, e^{-\frac{20\times10^3}{8.314\times t}} C_B$$

$\therefore$ High temperature and high concentration of C_A is needed for maximum yield of B.

21. In petroleum refining catalytic reforming is used to convert
(A) Paraffins and Naphthenes to aromatic
(B) Paraffins to hydrogen and carbon monoxide
(C) Gas oil to diesel and gasoline
(D) Light olefins to gasoline

Answer:- (A)

22. The final boiling points of gasoline, diesel, atmospheric gas oil (AGO) and lubricating oils vary as
(A) Gasoline > diesel > AGO > lubricating oils
(B) Lubricating oils > AGO >diesel > gasoline
(C) AGO > lubricating > oils > diesel > gasoline
(D) Lubricating oils > diesel >AGO > gasoline

Answer:- (C)

23. The main unit processes used for the production of hydrogen from natural gas are steam reforming (SR), pressure swing adsorption (PSA), low temperature water gas shift reaction (LT WGS) and high temperature water gas shift reaction (HT WGS). The correct sequence of these in the plant is
(A) SR;LT WGS; HTWGS; PSA
(B) PSA; SR; LTWGS; HTWGS
(C) SR; HTWGS; LTWGS; PSA
(D) PSA; HTWGS; LTWGS; SR

Answer:- (C)

24. The thermometer initially at 100ºC is dipped at t=0 into an oil bath, maintained at 150ºC. If the recorded temperature is 130ºC after 1 minute, then the time constant of thermometer (in mm) is
(A) 1.98
(B) 1.35
(C) 1.26
(D) 1.09

Answer:- (D)

Exp:- For thermometer,

$$y(t) = x(t)\left[1 - e^{-t/n}\right] \text{ or}$$

$$y(t) = A\left[1 - e^{-t/n}\right]$$

Here $A = 50,\ y(t) = 30,\ t = 1$

$$\therefore 30 = 50\left[1 - e^{-\frac{1}{T}}\right] \Rightarrow r = 1.09$$

25. The Bode stability criterion is applicable when
(A) Gain and phase curves decrease continuously with frequency
(B) Gain curve increases and phase curve decreases with frequency
(C) Gain curve and phase curve both increase with frequency
(D) Gain curve decreases and phase curve increases with frequency

Answer:-(B)

Q. No. 26 – 55 Carry Two Marks Each

26. The one-dimensional unsteady state heat conduction equation in a hollow cylinder with a constant heat source q is

$$\frac{\partial T}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + q$$

If A and B are arbitrary constants, then the steady state solution to the above equation is

(A) $T(r) = -\frac{qr^2}{2} + \frac{A}{r} + B$ (B) $T(r) = -\frac{qr^2}{4} + A\ln r + B$

(C) $T(r) = A\ln r + B$ (D) $T(r) = \frac{qr^2}{4} + A\ln r + B$

Answer:- (B)

Exp:- $\frac{\partial T}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + q$

For steady state solution, $\frac{\partial T}{\partial t} = 0$

$$\Rightarrow \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + q = 0 \Rightarrow \frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) = -q(r)$$

$$\Rightarrow r\frac{\partial T}{\partial r} = -\frac{qr^2}{2} + A \Rightarrow \frac{\partial T}{\partial r} = -\frac{qr}{2} + \frac{A}{r}$$

$$\Rightarrow T = -\frac{qr^2}{4} + A\ln r + B$$

27. If a is a constant, then the value of the integral $a^2\int_0^\infty xe^{-ax}dx$ is

(A) 1/a (B) a (C) 1 (D) 0

Answer:- (C)

Exp:- Given, $a^2\int_0^\infty xe^{-ax}dx$; Let $-ax = t \Rightarrow dt = -adx$

Upper Limit $= -\infty$ and lower limit $= 0$

$$\therefore a^2\int_0^\infty xe^{-ax}dx = a^2\int_0^{-\infty}\left(\frac{-t}{a}\right)e^t\frac{dt}{a} = -\int_{-\infty}^{1} t\,e^t\,dt = -\left[e^t(t-1)\right]_{-\infty}^{0} = 1$$

28. The Newton-Raphson method is used to find the roots of the equation

$f(x) = x - \cos \pi x \quad 0 \le x \le 1$

If the initial guess for the root is 0.5, then the value of x after the first iteration is

(A) 1.02 (B) 0.62 (C) 0.55 (D) 0.38

Answer:- (D)

Exp:- $f(x) = x - \cos \pi x \qquad 0 \le x \le 1$

Newton-Raphson method to find roots of $f(x)$

$$x_1 = x_0 - \frac{f(x_0)}{f'(x_0)};\ f(x) = x - \cos \pi x;\ f'(x) = 1 + \pi \sin \pi x$$

$$f\left(\frac{1}{2}\right) = \frac{1}{2} - \cos\frac{\pi}{2} = \frac{1}{2};\ f'\left(\frac{1}{2}\right) = 1 + \pi \sin\frac{\pi}{2} = 1 + \pi$$

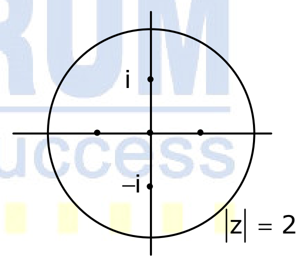
$$x_1 = \frac{1}{2} - \frac{\frac{1}{2}}{1+\pi} = 0.38$$

29. If $i = \sqrt{-1}$, the value of the integral $\oint_c \frac{7z+i}{z(z^2+1)} dz \quad |z| < 2$ using Cauchy residue theorem is

(A) $2\pi i$ (B) 0 (C) -6π (D) 6π

Answer:- (B)

Exp:- $i = \sqrt{-1};\ \oint_c \frac{7z+i}{z(z^2+1)} dz \quad |z| < 2$



Point s of singularity z=0, z= ±i, all three parts be inside the counter $|z| = 2$.

By Cauchy's Residue theorem,

$$\oint_c \frac{7z+i}{z(z^2+1)} dz = \frac{2\pi}{i}\left[\mathrm{Res}(z=0) + \mathrm{Res}(z=i) + \mathrm{Res}(z=i)\right]$$

$$= 2\pi i\left[\lim_{z\to 0}\frac{7z+i}{z^2+1} + \lim_{z\to i}\frac{7z+i}{z(z+i)} + \lim_{z\to -i}\frac{7z+i}{z(z+i)}\right] = 2\pi i\left[i - 4i + 3i\right] = 0$$

30. An insulated, evacuated container is connected to a supply line of an ideal gas at pressure P_s, temperature T_s, and specific volume v_s. The container is filled with the gas until the pressure in the container reaches P_s. There is no heat transfer between the supply line to the container, and kinetic and potential energies are negligible. If C_p and C_v are the heat capacities at constant pressure and constant volume, respectively $(\gamma = C_p / C_v)$, then the final temperature of the gas in the container is

(A) γT_s (B) T_s (C) $(\gamma - 1) T_s$ (D) $(\gamma - 1) T_s / \gamma$

Answer:- (B)

31. Consider a binary liquid mixture at constant temperature T and pressure P. If the enthalpy change of missing, $\Delta H = 5x_1x_2$, where x_1 and x_2 are mole fraction of species 1 and 2 respectively, and the entropy change of mixing $\Delta S = -R\left[x_1 \ln x_1 + x_2 \ln x_2\right]$ (with R=8.314J/mol.K), then the minimum value of the Gibbs free energy change of mixing at 300K occurs when

(A) $x_1 = 0$ (B) $x_1 = 0.2$ (C) $x_1 = 0.4$ (D) $x_1 = 0.5$

Answer:- (D)

Exp:- Given, $\Delta H = 5x_1x_2$; $\Delta S = -R\left[x_1 \ln x_1 + x_2 \ln x_2\right]$

$$G = H - TS$$

$$\Delta G = \Delta H - T\Delta S$$

For ΔG to be minimum, $\frac{\partial(\Delta G)}{\partial x_1} = 0$

$$\Rightarrow \frac{\partial}{\partial x_1}(5x_1x_2) - \frac{\partial}{\partial x_1}T\left[-R\{x_1 \ln x_1 + x_2 \ln x_2\}\right] = 0$$

$$\Rightarrow 5\left[x_2 - x_1\right] - RT\left[1 + \ln x_1 - 1 - \ln x_2\right] = 0$$

$$\Rightarrow 5\left[x_2 - x_1\right] - R_T\left[\ln x_1 - \ln x_2\right] = 0$$

This is possible only when $x_1 = x_2 = 0.5$

32. A bed of spherical glass beads (density 3000kg/m^3, diameter 1mm, bed porosity 0.5) is to be fluidized by a liquid of density 1000 kg/m^3 and viscosity 0.1Pa.s. Assume that the Reynolds number based on particle diameter is small compared to one. If g=10m/s^2, then the minimum velocity (in m/s) required to fluidize the bed is

(A) 3.33×10^{-4} (B) 3.33×10^{-1} (C) 3 (D) 30

Answer:- (A)

Exp:- For packed bed,

$$\frac{\Delta P}{L} = \frac{150\mu U}{D_P^2}\frac{(1-\varepsilon)^2}{\varepsilon^3}$$

$$\Delta P = gL(1-\varepsilon)(\rho_p - \rho) \text{ (for minimum fluidization)}$$

$$\Rightarrow \frac{gL(1-\varepsilon)(\rho_p-\rho)}{L} = \frac{(150)(\mu)U_m(1-\varepsilon)^2}{D_p^2\,\varepsilon^3}$$

$$\Rightarrow 10\times(1-0.5)(3000-1000) = \frac{(150)(0.1)(U_m)}{(1\times10^{-3})^2}\frac{(1-0.5)^2}{2}$$

$$\Rightarrow U_m = 3.33\times10^{-4} \text{ m/s}$$

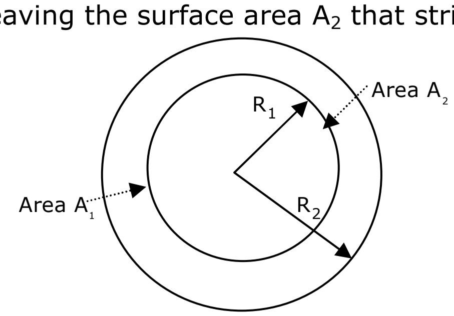
33. For the enclosure formed between two concentric spheres as shown below ($R_2=2R_1$), the fraction of radiation leaving the surface area A_2 that strikes itself is

(A) ¼

(B) ½

(C) $1/\sqrt{2}$

(D) ¾



Answer:- (A)

Exp:- $F_{12} = F_{21}\dfrac{A_2}{A_1} = \dfrac{A_2}{A_1} = \dfrac{\pi\left(R^2\right)}{\pi\left(2R^2\right)} = \dfrac{1}{4}$

$q_{12} = \sigma_{A,}\ F_{12}\ \left(r_1^4 - r_2^4\right)$

$\therefore$ Fraction $= \dfrac{1}{4}$

34. Heat generated at a steady rate of 100W due to resistance heating in a long wire $(\text{length} = 5\text{m, diameter} = 2\text{mm})$. This wire is wrapped with an insulation of thickness 1mm that has a thermal conductivity of 0.1W/m K. The insulated wire is exposed to air at 30ºC. The convective heat transfer between the wire and surrounding air is characterized by a heat transfer coefficient of 10W/m^2.K. The temperature in ºC at the interface the wire and the insulation is

(A) 211.2 (B) 242.1 (C) 311.2 (D) 484.2

Answer:- (C)

35. In a counter-flow double pipe heat exchanger, oil $\left(\dot{m} = 2\text{kg/s},\ C_p = 2.1\text{kJ/kg}^\circ\text{C}\right)$ is cooled from 90ºC to 40ºC by water $\left(\dot{m} = 1\text{kg/s},\ C_p = 4.2\text{kJ/kg}^\circ\text{C}\right)$ which enters the inner tube at 10ºC. The radius of the inner tube is 3cm and its length is 5m. Neglecting the wall resistance, the overall heat transfer coefficient based on the inner radius in $\left(\text{kW/m}^2.\text{K}\right)$ is

(A) 0.743 (B) 7.43 (C) 74.3 (D) 2475

Answer:- (A)

Exp:- Heat balance

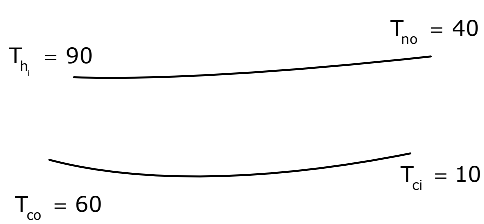
$\Rightarrow 2\times2.1\times(90-40) = 1\times4.2\ (T-10)$

$\Rightarrow\quad T = 60$

$\therefore$ LMTD $= 30^\circ$C

$\therefore U_i\ A_i\ (\Delta T_i) = mc_p\Delta T$

$\Rightarrow U_i = \dfrac{2\times2.1\times(50)}{6\times10^{-2}\times5\times\pi\times(273+30)} = 0.743$



36. The rate controlling step for the solid catalyzed irreversible reaction

$A + B \longrightarrow C$

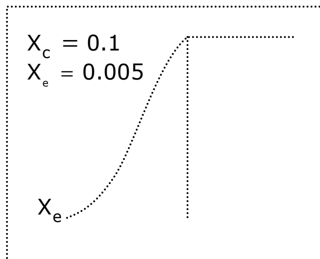
is known to be the reaction of adsorbed A with adsorbed B to give adsorbed C. If P_i is the partial pressure of component I and K_i is the adsorption equilibrium constant of component I, then the form of the Langmuir-Hinshelwood rate expression will be

(A) rate $\propto \dfrac{P_A P_B}{1+K_A P_A + K_B P_B + K_C P_C}$ (B) rate $\propto \dfrac{P_A P_B}{\left(1+K_A P_A + K_B P_B + K_C P_C\right)^2}$

(C) rate $\propto \dfrac{P_A P_B}{\left(1+K_A P_A + K_B P_B + K_C P_C\right)^{0.5}}$ (D) rate $\propto \dfrac{P_A P_B}{P_C}$

Answer:- (B)

37. Consider the drying operation shown in the figure below for a solid loading (dry basis) of $50 kg/m^2$ with a constant drying rate of $5 kg/m^2.h$. The falling rate of drying is linear with moisture content.



The drying time in hours required to reduce an initial moisture content of 25% to a final moisture content of 2% is

(A) 1.55 (B) 1.75 (C) 3.25 (D) 4.55

Answer:- (C)

Exp:- $\dfrac{50}{5}\left[(0.25-0.1)+(0.1-0.005)\ln\left(\dfrac{0.1-0.005}{0.02-0.005}\right)\right] = 3.25 hrs$

38. An equimolar mixture of A and B (A being more volatile) is flash distilled continuously at a feed rate of 100kmol/h, such that the liquid product contains 40mol% of A. If the relative volatility is 6, then the vapour product in kmol/h is

(A) 10 (B) 20 (C) 25 (D) 45

Answer:- (C)

Exp:- $F = L + V$ $\left(y = \dfrac{\alpha x}{1+(\alpha-1)x} = \dfrac{(6)(0.4)}{1+5\times 0.4}\right)$

$Fx_f = Lx_2 + vx_v$

$\Rightarrow (100)(0.5) = (100-V)0.4 + V(0.8) = 0.8 \Rightarrow V = \dfrac{50-40}{0.4} = 25$

39. A thermocouple having a linear relationship between 0ºC and 350ºC shows an emf of zero and 30.5mV, respectively at these two temperatures. If the cold junction temperature is shifted from 0ºC to 30ºC, then the emf correction (in mV) is

(A) 3.13 (B) 2.92 (C) 2.61 (D) 2.02

Answer:- (C)

Exp:- Since, the relationship is linear, New cold junction emf $= \dfrac{(30.5.0)}{(350-0)}(30-0) = 2.614\,\text{mV}$

40. The characteristic equation for the system is

$$s^3 + 9s^2 + 26s + 12(2+K_c) = 0$$

Using Routh test, the value of K_c that will keep the system on the verge of instability is

(A) 20.9 (B) 18.4 (C) 17.5 (D) 15.3

Answer:- (C)

Exp:-

Routh array	
1	26
9	$12(2+K_C)$
$\dfrac{9\times 26 - 12(2+K_C)}{9}$	

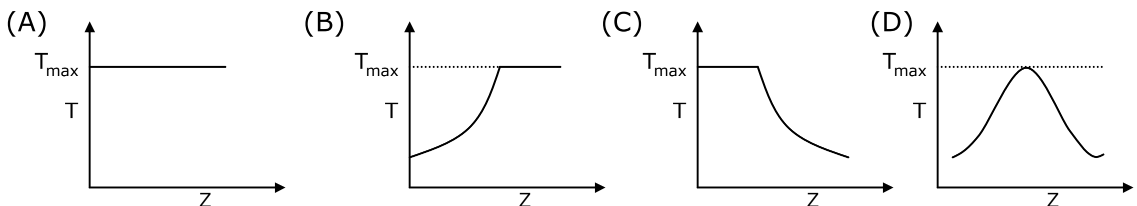
$\Rightarrow$ For stability $\dfrac{9\times 26 - 12(2+K_C)}{a} > 0 \Rightarrow K_C > 17.5$

$\therefore$ On the verge of stability $K_c = 17.5$

41. The elementary reversible exothermic gas-phase reaction

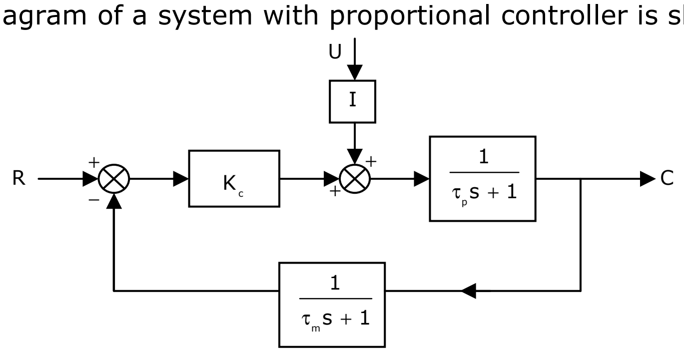
$$A + 3B \rightleftharpoons 2C$$

is to be conducted in a non-isothermal, non-adiabatic plug flow reactor. The maximum allowable reactor temperature is T_{max}. To minimize the total reactor volume, the variation of reactor temperature (T) with axial distance from inlet (Z) be



Answer:- (B)

42. The block diagram of a system with proportional controller is shown below



A unit step input is introduced in the set point. The value of K_c to provide a critically damped response for U=0, $\tau_p = 8$ and $\tau_m = 1$ is

(A) 3.34 (B) 2.58 (C) 1.53 (D) 1.12

Answer:- (C)

Exp:- $$Y = \frac{\dfrac{K_C}{(\tau_{ps}+1)}}{1+\dfrac{K_C}{(\tau_p s+1)}\dfrac{1}{(\tau_n s+1)}} = \frac{K_C(s+1)}{K_C+(8s+1)(s+1)}$$

$$= \frac{K_c(s+1)}{8s^2+9s+1+K_c} = \frac{K_c(s+1)}{\dfrac{8}{1+K_c}+\dfrac{9}{1+K_c}+1}$$

For critically damped system, $\varepsilon = 1$

$$\Rightarrow 2\varepsilon\tau = \frac{9}{1+K_c} \Rightarrow 2\tau = \frac{9}{1+K_c} \Rightarrow \tau = \frac{4.5}{1+K_c}$$

and $\tau^2 = \dfrac{8}{1+K_c}$

$$\therefore \left(\frac{4.5}{1+K_c}\right)^2 = \frac{8}{1+K_c} \Rightarrow 20.25 = 8(1+K_c) \Rightarrow K_c = 1.53125$$

43. A batch reactor produces 1×10^5kg of a product per year. The total batch time in hours of the reactor is $k\sqrt{P_B}$, where P_B is the product per batch in kg and $k = 1.0h/\sqrt{kg}$. The operating cost of the reactor is 200 /h. The total annual fixed charges are Rs. 340 x P_B and the annual raw material cost is Rs 2 x 10^6. The optimum size in kg of each batch (adjusted to the nearest integer) is

(A) 748 (B) 873 (C) 953 (D) 1148

Answer:- (C)

Exp:- Total number of batches $= \dfrac{1\times10^5}{P_B}$

$$\therefore \text{Total cost} = 200\left(\frac{1\times10^5}{P_B}\right)\times k\sqrt{P_B} + 340P_B + 2\times10^6$$

For optimum $\dfrac{\partial(\text{cost})}{\partial P_B} = 0 \Rightarrow \dfrac{-200\times10^5\times1}{2\times(P_B)^{\frac{3}{2}}} + 340 = 0$

$$\Rightarrow P_B^{\frac{3}{2}} = 29411.76 \Rightarrow P_B = 952.8\,kg$$

44. Heat integration is planned in a process plant at an investment Rs. 2 x 10^6. This would result in a net energy savings of 20GJ per year. If the nominal rate of interest is 15% and the plant life is 3 years, then the breakeven cost of energy, in Rs. Per GJ (adjusted to the nearest hundred), is

(A) 33500 (B) 43800 (C) 54200 (D) 65400

Answer:- (B)

Exp:- $R = \frac{pi(1+i)^n}{(1+i)^n - 1} = \frac{2\times10^6 \times 0.15(1+0.15)^3}{(1+0.15)^3 - 1}$

$(20)(x) = 875953.9237 \Rightarrow x = 43797.696 \simeq 43800$

45. In a 1-1 pass floating head type shell and tube heat exchanger, the tubes (od=25mm; id=21mm) and arranged in a square pitch. The tube pitch is 32mm. The thermal conductivity of the shell side fluid is 0.19 W/mK, and the Nusselt number is 200. The shell side heat transfer coefficient in $W/m^2 \cdot K$ rounded off to the nearest integer is

(A) 1100 (B) 1400 (C) 1800 (D) 2100

Answer:- (C)

46. Match the process in List I with catalyst in List II.

List I		List II	
P	Fischer-Tropsch synthesis	1	Nickel
Q	Formaldehyde from methanol	2	Fe_2O_3
R	Hydrogenation of vegetable oils	3	Silver
S	Dehydrogenation of ethylbenzene	4	Cobalt

(A) P-3, Q-4, R-1, S-2 (B) P-4, Q-2, R-1, S-3
(C) P-4, Q-3, R-1, S-2 (D) P-3, Q-4, R-2, S-1

Answer:- (C)

47. Match polymer in List I with polymer characteristic in List II

List I		List II	
P	Polythylene	1	Elastomer
Q	Phenol-formaldehyde polymer	2	Fiber
R	Polyiosoprene	3	Thermoplastic
S	Polyester	4	Thermosetting polymer

(A) P-3, Q-4, R-1, S-2 (B) P-4, Q-2, R-3, S-1
(C) P-3, Q-2, R-1, S-4 (D) P-4, Q-3, R-1, S-2

Answer:- (A)

Common Data for Questions: 48 & 49

A counter-current extraction column is designed to remove 99% of solute C from a solution of solvent A and solute C using pure solvent B. The initial concentration of solute in the solution of A + C is 20 wt%, and the total flow of solution is 1000kg/h. If the equilibrium relationship is Y=2X, where Y = mass of C/ mass of A and X = mass of C / mass of B.

48. The minimum flow rate of solvent B required in kg/h is

(A) 1454 (B) 1584 (C) 1676 (D) 1874

Answer:- (B)

Exp:- Total flwo of $(A+C)$, Initially $=1000\,kg/h$

$\therefore$ Amount of $C = 1000 \times 0.2 = 200\,kg$

Amount of $A = 1000 - 200 = 800$ kg

Final concentration $= 1\%$ of $200 = 0.01 \times 200 = 2$ in A

$\therefore Y = 2x$

$$\Rightarrow \frac{2}{800} = 2 \times \frac{(1.98)}{\text{mass of B}}$$

$\Rightarrow$ mass of $B = 1584$ kg/hr

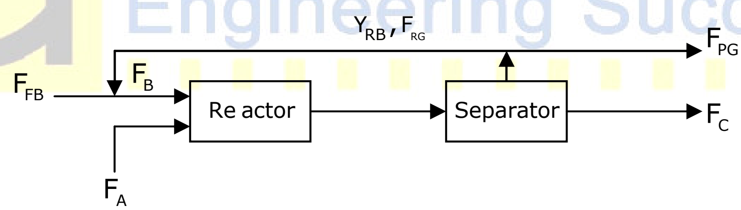
49. If the flow rate of B is 2400kg/h, then the theoretical number of stages in the column, using Kremser's equation adjusted to the next integer is

(A) 5 (B) 9 (C) 11 (D) 13

Answer:-

Common Data for Questions: 50 & 51

The reaction $A_{(liq)} + B_{(gas)} \longrightarrow C_{(liq)} + D_{(gas)}$ is carried out in a reactor followed by a separator as shown below:



Notation:

Molar flow rate of fresh B is F_{FB}

Molar flow rate of A is F_A

Molar flow rate of recycle gas is F_{RG}

Mole fraction of B in recycle gas is Y_{RB}

Molar flow rate of purge gas is F_{PG}

Molar flow rate of C is F_C

Here F_{FB}=2mol/s; F_A=1mol/s; $\frac{F_B}{F_A} = 5$ and A is completely converted

50. If $Y_{RB} = 0.3$, the ratio of recycle gas to purge gas (F_{RG}/F_{PG}) is

(A) 2 (B) 5 (C) 7 (D) 10

Answer:- (A)

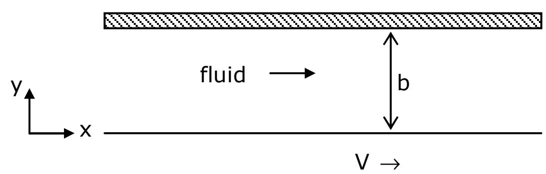
51. If the ratio of recycle gas to purge gas (F_{RG}/F_{PG}) is 4, then Y_{RB} is

(A) 3/8 (B) 2/5 (C) 1/2 (D) 3/4

Answer:- (A)

Statement for Linked Answer Questions: 52 & 53

A Newtonian fluid of viscosity μ flows between two parallel plates due to the motion of the bottom plate as shown below, which is moved with a velocity V. The top plate is stationary.



52. The steady, laminar velocity profile in the x-direction is

(A) $V\left[\frac{y}{b}\right]$ (B) $V\left[\left(\frac{y}{b}\right)^2 - 1\right]$ (C) $V\left[1-\left(\frac{y}{b}\right)^2\right]$ (D) $V\left[1-\left(\frac{y}{b}\right)\right]$

Answer:- (B)

53. The force per unit area (in the x-direction) that must be exerted on the bottom plate to maintain the flow is

(A) $\frac{\mu V}{b}$ (B) $\frac{-\mu V}{b}$ (C) $\frac{2\mu V}{b}$ (D) $\frac{-2\mu V}{b}$

Answer:- (B)

Statement for Linked Answer Questions: 54 & 55

The first order liquid phase reaction $A \rightarrow P$ is conducted isothermally in a plug flow reactor of 5 liter volume. The inlet volumetric flow rate is 1 liter / min and the inlet concentration of A is 2 mole/liter.

54. If the exit concentration of A is 0.5 mole / liter, then the rate constant, in min^{-1} is

(A) 0.06 (B) 0.28 (C) 0.42 (D) 0.64

Answer:- (B)

Exp:- For plug flow reactor,

$$\tau = \frac{-dc_A}{kC_A} \Rightarrow \ln\frac{C_{A0}}{C_A} = k\tau$$

$$k = \frac{\left(\ln\frac{2}{0.5}\right)}{\tau} = \frac{\ln 4}{\left(\frac{5}{1}\right)} = 0.277\,\text{min}^{-1}$$

55. The plug flow reactor is replaced by 3 mixed flow reactors in series, of 2.0 liters volume. The exact conversion of A (in %) is

(A) 35.9 (B) 52.5 (C) 73.7 (D) 94.8

Answer:- (C)

Exp:- $1 - X_A = \frac{1}{(1+k\tau)^3}$

$$\Rightarrow X_A = 1 - \frac{1}{(1+k\tau)^3} = 1 - \frac{1}{\left[1 + 0.28 \times \frac{3}{1}\right]^3} = 73.659\%$$

Q. No. 56 – 60 Carry One Mark Each

56. Which one of the following options is the closest in meaning to the word given below?

Mitigate

(A) Diminish (B) Divulge (C) Dedicate (D) Denote

Answer: (A)

57. Choose the most appropriate alternative from the options given below to complete the following sentence:

Despite several __________ the mission succeeded in its attempt to resolve the conflict.

(A) attempts (B) setbacks (C) meetings (D) delegations

Answer: (B)

58. The cost function for a product in a firm is given by $5q^2$, where q is the amount of production. The firm can sell the product at a market price of Rs.50 per unit. The number of units to be produced by the firm such that the profit is maximized is

(A) 5 (B) 10 (C) 15 (D) 25

Answer: (A)

Exp:- $P = 50q - 5q^2$

$$\frac{dp}{dq} = 50 - 10q; \quad \frac{d^2p}{dq^2} < 0$$

$\therefore$ p is maximum at $50 - 10q = 0$ or, $q = 5$

Else check with options

59. Choose the most appropriate alternative from the options given below to complete the following sentence:

Suresh's dog is the one ________ was hurt in the stampede.

(A) that (B) which (C) who (D) whom

Answer: (A)

60. Choose the grammatically **INCORRECT** sentence:
(A) They gave us the money back less the service charges of Three Hundred rupees.
(B) This country's expenditure is not less than that of Bangladesh.
(C) The committee initially asked for a funding of Fifty Lakh rupees, but later settled for a lesser sum.
(D) This country's expenditure on educational reforms is very less

Answer: (D)

Q. No. 61 – 65 Carry Two Marks Each

61. An automobile plant contracted to buy shock absorbers from two suppliers X and Y. X supplies 60% and Y supplies 40% of the shock absorbers. All shock absorbers are subjected to a quality test. The ones that pass the quality test are considered reliable Of X's shock absorbers, 96% are reliable. Of Y's shock absorbers, 72% are reliable.

The probability that a randomly chosen shock absorber, which is found to be reliable, is made by Y is

(A) 0.288 (B) 0.334 (C) 0.667 (D) 0.720

Answer: (B)

Exp:-

	x	y
Supply	60%	40%
Reliable	96%	72%
Overall	0.576	0.288

$$\therefore P(x) = \frac{0.288}{0.576 + 0.288} = 0.334$$

62. A political party orders an arch for the entrance to the ground in which the annual convention is being held. The profile of the arch follows the equation $y = 2x - 0.1x^2$ where y is the height of the arch in meters. The maximum possible height of the arch is

(A) 8 meters (B) 10 meters (C) 12 meters (D) 14 meters

Answer: (B)

Exp:- $y = 2x - 0.1x^2$

$$\frac{dy}{dx} = 2 - 0.2x$$

$$\frac{d^2y}{dx^2} < 0 \therefore y \text{ maximises at } 2 - 0.2x = 0$$

$$\Rightarrow x = 10$$

$$\therefore\ y = 20 - 10 = 10\,m$$

63. Wanted Temporary, Part-time persons for the post of Field Interviewer to conduct personal interviews to collect and collate economic data. Requirements: High School-pass, must be available for Day, Evening and Saturday work. Transportation paid, expenses reimbursed.

Which one of the following is the best inference from the above advertisement?

(A) Gender-discriminatory
(B) Xenophobic
(C) Not designed to make the post attractive
(D) Not gender-discriminatory

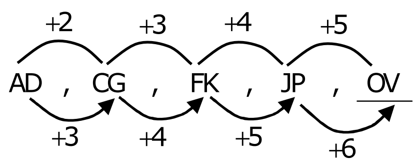
Answer: (C)

Exp:-Gender is not mentioned in the advertisement and (B) clearly eliminated

64. Given the sequence of terms, AD CG FK JP, the next term is

(A) OV (B) OW (C) PV (D) PW

Answer: (A)



65. Which of the following assertions are CORRECT?

P: Adding 7 to each entry in a list adds 7 to the mean of the list
Q: Adding 7 to each entry in a list adds 7 to the standard deviation of the list
R: Doubling each entry in a list doubles the mean of the list
S: Doubling each entry in a list leaves the standard deviation of the list unchanged

(A) P, Q (B) Q, R (C) P, R (D) R, S

Answer: (C)

Exp:- P and R always holds true

Else consider a sample set {1, 2, 3, 4} and check accordingly