Q.No-1-5 Carry One Mark Each

1. A student is required to demonstrate a high level of comprehension of the subject, especially in the social sciences.
The word closest in meaning to comprehension is
(A) understanding (B) meaning (C) concentration (D) stability

Answer: (A)

2. Choose the most appropriate word from the options given below to complete the following sentence.
One of his biggest ______ was his ability to forgive.
(A) vice (B) virtues (C) choices (D) strength

Answer: (B)

3. Rajan was not happy that Sajan decided to do the project on his own. On observing his unhappiness, Sajan explained to Rajan that he preferred to work independently.
Which one of the statements below is logically valid and can be inferred from the above sentences?
(A) Rajan has decided to work only in a group.
(B) Rajan and Sajan were formed into a group against their wishes.
(C) Sajan had decided to give in to Rajan's request to work with him.
(D) Rajan had believed that Sajan and he would be working together.

Answer: (D)

4. If $y = 5x^2 + 3$, then the tangent at $x = 0, y = 3$
(A) passes through $x = 0, y = 0$ (B) has a slope of +1
(C) is parallel to the x-axis (D) has a slope of -1

Answer: (C)

Exp: $y = 5x^2 + 3, \frac{dy}{dx} = 10x$

$$\text{Slope of tangent} = \left(\frac{dy}{dx}\right)_{x=0,\, y=3} = 10 \times 0 = 0$$

Slope = 0 ⇒ tangent is parallel to x-axis.

5. A foundry has a fixed daily cost of Rs 50,000 whenever it operates and a variable cost of Rs 800Q, where Q is the daily production in tonnes. What is the cost of production in Rs per tonne for a daily production of 100 tonnes?

Answer: 1300 to 1300

Exp: Fixed cost = Rs. 50,000
Variable cost = Rs. 800Q
Q = daily production in tones
For 100 tonnes of production daily, total cost of production
= 50,000+800×100 = 130,000

$$\text{So, cost of production per tonne of daily production} = \frac{130,000}{100} = \text{Rs.}1300.$$

Q.No-6-10 Carry Two Marks Each

6. Find the odd one in the following group: ALRVX, EPVZB, ITZDF, OYEIK

(A) ALRVX (B) EPVZB (C) ITZDF (D) OYEIK

Answer: (D)

Exp: ALRVX→only one vowel
EPVZB→only one vowel
ITZDF→only one vowel
OYEIK→three vowels

7. Anuj, Bhola, Chandan, Dilip, Eswar and Faisal live on different floors in a six-storeyed building (the ground floor is numbered 1, the floor above it 2, and so on). Anuj lives on an even-numbered floor. Bhola does not live on an odd numbered floor. Chandan does not live on any of the floors below Faisal's floor. Dilip does not live on floor number 2. Eswar does not live on a floor immediately above or immediately below Bhola. Faisal lives three floors above Dilip. Which of the following floor-person combinations is correct?

	Anuj	Bhola	Chandan	Dilip	Eswar	Faisal
(A)	6	2	5	1	3	4
(B)	2	6	5	1	3	4
(C)	4	2	6	3	1	5
(D)	2	4	6	1	3	5

Answer: (B)

Exp: (a) Anuj: Even numbered floor (2,4,6)
(b) Bhola: Even numbered floor (2,4,6)
(c) Chandan lives on the floor above that of Faisal.
(d) Dilip: not on 2^{nd} floor.
(e) Eswar: does not live immediately above or immediately below Bhola
From the options its clear, that only option (B) satisfies condition (e).
So, correct Ans is (B).

8. The smallest angle of a triangle is equal to two thirds of the smallest angle of a quadrilateral. The ratio between the angles of the quadrilateral is 3:4:5:6. The largest angle of the triangle is twice its smallest angle. What is the sum, in degrees, of the second largest angle of the triangle and the largest angle of the quadrilateral?

Answer: 180 to 180

Exp: Let the angles of quadrilateral are 3x, 4x, 5x, 6x
So, $3x+4x+5x+6x = 360$
$x = 20$
Smallest angle of quadrilateral = $3\times20 = 60°$
Smallest angle of triangle = $\frac{2}{3}\times 60° = 40°$
Largest angle of triangle = $2\times40° = 60°$
Three angles of triangle are 40°, 60°, 80°
Largest angle of quadrilateral is 120°
Sum (2^{nd} largest angle of triangle + largest angle of quadrilateral)
$= 60°+120°=180°$.

9. One percent of the people of country X are taller than 6 ft. Two percent of the people of country Y are taller than 6 ft. There are thrice as many people in country X as in country Y. Taking both countries together, what is the percentage of people taller than 6 ft?

(A) 3.0 (B) 2.5 (C) 1.5 (D) 1.25

Answer: (D)

Exp: Let number of people in country y = 100

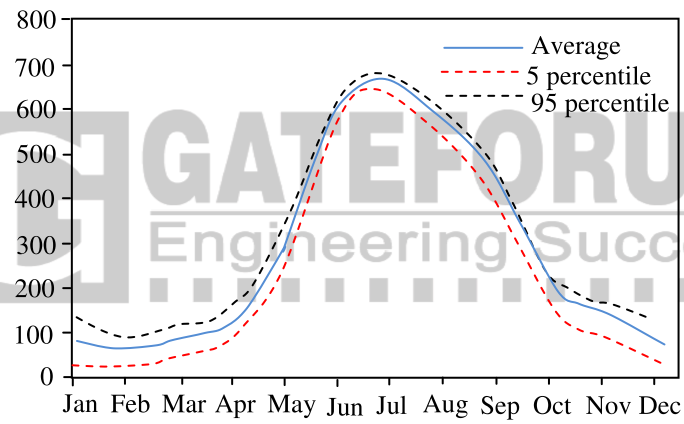
So, number of people in country x = 300

Total number of people taller than 6ft in both the countries

$$= 300 \times \frac{1}{100} + 100 \times \frac{2}{100} = 5$$

% of people taller than 6ft in both the countries $= \frac{5}{400} \times 100 = 1.25\%.$

10. The monthly rainfall chart based on 50 years of rainfall in Agra is shown in the following figure. Which of the following are true? (k percentile is the value such that k percent of the data fall below that value)



(i) On average, it rains more in July than in December

(ii) Every year, the amount of rainfall in August is more than that in January

(iii) July rainfall can be estimated with better confidence than February rainfall

(iv) In August, there is at least 500 mm of rainfall

(A) (i) and (ii) (B) (i) and (iii) (C) (ii) and (iii) (D) (iii) and (iv)

Answer: (B)

Exp: In the question the monthly average rainfall chart for 50 years has been given.

Let us check the options.

(i) On average, it rains more in July than in December $\Rightarrow$ correct.

(ii) Every year, the amount of rainfall in August is more than that in January.

$\Rightarrow$ may not be correct because average rainfall is given in the question.

(iii) July rainfall can be estimated with better confidence than February rainfall.

$\Rightarrow$ From chart it is clear the gap between 5 percentile and 95 percentile from average is higher in February than that in July $\Rightarrow$ correct.

(iv) In August at least 500 mm rainfall

$\Rightarrow$ May not be correct, because its 50 year average.

So correct option (B) (i) and (iii).

Q.No-1-25 Carry One Mark Each

1. Gradient of a scalar variable is always

(A) a vector (B) a scalar (C) a dot product (D) zero

Answer: (A)

Exp. Gradient $\nabla = \hat{i}\frac{\partial}{\partial x} + \hat{j}\frac{\partial}{\partial y} + \hat{k}\frac{\partial}{\partial z}$

If f is a scalar point function

$\nabla f = \text{grad } f = \hat{i}\frac{\partial f}{\partial x} + \hat{j}\frac{\partial f}{\partial y} + \hat{k}\frac{\partial f}{\partial z}$ is a vector.

2. For the time domain function, $f(t) = t^2$,which **ONE** of the following is the Laplace transform of $\int_0^t f(t)\,dt$?

(A) $\frac{3}{s^4}$ (B) $\frac{1}{4s^2}$ (C) $\frac{2}{s^3}$ (D) $\frac{2}{s^4}$

Answer: (D)

Exp. We have $L\left[\int_0^t f(t)\,dt\right] = \frac{F(s)}{s}$ where $F(s) = L[f(t)]$

$\Rightarrow L\left[\int_0^t t^2\,dt\right] = \left(\frac{2}{s^3}\right)\Big/3 = \frac{2}{s^4}\left(\because L\left[t^2\right] = \frac{2}{s^3}\right)$

3. If f*(x) is the complex conjugate of f(x) = cos(x) + i sin(x), then for real a and b, $\int_a^b f^*(x) f(x)\,dx$ is ALWAYS

(A) positive (B) negative (C) real (D) imaginary

Answer: (C)

Exp. $f(x) = \cos(x) + i\sin(x)$

$f^*(x) = \cos(x) - i\sin(x)$

$\int_a^b f^*(x).f(x)\,dx = \int_a^b (\cos x - i\sin x)(\cos + i\sin x)\,dx$

$= \int_a^b e^{-ix}.e^{ix}\,dx = \int_a^b 1.dx = b - a \in R \;(\because a, b, \in R)$

$\Rightarrow$ Real for real a & b.

4. If f(x) is a real and continuous function of x, the Taylor series expansion of f(x) about its minima will NEVER have a term containing

(A) first derivative (B) second derivative

(C) third derivative (D) any higher derivative

Answer: (A)

Exp. For a real valued function y = f(x)

Taylor series expansion about 'a'

$$f(x) = f(a) + (x-a)f'(a) + \frac{(x-a)^2}{2!}f''(a) + ...$$

For minima at $x = a, f'(a) = 0$.

So, Taylor series expansion of f(x) about 'a' will never contain first derivative term.

5. From the following list, identify the properties which are equal in both vapour and liquid phases at equilibrium

P. Density Temperature

R. Chemical potential S. Enthalpy

(A) P and Q only (B) Q and R only

(C) R and S only (D) P and S only

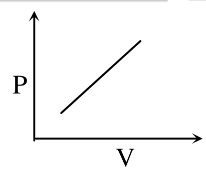
Answer: (B)

Exp. For phase equilibrium

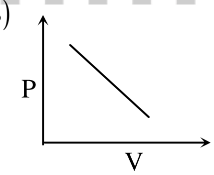
$$\left.\begin{array}{l} \text{Temperature; } T^g = T^l \\ \text{Pressure; } P^g = P^l \\ \text{Chemical potential; } \mu^g = \mu^l \end{array}\right\} \text{correct Ans is (B).}$$

6. In a closed system, the isentropic expansion of an ideal gas with constant specific heats is represented by

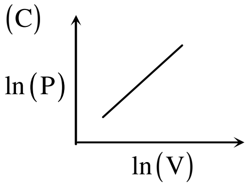
(A)



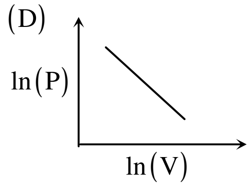
(B)



(C)



(D)



Answer: (D)

Exp. For isentropic expansion,

$PV^{\gamma} = \text{constant}$

Taking log on both sides

$\ln P + \gamma \ln V = 0$

$$\frac{\ln P}{\ln V} = -\gamma = \text{negative}$$

$\because \gamma$ is positive slope of $\ln P$ vs $\ln V$ is negative.

7. Match the following :

Group 1	Group 2
(P) $\left(\frac{\partial G}{\partial n_i}\right)_{T,P,n_{jet}}$	I. Arrhenius equagtion
(Q) $\left(\frac{\partial G}{\partial n_i}\right)_{S,V,n_{jet}}$	II. Reaction equilibrium constant
(R) $\exp\left(\frac{-\Delta G^0_{reaction}}{RT}\right)$	III. Chemical potential
(S) $\Sigma\left(n_i d\mu_i\right)_{T,P} = 0$	IV. Gibbs-Duhem equation

(A) Q-III, R-I, S-II (B) Q-III, R-II, S-IV
(C) P-III, R-II, S-IV (D) P-III, R-IV, S-I

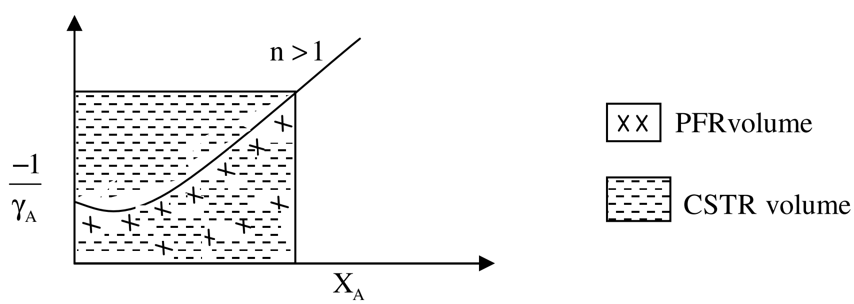
Answer: (C)

8. In order to achieve the same conversion under identical reaction conditions and feed flow rate for a non-autocatalytic reaction of positive order, the volume of an ideal CSTR is
(A) always greater than that of an ideal PFR
(B) always smaller than that of an ideal PFR
(C) same as that of an ideal PFR
(D) smaller than that of an ideal PFR only for first order reaction

Answer: (A)

Exp. For CSTR, volume $V = \frac{F_{A0}X_A}{-\gamma_A}$

For PFR volume $V = F_{A0}\int\frac{dX_A}{-\gamma_A}$



From plot it is clear that volume of ideal CSTR (area) is higher than that of the ideal PFR.

9. Integral of the time-weighted absolute error (ITAE) is expressed as

(A) $\int_0^\infty \frac{|\varepsilon(t)|}{t^2}dt$ (B) $\int_0^\infty \frac{|\varepsilon(t)|}{t}dt$

(C) $\int_0^\infty t|\varepsilon(t)|dt$ (D) $\int_0^\infty t^2|\varepsilon(t)|dt$

Answer: (C)

Exp. Let number of people in country y = 100

So, number of people in country x = 300

Total number of people taller than 6ft in both the countries $= 300 \times \frac{1}{100} + 100 \times \frac{2}{100} = 5$

% of people taller than 6ft in both the countries $= \frac{5}{400} \times 100 = 1.25\%$

10. A unit **IMPULSE** response of a first order system with time constant τ and steady state gain K_p is given by

(A) $\frac{1}{K_p \tau} e^{t/\tau}$ (B) $K_p e^{-t/\tau}$ (C) $\tau K_p e^{-t/\tau}$ (D) $\frac{K_p}{\tau} e^{-t/\tau}$

Answer: (D)

Exp. Unit Impulse input x(t) = δ(t)

So, X(s) = 1

$$G(s) = \frac{Y(s)}{X(s)} = \frac{K_p}{\tau s + 1} \Rightarrow y(s) = \frac{K_p}{\tau s + 1}.1$$

$$y(t) = \frac{K_p}{\tau} e^{-t/\tau}.$$

11. In a completely opaque medium, if 50% of the incident monochromatic radiation is absorbed, then which of the following statements are **CORRECT**?

(P) 50% of the incident radiation is reflected

(Q) 25% of the incident radiation is reflected

(R) 25% of the incident radiation is transmitted

(S) No incident radiation is transmitted

(A) P and S only (B) Q and R only (C) P and Q only (D) R and S only

Answer: (A)

Exp. For a completely opaque system $\tau = 0 \Rightarrow S$

Given $\propto = 0.5$

$\propto + \tau + \gamma = 1$

So, $\gamma = 0.5 \Rightarrow P$

Final Ans is (A) P and S only.

12. In case of a pressure driven laminar flow of a Newtonian fluid of viscosity (μ) through a horizontal circular pipe, the velocity of the fluid is proportional to

(A) μ (B) $\mu^{0.5}$ (C) μ^{-1} (D) $\mu^{-0.5}$

Answer: (C)

Exp. Pressure drop in case laminar flow is

$$\frac{\Delta P}{L} = \frac{32 \mu L V}{D^2}$$

clearly $V \propto \mu^{-1}$.

13. Which of the following statements are CORRECT?

(P) For a rheopectic fluid, the apparent viscosity increases with time under a constant applied shear stress

(Q) For a pseudoplastic fluid, the apparent viscosity decreases with time under a constant applied shear stress

(R) For a Bingham plastic, the apparent viscosity increases exponentially with the deformation rate

(S) For a dilatant fluid, the apparent viscosity increases with increasing deformation rate

(A) P and Q only (B) Q and R only (C) R and S only (D) P and S only

Answer: (D)

14. Assume that an ordinary mercury-in-glass thermometer follows first order dynamics with a time constant of 10s. It is at a steady state temperature of 0°C. At time t = 0, the thermometer is suddenly immersed in a constant temperature bath at 100°C. The time required (in s) for the thermometer to read 95°C, approximately is

(A) 60 (B) 40 (C) 30 (D) 20

Answer: (C)

Exp. Given $\tau = 10s$

For first order system

$$y(t) = K_p A\left(1 - e^{-t/\tau}\right)$$

$$95 = 100\left(1 - e^{-t/\tau}\right)$$

$$\Rightarrow \frac{t}{\tau} = 2.995 \sim 3 \Rightarrow t = 30\text{ sec.}$$

15. Packed towers are preferred for gas-liquid mass transfer operations with foaming liquids because

(A) in packed towers, high liquid to gas ratios are best handled

(B) in packed towers, continuous contact of gas and liquid takes place

(C) packed towers are packed with random packings

(D) in packed towers, the gas is not bubbled through the liquid pool

Answer: (D)

16. A spherical storage vessel is quarter–filled with toluene. The diameter of the vent at the top of the vessel is 1/20th of the diameter of the vessel. Under the steady state condition, the diffusive flux of toluene is maximum at

(A) the surface of the liquid

(B) the mid-plane of the vessel

(C) the vent

(D) a distance 20 times the diameter of the vent away from the vent

Answer: (C)

Exp. Diffusive flux is maximum at the vent and remains same throughout the vent line at steady state.

17. In order to produce fine solid particles between 5 and 10 µm, the appropriate size reducing equipment is

(A) fluid energy mill (B) hammer mill

(C) jaw crusher (D) smooth roll crusher

Answer: (A)

18. Slurries are most conveniently pumped by a
(A) syringe pump (B) diaphragm pump
(C) vacuum pump (D) gear pump

Answer: (B)

19. Assuming the mass transfer coefficients in the gas and the liquid phases are comparable, the absorption of CO_2 from reformer gas (CO_2+H_2) into an aqueous solution of diethanolamine is controlled by
(A) gas phase resistance (B) liquid phase resistance
(C) both gas and liquid phase resistances (D) composition of the reformer gas

Answer: (A)

20. Which ONE of the following statements is CORRECT for the surface renewal theory?
(A) Mass transfer takes place at steady state
(B) Mass transfer takes place at unsteady state
(C) Contact time is same for all the liquid elements
(D) Mass transfer depends only on the film resistance

Answer: (B)

21. Steam economy of a multiple effect evaporator system is defined as
(A) kilogram of steam used per hour
(B) kilogram of steam consumed in all the effects for each kilogram of steam fed
(C) kilogram of steam used in all the effects for each kilogram of water vaporized per hour
(D) kilogram of water vaporized from all the effects for each kilogram of steam fed to the first effect

Answer: (D)

22. Decomposition efficiency (η_D) of an electrolytic cell used for producing NaOH is defined as
(A) $\eta_D =$ (grams of NaOH produced / grams of NaCl decomposed) x 100
(B) $\eta_D =$ (grams of NaOH produced / grams of NaCl charged) x 100
(C) $\eta_D =$ (gram equivalents of NaOH produced / gram equivalents of NaCl charged) x 100
(D) $\eta_D =$ (theoretical current to produce one gram equivalent / actual current to produce one gram equivalent) x 100

Answer: (C)

23. The vessel dispersion number for an ideal CSTR is
(A) -1 (B) 0 (C) 1 (D) ∞

Answer: (D)

Exp. Dispersion number $= \frac{D}{UL}$

For an ideal CSTR, $\frac{D}{UL} \to \infty.$

24. Catalytic cracking is
(A) a hydrogen addition process (B) a carbon rejection process
(C) an exothermic process (D) a coking process

Answer: (B)

25. Which ONE of the following statements is CORRECT?
(A) The major components of biodiesel are triglycerides
(B) Biodiesel is essentially a mixture of ethyl esters
(C) Biodiesel is highly aromatic
(D) Biodiesel has a very low aniline point

Answer: (B)

Q.No-26-55 Carry Two Marks Each

26. Consider the following differential equation

$$\frac{dy}{dx} = x + \ln(y);\ y = 2 \text{ at } x = 0$$

The solution of this equation at x = 0.4 using Euler method with a step size of h= 0.2 is ________.

Answer: 2.3 to 2.4

Exp. $\frac{dy}{dx} = x + \ell ny$

$\frac{dy}{dx} = f(x,y) \Rightarrow f(x,y) = x + \ell ny$

given $x_0 = 0,\ y_0 = 2$

We have, $y_{n+1} = y_n + h_f(x_n, y_n)$ $n = 0,1,2,3,......$

for $x = 0$ $y_1 = y_0 + h_f(x_0, y_0)$

$h = 0.2,\ y_1 = y(x_1) = y(x_0 + h) = y(0+0.2) = y(0.2)$

$\therefore y(0.2) = y_1 = 2 + 0.2f(0,2) = 2 + 0.2(0 + \ell n_2) = 2 + 0.2(0.69315) = 2.13863$

$y_2 = y(x_2) = y(x_1 + h) = y(0.2+0.2) = y(0.4)$

$\therefore y(0.4) = y_2 = y_1 + h_f(x_1, y_1) = 2.13863 + 0.2f(0.2, 2.13863)$

$= 2.13863 + 0.2[0.2 + 1h(2.13863)]$

$= 2.13863 + 0.2(0.2 + 0.76016) = 2.33066$

27. The integrating factor for the differential equation

$$\frac{dy}{dx} - \frac{y}{1+x} = (1+x) \text{ is}$$

(A) $\frac{1}{1+x}$ (B) $(1+x)$ (C) $x(1+x)$ (D) $\frac{x}{1+x}$

Answer: (A)

Exp. Given differential equation $\frac{dy}{dx} - \frac{y}{1+x} = 1 + x$

$\frac{dy}{dx} + Py = Q \Rightarrow P = \frac{-1}{1+x}$

$I.F = e^{\int pdx} = e^{\int \frac{-1}{1+x}dx} = e^{-\log(1+x)} = \frac{1}{1+x}$

28. The differential equation $\frac{d^2y}{dx^2}+x^2\frac{dy}{dx}+x^3y=e^x$ is a

(A) non-linear differential equation of first degree
(B) linear differential equation of first degree
(C) linear differential equation of second degree
(D) non-linear differential equation of second degree

Answer: (B)

Exp. Given equation

$$\frac{d^2y}{dx^2}+x^2\frac{dy}{dx}+x^3y=e^x$$

This is clearly a linear differential equation

Order = 2

Degree = 1.

29. Consider the following two normal distributions

$f_1(x)=\exp(-\pi x^2)$

$f_2(x)=\frac{1}{2\pi}\exp\left\{-\frac{1}{4\pi}(x^2+2x+1)\right\}$

If μ and σ denote the mean and standard deviation, respectively, then

(A) $\mu_1<\mu_2$ and $\sigma_1^2<\sigma_2^2$ (B) $\mu_1<\mu_2$ and $\sigma_1^2>\sigma_2^2$
(C) $\mu_1>\mu_2$ and $\sigma_1^2<\sigma_2^2$ (D) $\mu_1>\mu_2$ and $\sigma_1^2>\sigma_2^2$

Answer: (C)

Exp. $f_1(x)\ =e^{-\pi x^2}$

Comparing with, $f(x)=\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$

$\Rightarrow \mu_1=0\ \&\ \sigma_1\ =\frac{1}{\sqrt{2\pi}}$

$f_2(x)\ =\frac{1}{2\pi}e^{-\frac{1}{4\pi}(x^2+2x+1)}\ =\frac{1}{2\pi}e^{-\frac{1}{4x}(x+1)^2}$

Comparing with , $f(x)\ =\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$

$\Rightarrow \mu_2=-1\ \&\ \sigma_2\ =\sqrt{2\pi}$

$\Rightarrow \mu_1>\mu_2\ \&\ \sigma_1^2<\sigma_2^2\Rightarrow(C)$

30. In rolling of two fair dice, the outcome of an experiment is considered to be the sum of the numbers appearing on the dice. The probability is highest for the outcome of _____________

Answer: 6.99 to 7.01

Exp.

X	2	3	4	5	6	7	8	9	10	11	12

P(x)	$\frac{1}{36}$	$\frac{2}{36}$	$\frac{3}{36}$	$\frac{4}{36}$	$\frac{5}{36}$	$\frac{6}{36}$	$\frac{5}{36}$	$\frac{4}{36}$	$\frac{3}{36}$	$\frac{2}{36}$	

Where X is a random variable denotes the sum of the numbers appearing on the dice.

$P(x) =$ corresponding probabilities

$\therefore$ The probability is highest for the outcome "7" i.e., $\frac{6}{36}$

31. A spherical ball of benzoic acid (diameter = 1.5 cm) is submerged in a pool of still water. The solubility and diffusivity of benzoic acid in water are 0.03 kmol/m³ and 1.25 x 10^{-9} m²/s respectively. Sherwood number is given as Sh = 2.0 + 0.6 $Re^{0.5}\,Sc^{0.33}$. The initial rate of dissolution (in kmol/s) of benzoic acid approximately is

(A) 3.54×10^{-11} (B) 3.54×10^{-12}

(C) 3.54×10^{-13} (D) 3.54×10^{-14}

Answer: (B)

Exp. $Sh = 2 + 0.6\,R_e^{0.5}\,Sc^{0.33}$

Diameter = 1.5 cm

Solubility = 0.03 k mol/m³

Diffusivity $= 1.25\times10^{-9}\ m^2/s$

Given $Sh = 2 + 0.6(Re)^{0.5}(Sc)^{0.33}$

Initially Sh ~ 2

$\frac{K_c d}{D_{AB}} = 2$, K_c = Mass transfer coefficient (m/s)

$$\Rightarrow K_c = \frac{2\times1.25\times10^{-9}}{1.5\times10^{-2}} = 1.67\times10^{-7}\ m/sec$$

Initial rate of dissolution $= K_cA(C_s - 0) = K_cAC_s$

$= 1.67\times10^{-7}\times\pi\times(1.5\times10^{-2})^2\times0.03 = 3.54\times10^{-12}$ kmol/sec

32. A wet solid of 100 kg is dried from a moisture content of 40wt% to 10wt%. The critical moisture content is 15wt% and the equilibrium moisture content is negligible. All moisture contents are on dry basis. The falling rate is considered to be linear. It takes 5 hours to dry the material in the constant rate period. The duration (in hours) of the falling rate period is ________

Answer: 1.1 to 1.3

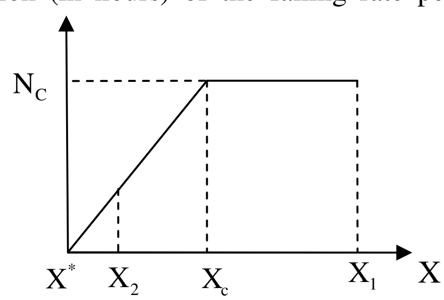
Exp. Given $X_1 = 0.4$

$X_2 = 0.10$

$X_C = 0.15$

$X^* = 0$

Constant rate period



$$5=\frac{S}{AN_C}(X_1-X_c)\Rightarrow\frac{S}{AN_C}=\frac{5}{0.25}=20$$

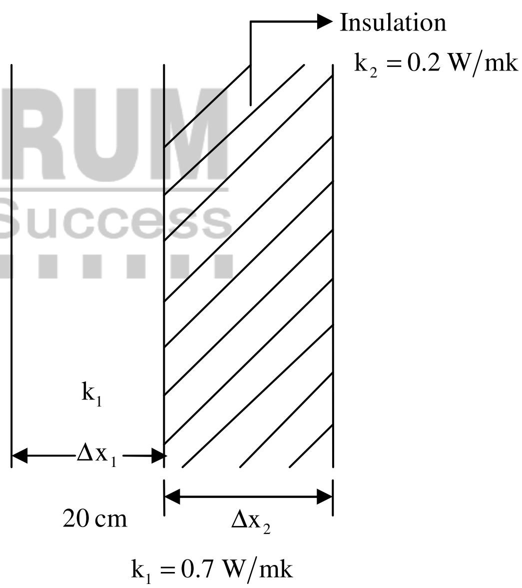
Falling rate period, $N=m(X-X^*)=\dfrac{N_C(X-X^*)}{(X_c-X^*)}$

$$t_f=-\int_{X_c}^{X_2}\frac{S}{A}\frac{dX}{\left(\frac{N_c}{X_c-X^*}\right)(X-X^*)}=\frac{S(X_c-X^*)}{AN_C}\ln\frac{X_c-X^*}{X_2-X^*}$$

$$t_f=20\times0.15\ln\frac{0.15}{0.10}=1.216\text{ hr.}$$

33. A brick wall of 20 cm thickness has thermal conductivity of 0.7 W m^{-1} K^{-1}. An insulation of thermal conductivity 0.2 W m^{-1} K^{-1} is to be applied on one side of the wall, so that the heat transfer through the wall is reduced by 75%. The same temperature difference is maintained across the wall before and after applying the insulation. The required thickness (in cm) of the insulation is ____________

Answer: 17.0 to 17.3



Exp. Before insulation heat flux

$$Q_1=-k_1A\frac{dT}{dx_1}=-k_1A\frac{\Delta T}{0.2}$$

After applying insulation heat transfer decreases by 75%

$$Q_2=-\frac{\Delta T}{\frac{\Delta x_1}{k_1A}+\frac{\Delta x_2}{k_2A}}$$

Taking $A=1m^2$

$$Q_2=0.25\,Q_1=0.25\frac{\Delta T}{\frac{0.2}{0.7}}=\frac{\Delta T}{\frac{0.2}{0.7}+\frac{\Delta x_2}{0.2}}$$

$$\Rightarrow\frac{0.8}{0.7}=\frac{0.2}{0.7}+\frac{\Delta x_2}{0.2}$$

$$\Rightarrow\Delta x_2=\frac{0.6\times0.2}{0.7}=0.1714m=17.14\text{ cm.}$$

34. An oil with a flow rate of 1000 kg/h is to be cooled using water in a double-pipe counter-flow heat exchanger from a temperature of 70°C to 40°C. Water enters the exchanger at 25°C and leaves at 40°C. The specific heats of oil and water are 2 kJ kg^{-1} K^{-1} and 4.2 kJ kg^{-1} K^{-1}, respectively. The overall heat transfer coefficient is 0.2 kW m^{-2} K^{-1}. The minimum heat exchanger area (in m^2) required for this operation is ______________

Answer: 3.75 to 3.95

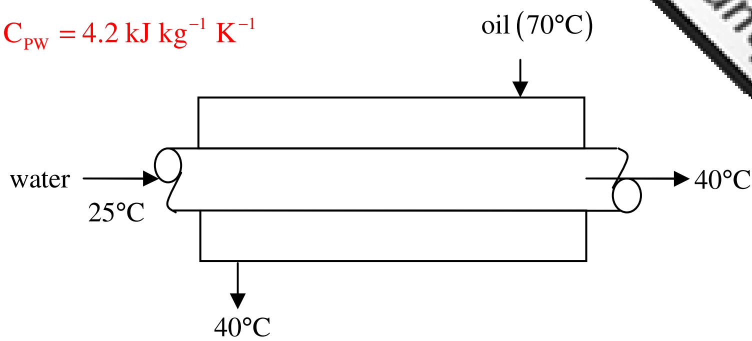
Exp.

Given $C_{PO} = 2\text{ kJ kg}^{-1}\text{K}^{-1}$ $\quad C_{PW} = 4.2\text{ kJ kg}^{-1}\text{ K}^{-1}$

$U = 0.2\text{ kW m}^{-2}\text{K}^{-1}$

$\Delta T_1 = 15°C, \Delta T_2 = 30°C$

$$LMTD = \frac{30-15}{\ln\left(\frac{30}{15}\right)} = 21.64°C$$



$$\text{Heat transfer } Q = \frac{1000}{3600} \times 2 \times (70° - 40°) = 16.67\text{ kJ}$$

$$Q = UA(LMTD)$$

$$A = \frac{16.67}{0.2 \times 21.64} = 3.85\text{ m}^2.$$

35. Which **ONE** of the following is **CORRECT** for an ideal gas in a closed system?

(A) $\left(\frac{\partial U}{\partial V}\right)_S V = nR\left(\frac{\partial U}{\partial S}\right)_v$ (B) $-\left(\frac{\partial H}{\partial P}\right)_S P = nR\left(\frac{\partial H}{\partial S}\right)_P$

(C) $\left(\frac{\partial U}{\partial V}\right)_S V = nR\left(\frac{\partial H}{\partial S}\right)_p$ (D) $\left(\frac{\partial H}{\partial P}\right)_S P = nR\left(\frac{\partial U}{\partial S}\right)_v$

Answer: (D)

Exp. (A) $\left(\frac{\partial u}{\partial v}\right)_s v = nR\left(\frac{\partial u}{\partial s}\right)_v$

Fundamental property relation

$dU = Tds - Pdv$

$\Rightarrow \left(\frac{\partial u}{\partial v}\right)_s = -P$ and $\left(\frac{\partial u}{\partial s}\right)_v = T$

$-PV = nRT \Rightarrow$ Incorrect

(B) $-\left(\frac{\partial H}{\partial P}\right)_s P = nR\left(\frac{\partial H}{\partial S}\right)_p$

Fundamental property relation

$dH = Tds + Vdp$

$\left(\frac{\partial H}{\partial P}\right)_s = V$ and $\left(\frac{\partial H}{\partial S}\right)_p = T$

$-PV = nRT \Rightarrow$ incorrect

(C) $-PV = nRT \Rightarrow$ incorrect

(D) $PV = nRT \Rightarrow$ correct.

36. A binary distillation column is operating with a mixed feed containing 20 mol% vap... the feed quality is changed to 80 mol% vapour, the change in the slope of the q-lin... ________

Answer: 3.6 to 3.9

Exp. Feed contains 20% vapour, so q = 0.8

$$\text{Slope of q line} = \frac{q}{q-1} = \frac{0.8}{-0.2} = -4$$

Now feed contains 80% vapour, q = 0.2

$$\text{Slope} = \frac{q}{q-1} = \frac{0.2}{-0.8} = \frac{-1}{4}$$

$$\text{Change in slope} = -\frac{1}{4} + 4 = 3.75.$$

37. A homogeneous reaction $(R \to P)$ occurs in a batch reactor. The conversion of the reactant *R* is 67% after 10 minutes and 80% after 20 minutes. The rate equation for this reaction is

(A) $-r_R = k$ (B) $-r_R = kC_R^2$ (C) $-r_R = kC_R^3$ (D) $-r_R = kC_R^{0.5}$

Answer: (B)

Exp. For an ideal batch reactor $A = \int_{C_{A0}}^{C_A} \frac{d\,C_A}{-\gamma} = \int_{C_{A0}}^{C_A} \frac{d\,C_A}{kC_A^n}$

$C_A = C_{A0}(1-X_A)$

$dC_A = -C_{A0}dX_A$

$$t = -C_{A0}\int \frac{dX_A}{kC_{A0}^n(1-X_A)^n} = -\frac{C_{A0}^{1-n}}{k}\int_0^{X_A} \frac{dX_A}{(1-X_A)^n}$$

$$t = \frac{C_{A0}^{1-n}}{k}\left[\frac{(1-X_A)^{1-n}}{1-n}\right]^{X_A}$$

$$t = \frac{C_{A0}^{1-n}}{k}\left[\frac{(1-X_A)^{1-n}-1}{1-n}\right]$$

for reaction $R \to P$; $X_A = 0.67, t = 10$ minutes

$X_A = 0.80$ t = 20 minutes

$$10 = C_{A0}^{1-n}\left[\frac{0.33^{1-n}-1}{1-n}\right] \text{—}(1)$$

$$20 = \frac{C_{A0}^{1-n}}{k}\left[\frac{0.2^{1-n}-1}{1-n}\right] \text{—}(2)$$

Dividing equation (1) by equation (2)

$$\frac{1}{2} = \frac{0.33^{1-n}-1}{0.2^{1-n}-1}$$

Solving we get n = 2

So, $-\gamma_R = k\,C_R^2$.

38. A vapour phase catalytic reaction $(Q+R\rightarrow S)$ follows Rideal mechanism (R and S a... adsorbed). Initially, the mixture contains only the reactants in equimolar ratio. The surfa... reaction step is rate controlling. With constants *a* and *b*, the initial rate of reaction $(-r_0)$ in terms of total pressure (P_T) is given by

(A) $-r_0=\dfrac{aP_T}{1+bP_T}$ (B) $-r_0=\dfrac{aP_T}{1+bP_T^2}$ (C) $-r_0=\dfrac{aP_T^2}{1+bP_T}$ (D) $-r_0=\dfrac{aP_T^2}{(1+bP_T)^2}$

Answer: (C)

Exp. R_{ideal} mechanism

$$A(g)+S \underset{K_{-1}}{\overset{K_1}{\rightleftharpoons}} A-S$$

$$A-S+B(g) \underset{K_{-2}}{\overset{K_2}{\rightleftharpoons}} AB-S \quad (\text{rate controlling})$$

$$AB-S \longrightarrow AB$$

Here s = adsorption site on catalyst surface

$$k_1=\frac{A-S}{(A)(S)}\_\_\_(I)$$

and for rate controlling step

$$-\gamma=K_2(A-s)(B)-K_{-2}(AB-S)\_\_(II)$$

Also, total number of sites is S_T

$$S_T=(S)+(A-S)+(AB-S)\_\_(III)$$

Initially surface coverage of AB will be very low, so $(AB-S)=0$

From (I), $K_1=\dfrac{(A-S)}{(A)(S_T-(A-S))}$

$$\Rightarrow K_1(A)S_T-K_1(A-S)(A)=(A-S)\Rightarrow\ (A-S)=\frac{K_1(A)S_T}{1+K_1(A)}$$

Now, for rate controlling step, $-\gamma=K_2(A-S)(B)-K_{-2}(AB-S)$

Initial rate mean concentration of $(AB-S)\rightarrow 0$

So, $-\gamma_0=K_2(A-S)(B)$

$$-\gamma_0=\frac{K_2K_1(A)(B)S_T}{1+K_1(A)}$$

For the given reaction Q+R→S with reactants in equimolar ratio

$$-\gamma_0=\frac{K_2K_2\,P_T.P_T}{1+K_1P_T}=\frac{a\,P_T^2}{1+bP_T}.$$

39. A incompressible fluid is flowing through a contraction section of length L and has a [...] direction) steady state velocity distribution, $u = u_0\left(1+\frac{2x}{L}\right)$. If $u_0 = 2m/s$ and L = 3m, th[...] convective acceleration (in m/s^2) of the fluid at L is ________

Answer: 7.99 to 8.01

Exp.

$$\text{Convective acceleration } \cancelto{=0}{\frac{du}{dt}} = \frac{\partial u}{\partial t} + u\cancelto{=0}{\frac{du}{dx}} + ...$$

$$= u_0\left(1+\frac{2x}{L}\right)\frac{2u_0}{L}$$

Putting $u_0 = 2, L = 3$

at $x = L$, convective acceleration $= 2\left(1+\frac{2L}{L}\right)\left(\frac{2\times 2}{3}\right) = 8\ m/s^2$.

40. Match the following:

Group 1	Group 2
(P) Tank in series model	(I) Non-isothermal reaction
(Q) Liquid-liquid extraction	(II) Mixer-settler
(R) Optimum temperature progression	(III) PFR with axial mixing
(S) Thiele modulus	(IV) Solid catalyzed reaction

(A) P-II, Q-IV, R-I, S-III (B) P-I, Q-II, R-III, S-IV

(C) P-III, Q-I, R-II, S-IV (D) P-III, Q-II, R-I, S-IV

Answer: (D)

Exp. Tank in series model $\rightarrow$ PFR with axial mixing

Liquid-liquid extraction $\rightarrow$ Mixer settler

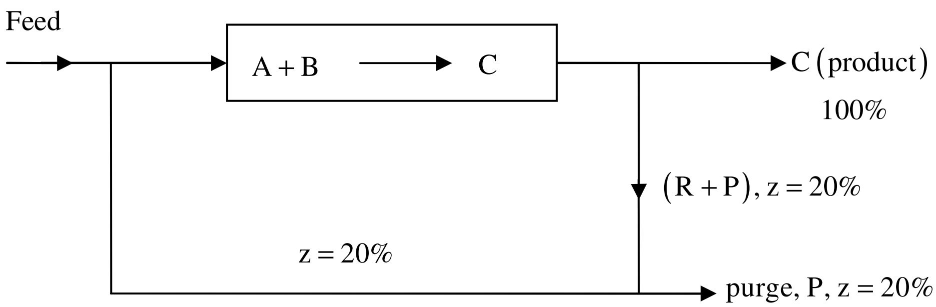
Optimum temperature progression $\rightarrow$ Non-isothermal reaction

Thiele modulus $\rightarrow$ Solid catalyst reaction.

41. Two elemental gases (*A* and *B*) are reacting to form a liquid (*C*) in a steady state process as per the reaction. $A + B \rightarrow C$. The single-pass conversion of the reaction is only 20% and hence recycle is used. The product is separated completely in pure form. The fresh feed has 49 mol% of A and B each along with 2 mol% impurities. The maximum allowable impurities in the recycle stream is 20 mol%. The amount of purge stream (in moles) per 100 moles of the fresh feed is ___________

Answer: 9.99 to10.01

Exp.



Basis = 100 moles of fresh feed

A = 49 moles; B = 49 moles;

Inert, z = 2 moles

Overall balance on inert

$2 = P\times 0.2 \Rightarrow P = 10$

42. Carbon monoxide (CO) is burnt in presence of 200% excess pure oxygen and the flame temperature achieved is 2298 K. The inlet streams are at 25 °C. The standard heat of formation (at 25 °C) of CO and CO_2 are -110kJ mol^{-1} and -390kJ mol^{-1}, respectively. The heat capacities (in J mol^{-1} K^{-1}) of the components are

$$C_{p_{O_2}} = 25 + 14\times 10^{-3}T$$

$$C_{p_{CO_2}} = 25 + 42\times 10^{-3}T$$

where, T is the temperature in K. The heat loss (in kJ) per mole of CO burnt is_____________

Answer: 32.0 to 38.0

Exp. $CO + \frac{1}{2}O_2 \longrightarrow CO_2$

Basis: 1 mole of CO burnt

O_2 supplied = 0.5×3 = 1.5 mole

Unreacted O_2 in product = 1 mole

Standard heat of reaction = - 390 – (-110) = - 280 kJ/mol.

Heat of reactants = 0 (at 298k)

$$\text{Heat of product} = \int_{298}^{2298} \left\{ \left(25 + 14\times 10^{-3}T\right) + \left(25 + 42\times 10^{-3}T\right) \right\} dT$$

$$= 86.344 + 159.032 = 245.376 \text{ kJ/mole}$$

$$\text{Heat loss} = 280 - 245.376 = 34.624 \text{ kJ}$$

43. A cash flow of Rs. 12,000 per year is received at the end of each year (uniform periodic payment) for 7 consecutive years. The rate of interest is 9% per year compounded annually. The present worth (in Rs.) of such cash flow at time zero is __________

Answer: 60000 to 61000

Exp. $\text{Present worth } P = R\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right]$

$$P = 12000\left[\frac{(1.09)^7 - 1}{0.09\times(1.09)^7}\right] = 60395.43$$

44. A polymer plant with a production capacity of 10,000 tons per year has an overall yield of 70%, on mass basis (kg of product per kg of raw material). The raw material costs Rs. 50,000 per ton. A process modification is proposed to increase the overall yield to 75% with an investment of Rs. 12.5 crore. In how many years can the invested amount be recovered with the additional profit? ___________

Answer: 2.55 to 2.70

Exp. Let number of years = n

Total product = 10,000 n

$$\text{Raw material used} = \frac{10{,}000\text{ n}}{0.7}$$

$$\text{Total cost of Raw material} = \frac{10{,}000\text{ n}}{0.7} \times 50{,}000$$

from question

$$\frac{50{,}000 \times 10{,}000\text{ n}}{0.7} - \frac{50{,}000 \times 10{,}000\text{ n}}{0.75} = 12.5 \times 10^7$$

Solving, n = 2.625 years.

45. A step change of magnitude 2 is introduced into a system having the following transfer function :

$$G(s) = \frac{2}{s^2 + 2s + 4}$$

The percent overshoot is ____________________.

Answer: 16.0 to 16.8

Exp. $$G(s) = \frac{2}{s^2 + 2s + 4} = \frac{0.5}{0.25s^2 + 0.5s + 1}$$

$$\text{Comparing with } G(s) = \frac{K_p}{\tau^2 s^2 + 2\rho\tau s + 1}$$

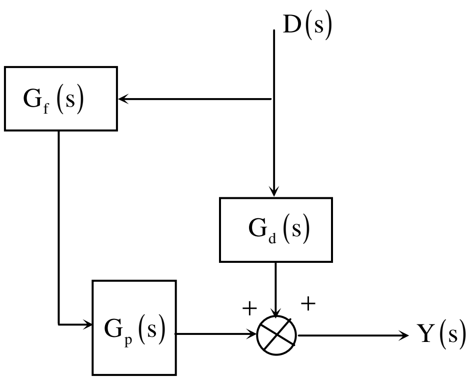
$\tau^2 = 0.25$ and $2\rho\tau = 0.5$

$\tau = 0.5$ $\rho = 0.5$

$$\text{overshoot} = \exp\left(-\frac{\pi\rho}{\sqrt{1-\rho^2}}\right) = \exp\left(\frac{-\pi \times 0.5}{\sqrt{1-0.25}}\right) = 0.1630$$

% overshoot = 16.3%.

46. Given below is a simplified block diagram of a feedforward control system.

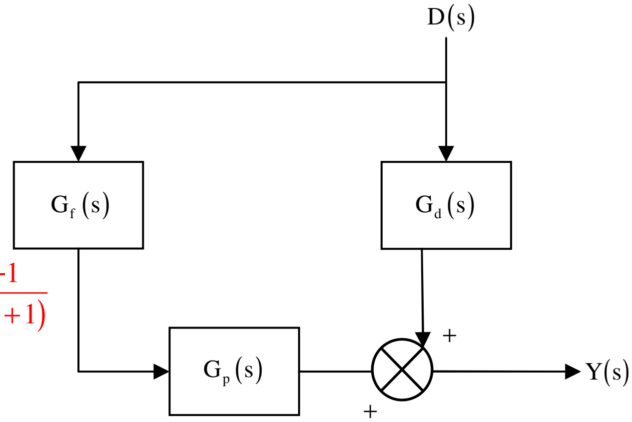


The transfer function of the process is $G_P = \frac{5}{s+1}$ and the disturbance transfer function is $G_d = \frac{1}{s^2+2s+1}$. The transfer function of the **PERFECT** feed forward controller, $G_f(s)$ is

(A) $\frac{-5}{(s+1)^3}$ (B) $\frac{-5}{(s+1)}$ (C) $\frac{-1}{5(s+1)}$ (D) $-5(s+1)$

Answer: (C)

Exp. $\frac{Y(s)}{D(s)} = G_f(s) \times G_p(s) + G_d(s)$



For perfect feed forward controller, no effect of load disturbances.

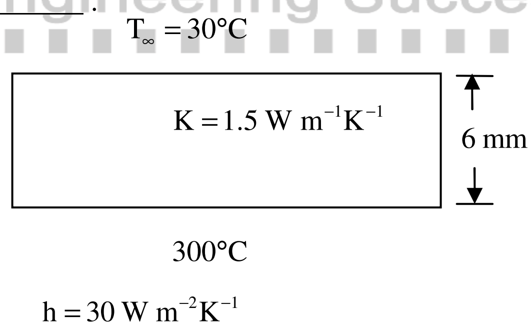
$\Rightarrow G_f(s) \times G_p(s) + G_d(s) = 0$

$\Rightarrow G_f(s) = \frac{-G_d(s)}{G_p(s)} = \frac{-1}{(s+1)^2 . \frac{5}{s+1}} = \frac{-1}{5(s+1)}$

47. The bottom face of a horizontal slab of thickness 6 mm is maintained at 300°C. The top face is exposed to a flowing gas at 30°C. The thermal conductivity of the slab is 1.5 W m^{-1} K^{-1} and the convective heat transfer coefficient is 30 W m^{-2} K^{-1}. At steady state, the temperature (in °C) of the top face is __________.

Answer: 268 to 274

Exp.



At steady state

heat flux due to conduction = heat flux due to convection

$\Rightarrow -kA\frac{(573 - T_s)}{6\times10^{-3}} = hA(T_s - 303)$

$\Rightarrow 1.5(573 - T_s) = 6\times10^{-3} \times 30(T_s - 303)$

$859.5 - 1.5\,T_s = 0.18\,T_s - 54.54$

$T_s = 544.07\text{ K} = 271.07°C.$

48. In a steady incompressible flow, the velocity distribution is given by $\overline{V} = 3x\hat{i} - Py\hat{j} +$ where, V is in m/s and x, y, and z are in m. In order to satisfy the mass conservation, the va of the constant P (in s^{-1}) is ____________.

Answer: 7.99 to 8.01

Exp. Given $\overline{V} = 3x\hat{i} - Py\hat{j} + 5z\hat{k}$

For mass conservation at constant density

$\Delta.\overline{V} = 0$

$$\Rightarrow \frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z} = 0$$

$$\Rightarrow 3 - P + 5 = 0 \Rightarrow P = 8.$$

49. Match the following

Group I	Group II
(P) Turbulence	(I) Reciprocating pump
(Q) NPSH	(II) Packed bed
(R) Ergun equation	(III) Fluctuating velocity
(S) Rotameter	(IV) Impeller
(T) Power number	(V) Vena contracta

(A) P-III, R-II, T-IV (B) Q-V, R-II, S-III
(C) P-III, R-IV, T-II (D) Q-III, S-V, T-IV

Answer: (A)

Exp. Turbulence: Characterized by fluctuating velocity.

Ergun equation: for calculating pressure drop in packed bed.

Power number: For calculating power consumption in mixing tank.

50. In a steady and incompressible flow of a fluid (density = 1.25 kg m^{-3}), the difference between stagnation and static pressures at the same location in the flow is 30 mm of mercury (density = 13600 kg m^{-3}). Considering gravitational acceleration as 10 m s^{-2}, the fluid speed (in m s^{-1}) is ______________

Answer: 79 to 82

Exp. Bernoulli's equation

$$\frac{P_s}{\rho_f g} + \frac{v^2}{2g} = \frac{P}{\rho_f g} + 0 \Rightarrow v = \sqrt{\frac{2(P - P_s)}{\rho_f}}$$

$$\text{Given } \frac{P - P_s}{\rho_f} = \frac{\rho g h}{\rho_f} = \frac{13600 \times 10 \times 30 \times 10^{-3}}{1.25} = 3264$$

$$v = \sqrt{2 \times 3264} = 80.8 \text{ m/sec.}$$

51. Consider a binary liquid mixture at equilibrium with its vapour at 25°C.

Antoine equation for this system is given as $\log_{10} p_1^{sat} = A - \frac{B}{t+C}$ where t is in °C and p in Torr.

The Antoine constants (*A*, *B*, and *C*) for the system are given in the following table.

Component	A	B	C
1	7.0	1210	230
2	6.5	1206	223

The vapour phase is assumed to be ideal and the activity coefficients (γ_i) for the non-ideal liquid phase are given by

$$\ln(\gamma_1) = x_2^2[2 - 0.6x_1]$$

$$\ln(\gamma_2) = x_1^2[1.7 + 0.6x_2]$$

If the mole fraction of component 1 in liquid phase (x_1) is 0.11, then the mole fraction of component 1 in vapour phase (y_1) is ___________

Answer: 0.65 to 0.75

Exp. $\log_{10} P_1^{sat} = A - \frac{B}{t+c}$

For component 1,

$$\log_{10} P_1^{sat} = 7 - \frac{1210}{25+230} = 2.2549$$

$$P_1^{sat} = 179.846 \text{ Torr}$$

and $\ln(\gamma_1) = x_2^2(2 - 0.6x_1)$

put $x_1 = 0.11$

$$\gamma_1 = \exp\left[0.89^2(2 - 0.6\times 0.11)\right] \Rightarrow \gamma_1 = 4.627$$

For component 2, $\log_{10} P_2^{sat} = 6.5 - \frac{1206}{25+223} = 1.637$

$P_2^{sat} = 43.36$ Torr and $\ln(\gamma_2) = x_1^2(1.7 + 0.6x_2)$

$$\gamma_2 = \exp\left[0.11^2(1.7 + 0.6\times 0.11)\right]$$

$$\Rightarrow \gamma_2 = 1.021598$$

From modified Raoult's law, $y_1 P = x_1\gamma_1 P_1^{sat}$ and $y_2 P = x_2\gamma_2 P_2^{sat}$

$$\Rightarrow y_1 = \frac{x_1\gamma_1 P_1^{sat}}{x_1\gamma_1 P_1^{sat} + x_2\gamma_2 P_2^{sat}}$$

$$\Rightarrow y_1 = \frac{0.11\times 4.627\times 179.846}{0.11\times 4.627\times 179.846 + 0.89\times 1.021598\times 43.36}$$

$$\Rightarrow y_1 = 0.699.$$

52. A process with transfer function, $G_P = \frac{2}{s-1}$ is to be controlled by a feedback proportional controller with a gain K_c. If the transfer functions of all other elements in the control loop are unity, then which **ONE** of the following conditions produces a stable closed loop response?

(A) $K_C = 0.25$ (B) $0 < K_C < 0.25$

(C) $0.25 < K_C < 0.5$ (D) $K_C > 0.5$

Answer: (D)

Exp. $G(s) = \frac{k_c G_p}{1 + k_c G_p}$

characteristic equation $1 + k_c G_p = 0$

$$1 + k_c.\frac{2}{s-1} = (s-1) + 2k_c = 0$$

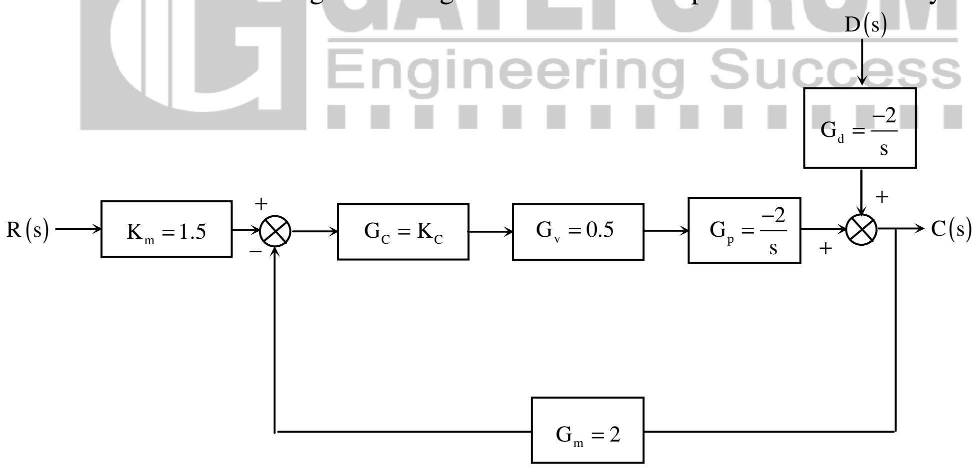
$$s + (2k_c - 1) = 0$$

for stable closed loop response

$$2k_c - 1 > 0$$

$$\Rightarrow k_c > 0.5 \Rightarrow (D).$$

53. Consider the following block diagram for a closed-loop feedback control system



A proportional controller is being used with $K_C = -4$. If a step change in disturbance of magnitude 2 affects the system, then the value of the offset is ____________

Answer: 0.49 to 0.51

Exp. $\frac{C(s)}{D(s)} = \frac{-2/s}{1 + 2k_c.0.5\left(\frac{-2}{5}\right)} = \frac{-2/s}{1 - \frac{2k_c}{s}} = \frac{-2}{s - 2k_c}$

$$D(s) = \frac{2}{s}$$

$$\text{offset} = 0 - \lim_{s \to 0} s\,C(s) = -\lim_{s \to 0} s.\frac{2}{s}\left(\frac{-2}{s - 2k_c}\right) = \frac{4}{8} = 0.50.$$

54. Determine the correctness or otherwise of the following Assertion [a] and Reason [r].

Assertion: Significant combustion of coke takes place only if it is heated at high temperature in presence of air.

Reason: $C + O_2 \rightarrow CO_2$ is an exothermic reaction.

(A) Both [a] and [r] are true and [r] is the correct reason for [a]
(B) Both [a] and [r] are true but [r] is not the correct reason for [a]
(C) [a] is correct but [r] is false
(D) Both [a] and [r] are false

Answer: (B)

Exp. Both [a] and [r] are true but [r] is not the correct reason for [a].

55. Match the raw materials of Groups 1 and 2 with the final products of Group 3

Group 1	Group 2	Group 3
P_1: Ethylene	Q_1: Ammonia	R_1: Synthetic fibre
P_2: Propylene	Q_2: 1-Butene	R_2: Nylon 66
P_3: Adipic acid	Q_3: Ethylene glycol	R_3: LLDPE
P_4: Terephthalic acid	Q_4: Hexamethylene diamine	R_4: Acrylonitrile

(A) $P_1 + Q_2 \rightarrow R_3;\ P_2 + Q_1 \rightarrow R_4; P_3 + Q_4 \rightarrow R_2; P_4 + Q_3 \rightarrow R_1$
(B) $P_1 + Q_1 \rightarrow R_3;\ P_2 + Q_3 \rightarrow R_4; P_3 + Q_4 \rightarrow R_4; P_4 + Q_2 \rightarrow R_2$
(C) $P_1 + Q_2 \rightarrow R_2;\ P_2 + Q_3 \rightarrow R_1; P_3 + Q_4 \rightarrow R_3; P_4 + Q_1 \rightarrow R_4$
(D) $P_1 + Q_1 \rightarrow R_4;\ P_2 + Q_2 \rightarrow R_3; P_3 + Q_4 \rightarrow R_2; P_4 + Q_3 \rightarrow R_1$

Answer: (D)

Exp.

Raw material	Product
Ethylene + 1 – Butene	LLDPE (Linear low density PE)
Propylene + Ammonia	Aerylonetrile
Adipic Acid + Hexomethylene diamine	Nylon – 66
Terephthalic acid + Ethylene glycol	Synthetic fibre