General Aptitude

Q.1 - Q.5 Carry ONE mark Each

Question 1

"You are delaying the completion of the task. Send _____ contributions at the earliest."

[Verbal Ability, 5]

(A) you are
(B) your
(C) you're
(D) yore

Ans. (B)

Sol. **Given :** You are delaying the completion of the task. Send **your** contributions at the earliest.

Hence, the correct option is (B).

Question 2

References : _____ : : Guidelines : Implement **[Verbal Ability, 1]**

(By word meaning)

(A) Sight
(B) Site
(C) Cite
(D) Plagiarise

Ans. (C)

Sol. **Given :** Sight means, a thing that one sees or that can be seen

Site means, build (some thing) in a particular place

Cite means, quote (a passage or book) as evidence for refer

Plagiarise means, the practice of taking some one else's work

As guidelines are related with word implement in the same way references is related with cite.

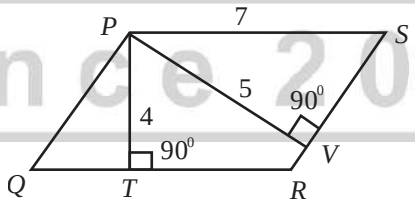
Guidelines are implemented and references are cited.

Hence, the correct option is (C).

Question 3

In the given figure, PQRS is a parallelogram with PS = 7 cm, PT = 4 cm and PV = 5 cm. What is the length of RS in cm? (The diagram is representative.)

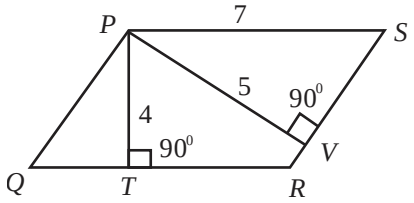
[Logical Reasoning, 3]



(A) $\frac{20}{7}$
(B) $\frac{28}{5}$
(C) $\frac{8}{2}$
(D) $\frac{35}{4}$

Ans. (B)

Sol. **Given :** In the given figure, PQRS is a parallelogram with PS = 7 cm, PT = 4 cm and PV = 5 cm. What is the length of RS is,



In the given figure,

Let $\angle PQT$ and $\angle PSR$ are equals to θ.

So, $\sin\theta = \frac{5}{7} = \frac{y}{x}$

$x = \frac{28}{5}$ cm

Hence, the correct option is (B).

Question 4

In 2022, June Huh was awarded the Fields medal, which is the highest prize in Mathematics.

When he was younger, he was also a poet. He did not win any medals in the International Mathematics Olympiads. He dropped out of college.

Based only on the above information, which one of the following statements can be logically inferred with certainty? **[Logical Reasoning, 2]**

(A) Every Fields medalist has won a medal in an International Mathematics Olympiad.

(B) Everyone who has dropped out of college has won the Fields medal.

(C) All Fields medalists are part-time poets.

(D) Some Fields medalists have dropped out of college.

Ans. **(D)**

Sol. **Given :** In 2022, June Huh was awarded the Fields medal, which is the highest prize in Mathematics.

When he was younger, he was also a poet. He did not win any medals in the International Mathematics Olympiads. He dropped out of college.

Option (A) and option (B) cannot be inferred, as we have information only for Huh and not for every field medalist.

Option (C) cannot be inferred, as we have no information about all field medalist.

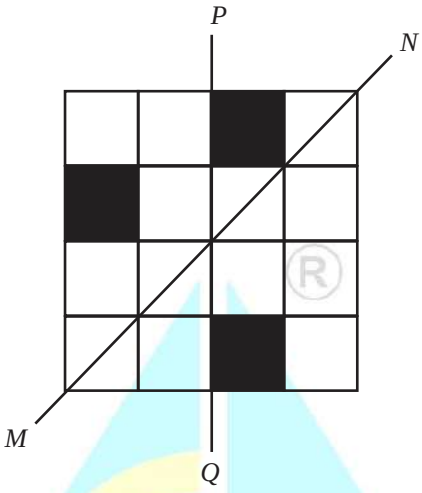
Option (D) can be certainly inferred, as it is stated that Huh is awarded the Fields medal and also he dropped out of college, so we can inferred some field medalists have dropped out of collage.

Hence, the correct option is (D).

Question 5

A line of symmetry is defined as a line that divides a figure into two parts in a way such that each part is a mirror image of the other part about that line.

The given figure consists of 16 unit squares arranged as shown. In addition to the three black squares, what is the minimum number of squares that must be coloured black, such that both PQ and MN form lines of symmetry? (The figure is representative) **[Spitial Aptitude]**



(A) 3 (B) 4

(C) 5 (D) 6

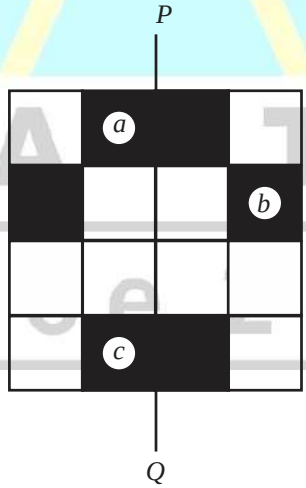
Ans. **C**

Sol. **Given :** The figure consists of 16 unit squares.

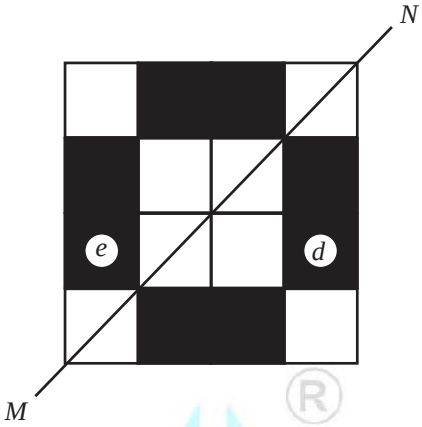
In addition to three block squares, the minimum number of squares that must be colored block, such that both PQ and MN form lines of symmetry, can be find as per the procedure.

Draw diagram given n question on

First of all we make PQ the line of symmetry and for this we need three more black squares (a, b, c) as shown in the given below figure.



Second one we will make this figure symmetric with MN, for that we need two more block squares (d, c) as shown in the given below figure.



The minimum numbers of squares that must be coloured black are 5, such that both PQ and MN forms line of symmetric.

Hence, the correct option is (C).

Q. 6 - Q. 10 Carry TWO marks Each

Question 6

Human beings are one among many creatures that inhabit an imagined world. In this imagined world, some creatures are cruel. If in this imagined world, it is given that the statement "Some human beings are not cruel creatures" is FALSE, then which of the following set of statement(s) can be logically inferred with certainty? **[Verbal Ability, 2]**

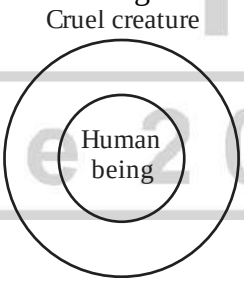
(i) All human beings are cruel creatures.
(ii) Some human beings are cruel creatures.
(iii) Some creatures that are cruel are human beings.
(iv) No human beings are cruel creatures.

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

Ans. (D)

Sol. **Given :** "Some human beings are not cruel creatures" is FALSE.

The venn diagram for the statement is shown in the figure below.



From this statement we can say that "All human beings are cruel creature", according to this.

(i) All human beings are cruel creatures, can be inferred with certainty.
(ii) Some human beings are cruel creatures, can be inferred as if all is definite them some is also definite.
(iii) Some creatures that are cruel are human beings, can be inferred as all human beings are cruel creature.
(iv) No human beings are cruel creatures cannot be inferred as all human beings are cruel creature.

Hence, the correct option is (D).

Question 7

To construct a wall, sand and cement are mixed in the ratio of 3:1. The cost of sand and that of cement are in the ratio of 1:2.

If the total cost of sand and cement to construct the wall is 1000 rupees, then what is the cost (in rupees) of cement used? **[Logical Reasoning, 3]**

(A) 400 (B) 600

(C) 800 (D) 200

Ans. (A)

Sol. **Given :** To construct a wall, sand and cement are mixed in the ratio of 3:1. The cost of sand and that of cement are in the ratio of 1:2.

If the total cost of sand and cement to construct the wall is 1000 rupees, then the cost (in rupees) of cement used is,

Composition ratio of sand and cement is 3:1

Cost ratio of sand and cement is 1 : 2

Total cost of sand $= \text{Quantity} \times \text{Cost}$

$= 3x \times 1 = 3x$

Total cost of cement $= \text{Quantity} \times \text{Cost}$

$= 1x \times 2 = 2x$

Total cost of sand and cement $= 3x + 2x = 5x$

According to the information, $5x = 1000$

$x = 200$

So, total cost of cement $= 2x = 2 \times 200 = 400$ Rs.

Hence, the correct option is (A).

Question 8

The World Bank has declared that it does not plan to offer new financing to Sri Lanka, which is battling its worst economic crisis in decades, until the country has an adequate macroeconomic policy framework in place. In a statement, the World Bank said Sri Lanka needed to adopt structural reforms that focus on economic stabilisation and tackle the root causes of its crisis. The latter has starved it of foreign exchange and led to shortages of food, fuel, and medicines. The bank is repurposing resources under existing loans to help alleviate shortages of essential items such as medicine, cooking gas, fertiliser, meals for children, and cash for vulnerable households. **[Verbal Ability, 6]**

Based only on the above passage, which one of the following statements can be inferred with certainty?

(A) According to the World Bank, the root cause of Sri Lanka's economic crisis is that it does not have enough foreign exchange.

(B) The World Bank has stated that it will advise the Sri Lankan government about how to tackle the root causes of its economic crisis.

(C) According to the World Bank, Sri Lanka does not yet have an adequate macroeconomic policy framework.

(D) The World Bank has stated that it will provide Sri Lanka with additional funds for essentials such as food, fuel, and medicines.

Ans. **(C)**

Sol. **Given :** The World Bank has declared that it does not plan to offer new financing to Sri Lanka, which is battling its worst economic crisis in decades, until the country has an adequate macroeconomic policy framework in place. In a statement, the World Bank said Sri Lanka needed to adopt structural reforms that focus on economic stabilization and tackle the root causes of its crisis. The latter has starved it of foreign exchange and led to shortages of food, fuel, and medicines. The bank is repurposing resources under existing loans to help alleviate shortages of essential items such as medicine, cooking gas, fertilizer, meals for children, and cash for vulnerable households.

Option (C) can be inferred with certainty. As the given information in passage. The World Bank has declared that it does not plan to offer new financing to Sri Lanka, which is battling its worst economic crisis in de-codes, until the country has an adequate macroeconomic policy framework in place.

According this info, Sri-Lanka does not yet have an adequate macroeconomic policy framework.

Hence, the correct option is (C).

Question 9

The coefficient of x^4 in the polynomial $(x-1)^3(x-2)^3$ is equal to _____. **[Logical Reasoning, 3]**

(A) 33 (B) –3

(C) 30 (D) 21

Ans. **(A)**

Sol. **Given :** The coefficient of x^4 in the polynomial $(x-1)^3(x-2)^3$ can be find as,

$(a-b)^3 = a^3 - b^3 - 3a^2b + 2ab^2$

$(x-1)^3 = x^3 - 1^3 + 3x^2 + 3x$ …(i)

$(x-2)^3 = x^3 - 8^3 + 6x^2 + 12x$ …(ii)

By multiplying equation (i) and (ii), we get

$x^6 - 45x^3 + 33x^4 + 9x^5 + 6x^2 - 36x + 8 = 0$

$x^6 + 9x^5 + 33x^4 - 45x^3 + 6x^2 - 36x + 8 = 0$

From the above equation,

Coefficient of x^4 is 33.

Hence, the correct option is (A).

Question 10

Which one of the following shapes can be used to tile (completely cover by repeating) a flat plane, extending to infinity in all directions, without leaving any empty spaces in between them? The copies of the shape used to tile are identical and are not allowed to overlap. **[Spitial Aptitude]**

(A) circle (B) regular octagon

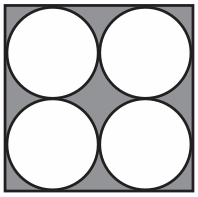
(C) regular pentagon (D) rhombus

Ans. **(D)**

Sol. **Given :** A flat plane, which has to be completely cover by repeating a particular shape tile extending to infinity in all directions, without leaving any empty spaces in between them.

Also the copies of the shape used to tile are identical and are not allowed to overlap.

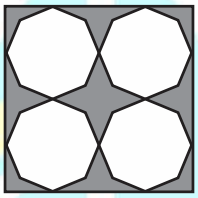
For fulfilling this condition, let's start with the option (A) circle, and tile it on a plane, as shown in below figure,



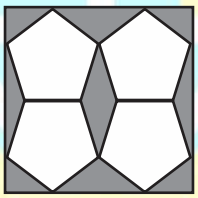
We can clearly see from the figure, if taking a circular tile for convening a flat plane there will be some remaining space, which will not be covered.

Now let's take option (B) regular octagon, and tile it on the flat plane as shown in figure.

We can clearly see from the figure, if taking a regular octagon tile there will be some remaining space, which will not be covered.

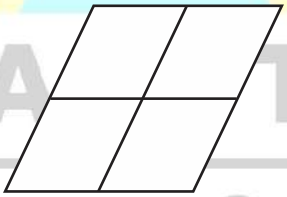


Now let's take option (C) regular pentagon, and tittle on the flat plane as shown in figure.



We can clearly see from the figure if taking a regular pentagon there will be some remaining space, which will not be covered.

Now lets take option (D) rhombus, and tile it on the flat plane as shown in the figure.



We can clearly see from the figure that there is no free space remaining on the flat plane.

Hence, the correct option is (D).

Technical Section

Question 11

Which one of the following is the CORRECT value of y, as defined by the expression given below?

$$y = \lim_{x \to 0} \frac{2x}{e^x - 1}$$

[Engineering Mathematics, Limit and series expansion]

(A) 1 (B) 2

(C) 0 (D) ∞

Ans. (B)

Sol. Given $y = \lim_{x \to 0} \frac{2x}{e^x - 1}$

$$\Rightarrow \quad y = \frac{2 \times 0}{e^0 - 1} = \frac{0}{0}$$ [Indeterminate form]

On Applying L – Hospital's rule, we get

$$y = \lim_{x \to 0} \frac{\frac{d}{dx}(2x)}{\frac{d}{dx}(e^x - 1)}$$

$$\Rightarrow \quad y = \lim_{x \to 0} \frac{2}{e^x} = \frac{2}{e^0} = 2$$

Hence, the correct option is (B).

Question 12

The vector $\vec{v}$ is defined as $\vec{v} = zx\hat{i} + 2xy\hat{j} + 3yz\hat{k}$. Which one of the following is the CORRECT value of divergence of $\vec{v}$, evaluated at the point $(x, y, z) = (3, 2, 1)$?

[Engineering Mathematics, Vector Calculus]

(A) 0 (B) 3

(C) 14 (D) 13

Ans. (D)

Sol. **Given :** $\vec{v} = zx\hat{i} + 2xy\hat{j} + 2xy\hat{j} + 3yz\hat{k}$

Divergence of $\vec{v}$ can be calculated as

$$\nabla.\vec{v} = \frac{\partial}{\partial x}(zx) + \frac{\partial}{\partial y}(2xy) + \frac{\partial}{\partial z}(3yz)$$

$$= z + 2x + 3y$$

$\nabla.\vec{v}$ at the point (3, 2, 1) = 1+2 (3) + 3(2) = 13

Hence, the correct option is (D).

Question 13

Given that $F=\dfrac{|z_1+z_2|}{|z_1|+|z_2|}$, where $z_1=2+3i$ and $z_2=-2+3i$ with $i=\sqrt{-1}$, which one of the following options is CORRECT ? **[Engineering Mathematics, Complex Variable]**

(A) $F<0$ (B) $F<1$

(C) $F>1$ (D) $F=1$

Ans. (B)

Sol. **Given :** $F=\dfrac{|z_1+z_2|}{|z_1|+|z_2|}$

where, $z_1=2+3i$ and $z_2=-2+3i$

On substituting z_1 and z_2 in F we get

$$F=\frac{|2+3i-2+3i|}{|2+3i|+|-2+3i|}$$

$$F=\frac{|6i|}{|2+3i|+|-2+3i|}$$

$$F=\frac{6}{\sqrt{13}+\sqrt{13}}=\frac{6}{2\sqrt{13}}$$

$$F=\frac{3}{\sqrt{13}}=0.83$$

$\therefore$ The value of F is Less than 1.

Hence, the correct option is (B).

Question 14

For a two-dimensional plane, the unit vectors, $(\hat{e}_r,\hat{e}_\theta)$ of the polar coordinate system and $(\hat{i},\hat{j})$ of the cartesian coordinate system, are related by the following two equations.

$$\hat{e}_r=\cos\theta\hat{i}+\sin\theta\hat{j}$$

$$\hat{e}_\theta=-\sin\theta\hat{i}+\cos\theta\hat{j}$$

Which one of the following is the CORRECT value of $\dfrac{\partial(\hat{e}_r+\hat{e}_\theta)}{\partial\theta}$?

[Engineering Mathematics, Vector Calculus]

(A) 1 (B) $\hat{e}_\theta$

(C) $\hat{e}_r+\hat{e}_\theta$ (D) $-\hat{e}_r+\hat{e}_\theta$

Ans. (D)

Sol. **Given :** $\hat{e}_r=\cos\theta\hat{i}+\sin\theta\hat{j}$

$$\hat{e}_\theta=-\sin\theta\hat{i}+\cos\theta\hat{j}$$

$$\hat{e}_r+\hat{e}_\theta=\cos\theta\hat{i}+\sin\theta\hat{j}-\sin\theta\hat{i}+\cos\theta\hat{j}$$

$$= (\cos\theta - \sin\theta)\hat{i} + (\sin\theta + \cos\theta)\hat{j}$$

$$\frac{\partial}{\partial\theta}[\hat{e}_r + \hat{e}_\theta] = \frac{\partial}{\partial\theta}(\cos\theta - \sin\theta)\hat{i} + \frac{\partial}{\partial\theta}(\sin\theta + \cos\theta)\hat{j}$$

$$\frac{\partial}{\partial\theta}(\hat{e}_r + \hat{e}_\theta) = (-\sin\theta - \cos\theta)\hat{i} + (\cos\theta - \sin\theta)\hat{j} \quad \ldots(i)$$

Now $-\hat{e}_r = -\cos\theta\hat{i} - \sin\theta\hat{j}$

$\therefore$ $-\hat{e}_r + \hat{e}_\theta = -\cos\theta\hat{i} - \sin\theta\hat{j} - \sin\theta\hat{i} + \cos\theta\hat{j}$

$$-\hat{e}_r + \hat{e}_\theta = (-\sin\theta - \cos\theta)\hat{i} + (\cos\theta - \sin\theta)\hat{j} \quad \ldots(ii)$$

From equation (i) and (ii),

$$\frac{\partial}{\partial\theta}[\hat{e}_r + \hat{e}_\theta] = -\hat{e}_r + \hat{e}_\theta$$

Hence, the correct option is (D).

Question 15

Which one of the following statements related to octane number is NOT correct?

(A) Linear alkanes with higher carbon number have higher octane number.
(B) Branching in linear alkanes increases their octane number.
(C) Catalytic reforming of hydrocarbons increases their octane number.
(D) Gasoline quality is measured in terms of octane number.

[Chemical Technology, 1 Marks]

Ans. (A)

Sol. About octane no. we know that :

- Branching in linear alkanes increase their octane number.
- Catalytic reforming of hydrocarbons increases their octane number.
- Gasoline (petrol) quality is measured in terms of octane number.

Thus, option (A) is incorrect.

Question 16

Which one of the following options represents the major components of oleum?

(A) Sulfuric acid and nitric acid
(B) Concentrated sulfuric acid and petroleum jelly
(C) Sulfuric acid and hydrochloric acid
(D) Sulfuric acid and sulfur trioxide

[Chemical Technology, 1 Marks]

Ans. (D)

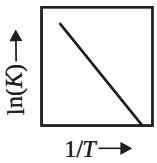
Sol. Major components of Oleum is sulfuric acid and sulfur Trioxide.

$$H_2SO_4 + SO_3 \rightarrow H_2S_2O_7$$

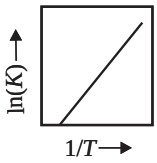
Question 17

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? **[Chemical Reaction Engineering , 1 Marks]**

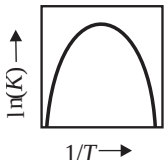
(A)



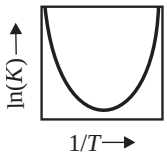
(B)



(C)



(D)

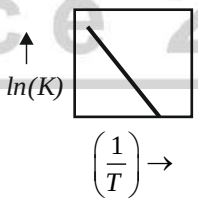


Ans. **(A)**

Sol. From Vant Hoff's equation,

$$\frac{d\ln(K)}{dT} = \frac{\left(\Delta H^0\right)_{rx^n}}{RT^2}$$

$$\ln K = -\frac{\left(\Delta H\right)_{rx^n}}{RT} + C$$



Question 18

Nitrile rubber is manufactured via polymerization process. Which one of the following options is the CORRECT pair of monomers used in this process? **[Chemical Technology, 1 Marks]**

(A) Acrylonitrile and styrene
(B) Acrylonitrile and butadiene

(C) Butadiene and styrene
(D) Butadiene and isoprene

Ans. **(B)**

Sol. Acrylonitrile + Butadiene $\rightarrow$Nitrile Rubber

Question 19

John and Jane independently performed a thermodynamic experiment, in which ***X*** and ***Y*** represent the initial and final thermodynamic states of the system, respectively. John performed the experiment under reversible conditions, for which the change in entropy of the system was . Jane performed the experiment under irreversible conditions, for which the change in entropy of the system was . Which one of the following relationships is CORRECT? **[Thermodynamics, 1 Marks]**

(A) $\Delta S_{rev} = \Delta S_{irr}$

(B) $\Delta S_{rev} > \Delta S_{irr}$

(C) $\Delta S_{rev} < \Delta S_{irr}$

(D) $\Delta S_{rev} = 2\Delta S_{irr}$

Ans. **(A)**

Sol. As entropy is a state function

$$\oint ds = (\Delta S)_{cycle} = 0$$

For a cyclic operation, entropy change is zero.

$$(\Delta S)_{rev.} = (\Delta S)_{irr}$$

Question 20

For a packed-bed comprising of uniform-sized spherical particles of diameter D_p, the pressure drop across the bed is given by the Kozeny-Carman equation when the particle Reynolds number $(\mathrm{Re}_p) < 1$. Under this condition, minimum fluidization velocity is proportional to D_p^n. Which one of the following is the CORRECT value of exponent ? **[Mechanical Operation, 1 Marks]**

(A) 2
(B) –1
(C) –2
(D) 1

Ans. **(A)**

Sol. Kozeny – Carmann's Equation

$$\frac{\Delta P}{L} = \frac{150\mu u(1-\varepsilon)^2}{(\phi_S d_p)^2 \varepsilon^3}$$

Where, u is a minimum fluidization velocity

$$u \propto (\phi_S d_p)^2$$

For spherical particles $\phi_S = 1$

$$u \propto \left(d_p\right)^2$$

Given :

$$u \propto \left(d_p\right)^n$$

Thus, $n = 2$

Question 21

Match the quantities in Group 1 with their units in Group 2 listed in the table below.

Group 1	Group 2
P) Thermal conductivity	I) $W.m^{-2}K^{-1}$
Q) Convective heat transfer coefficient	II) $W.m^{-1}K^{-1}$
R) Stefan-Boltzmann constant	III) $W.K^{-1}$
S) Heat capacity rate	IV) $W.m^{-2}K^{-4}$

[Heat Transfer, 1 Mark]

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

Ans. **(A)**

Sol. Thermal conductivity $\rightarrow Wm^{-1}K^{-1}$

Convective heat transfer coefficient $\rightarrow Wm^{-2}K^{-1}$

Stefan - Boltzmann constant $\rightarrow Wm^{-2}K^{-4}$

Heat capacity rate $\rightarrow WK^{-1}$

$$K = \frac{Q}{A\left(\frac{\Delta T}{\Delta X}\right)} \Rightarrow K = \frac{W}{M^2K}$$

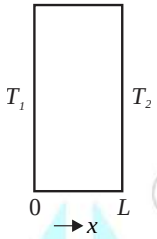
$$H = \frac{Q}{A\left(\Delta T\right)} \Rightarrow h = \frac{W}{M^2K}$$

$$\sigma = \frac{Q}{A\left(\Delta T\right)^4} \Rightarrow \sigma = \frac{W}{M^2K^4}$$

Heat capacity rate $= \frac{W}{K}$

Question 22

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? **[Heat Transfer, 1 Mark]**



(A) $\frac{L}{kA}$

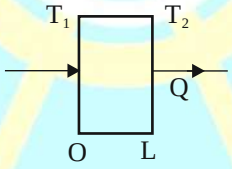
(B) $\frac{L}{kA}$

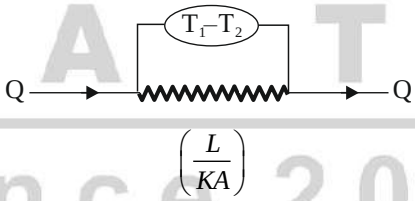
(C) $\frac{kA(T_1 - T_2)}{L}$

(D) $\frac{A}{Lk}$

Ans. (A)

Sol.





Thermal resistance $= \frac{L}{KA}$

Question 23

Spray dryers have many advantages. Which one of the following is NOT an advantage of a typical spray dryer? **[Mechanical Operation, 1 Mark]**

(A) Has short drying time

(B) Produces hollow spherical particles

(C) Has high heat efficiency

(D) Is suitable for heat sensitive materials

Ans. **(C)**

Sol. Spray drying is an unit operation in which high energy consumption take place with relatively low energy utilization.

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

Question 24

Which one of the following quantities of a flowing fluid is measured using a rotameter?

[Fluid Mechanics, 1 Mark]

(A) Static pressure

(B) Dynamic pressure

(C) Volumetric flow rate

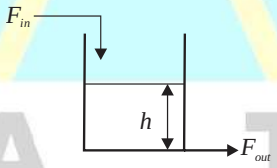
(D) Viscosity

Ans. **(C)**

Sol. Volumetric flow rate of the liquid is measured by rotameter.

Question 25

A liquid surge tank has F_{in} and F_{out} as the inlet and outlet flow rates respectively, as shown in the figure below. F_{out} is proportional to the square root of the liquid level h. The cross-sectional area of the tank is $20\ \text{cm}^2$. Density of the liquid is constant everywhere in the system. At steady state, $F_{in} = F_{out} = 10\ \text{cm}^3\text{s}^{-1}$ and h=16 cm. The variation of h with Fin is approximated as a first order transfer function. Which one of the following is the CORRECT value of the time constant (in seconds) of this system?



[Instrumentation and Process Control, 1 Mark]

(A) 20

(B) 32

(C) 64

(D) 128

Ans. **(C)**

Sol. $10 = \beta\sqrt{h_S} = F_{out}$

$$\frac{10}{4} = \beta \Rightarrow \beta = \frac{5}{2}$$

$$F_{out} \alpha \sqrt{h}$$

$$\frac{1}{R}=\frac{dF_{out}}{dh}$$

$$\frac{1}{R}=\frac{d(\beta\sqrt{h})}{dh}$$

$$\frac{1}{R}=\frac{\beta}{2\times\sqrt{h_{SS}}}$$

$$R=\frac{2\times\sqrt{h_{SS}}}{\beta}$$

Time constant , $\tau_P = A\times R$

$$\tau_P=\frac{2\sqrt{h_S}}{\beta}\times A$$

$$\tau_P=\frac{2\sqrt{16}}{\left(\frac{5}{2}\right)}\times 20$$

$$\tau_P=64$$

Question 26

A packed distillation column, with vapor having an average molecular weight of $45\ \text{kg.mol}^{-1}$, density of $2\ \text{kg.m}^{-3}$ and a molar flow rate of $0.1\ \text{kmol.s}^{-1}$, has a flooding velocity of $0.15\ \text{m.s}^{-1}$. 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)? **[Mass Transfer, 1 Marks]**

(A) $\frac{5}{\sqrt{\pi}}$

(B) $5\sqrt{\pi}$

(C) 4π

(D) $\frac{10}{\pi}$

Ans. **(D)**

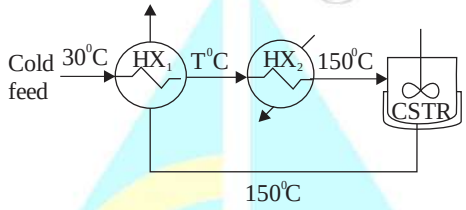
Sol. $$M=\frac{\rho_v}{M_V}\left(\frac{\pi D^2}{4}\right)u_F$$

$$0.1=\frac{2}{45}\left(\frac{\pi D^2}{4}\right)(0.15\times 0.6)$$

$$D = \frac{10}{\sqrt{\pi}}$$

Question 27

An isothermal jacketed continous stirred tank reactor (CSTR) operating at 150^0C is shown in the figure below. The cold feed entering the system at 30^0C is preheated to a temperature T ($T < 150^0$C) using a heat exchanger HX_1. This preheated feed is further heated 150^0C to 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? **[Heat Transfer, 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

(D) Decrease the heat transfer area of HX_1 and increase the heat duty of HX_2.

Ans. **(C)**

Sol. To increase the value of T we should increase the heat transfer area of HX_1 and decrease the heat duty of HX_2

Question 28

Consider a system where a Carnot engine is operating between a source and a sink. Which of the following statements about this system is/are NOT correct? **[Thermodynamics, 1 Mark]**

(A) This engine is reversible.

(B) The engine efficiency is independent of the source and sink temperatures.

(C) This engine has the highest efficiency among all engines that operate between the same source and sink.

(D) The total entropy of this system increases at the completion of each cycle of the engine.

Ans. **(B, D)**

Sol. For Carnot Engine,

$$\eta = \frac{W_{net}}{Q_h} = 1 + \frac{T_2 \ln\left(P_C / P_D\right)}{T_1 \ln\left(P_A / PL_B\right)}$$

$$\eta = \frac{W_{net}}{Q_1} = 1 - \frac{T_2}{T_1}$$

$$\eta = f\left(T_1, T_2\right)$$

Thus, option (B) is correct.

- Carnot engine follows cyclic operation thus entropy will be constant.

Thus, option (D) also is correct.

Question 29

For a fully developed turbulent flow of an incompressible Newtonian fluid through a pipe of constant diameter, which of the following statements is/are CORRECT? **[Fluid Mechanics, 1 Mark]**

(A) Reynolds stress, averaged over a sufficiently long time, is zero everywhere inside the pipe.

(B) Reynolds stress at the pipe wall is zero.

(C) Average velocity of the fluid is half of its center-line velocity.

(D) Average pressure gradient in the flow direction is constant.

Ans. **(A, B, D)**

Sol. Reynold stress, averaged over a sufficiently long time is zero everywhere inside the pipe.

- Reynolds stress at the pipe wall is zero.
- For Turbulent Flow –

$$v_{avg} = 0.817 v_{\max}$$

Question 30

Given that E (in W.m^{-2}) is the total hemispherical emissive power of a surface maintained at a certain temperature, which of the following statements is/are CORRECT? **[Heat Transfer, 1 Mark]**

(A) E does not depend on the direction of the emission.

(B) E depends on the viewfactor.

(C) E depends on the wavelength of the emission.

(D) E does not depend on the frequency of the emission.

Ans. **(A, C)**

Sol.

- Total Emissive Power does not depend upon the direction of the emission.
- E depends on the wavelength of the emission.

Question 31

The position $x(t)$ of a particle, at constant ω, is described by the equation $\frac{d^2x}{dt^2} = -\omega^2 x$. The initial conditions are $x(t=0)=1$ and $\left.\frac{dx}{dt}\right|_{t=0} = 0$. The position of the particle at $t = (3\pi/\omega)$ is _____ (in integer). **[Engineering Mathematics, Differential Equation]**

Ans. **(–1)**

Sol. Given : $\frac{d^2x}{dt^2} = -\omega^2 x$ …(i)

Also given $x(0) = 1$ and $\left.\frac{dx}{dt}\right|_{t=0} = 0$

From equation (i),

$$\frac{d^2x}{dt^2} + \omega^2 x = 0$$

$$D^2x + \omega^2 x = 0 \qquad \text{where, } D = \frac{d}{dt}$$

$$(D^2 + \omega^2)x = 0 \qquad \text{…(ii)}$$

The auxiliary equation from (ii) can be written as

$$D^2 + \omega^2 = 0$$

$$D^2 = -\omega^2$$

$$D = \pm\sqrt{-\omega^2} = \pm j\omega$$

$\therefore$ The solution of the differential equation will be

$$x(t) = C_1 \cos\omega t + C_2 \sin\omega t$$

where, C_1 and C_2 are constants.

$$\frac{dx(t)}{dt} = -C_1\omega \sin\omega t + C_2\omega\cos\omega t$$

$$\left.\frac{dx(t)}{dt}\right|_{t=0} = 0 + C_2\omega = 0$$

$$C_2 = 0$$

$\therefore$ $x(t) = C_1 \cos\omega t$

$$x(0) = C_1 \cos 0 = C_1 = 1$$

$$x(t) = \cos\omega t$$

$\therefore$ $x\left(\frac{3\pi}{\omega}\right) = \cos\omega \times \frac{3\pi}{\omega} = \cos 3\pi = -1$

Hence, the correct answer is – 1.

Question 32

Burning of methane in a combustor yields carbon monoxide, carbon dioxide, and water vapor. Methane is fed to the combustor at 100 mol.hr^{-1}, of which 50 % reacts. The theoretical oxygen requirement (in mol.hr^{-1}) is _____ (rounded off to one decimal place). **[Process Calculation, 1 Mark]**

Ans. 199.5 to 200.5

Sol. $CH_4 + 2O_2 \rightarrow CO_2 + H_2O$

Methane is fed to the combustor at 100 mol/hr. The theoretical Oxygen requirement will be according to the compute combustion of CH_4.

Thus theoretical Oxygen requirement will be 200 mol/hr

Question 33

The viscosity of an incompressible Newtonian fluid is measured using a capillary tube of diameter 0.5 mm and length 1.5 m. The fluid flow is laminar, steady and fully developed. For a flow rate of 1 cm^3s^{-1}, the pressure drop across the length of the tube is 1 MPa. If the viscosity of the fluid is $k\times10^{-3}$ Pa.s, the value of ***k*** is _____ (rounded off to two decimal places). **[Fluid Mechanics, 1 Mark]**

Ans. **1.01 to 1.03**

Sol. For Laminar flow, Hagen's Puisiule Equation –

$$\frac{\Delta P}{L}=\frac{32\mu v}{D^2}=\frac{32\mu Q}{\frac{\pi}{4}D^4}$$

$$\mu=\frac{\left(\frac{\Delta\cdot P}{L}\right)\frac{\pi}{4}D^4}{32Q}=\frac{10^6}{1.5}\times\frac{\pi\times\frac{1}{4}\times\left(0.5\times10^{-3}\right)^4}{32\times10^{-6}}$$

$$\mu=1.022\times10^{-3}\ \text{Pa}\cdot\text{S}$$

$$\Rightarrow\quad \mu=1.0221$$

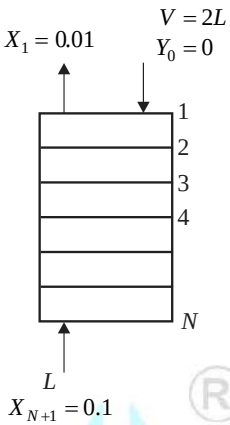
Question 34

A liquid ***L*** containing a dissolved gas ***S*** is stripped in a countercurrent 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).

[Mass Transfer, 1 Mark]

Ans. **3 to 3**

Sol.



$$\text{NTP} = \frac{\ln\left[\left(\frac{X_{N+1} - \frac{Y_0}{m}}{X_1 - \frac{Y_0}{m}}\right)\left(1 - \frac{1}{S}\right) + \frac{1}{S}\right]}{\ln S}$$

Where $S = \frac{1}{A} = \frac{mV}{L} = \frac{1 \times 2L}{L} = 2$

$$\text{NTP} = \frac{\ln\left[\left(\frac{0.1 - 0}{0.01 - 0}\right)\left(1 - \frac{1}{2}\right) + \frac{1}{2}\right]}{\ln 2}$$

$$\text{NTP} = 2.4594$$

$$\text{NTP} \simeq 3$$

Question 35

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. NA, 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). **[Mass Transfer, 1 Mark]**

Ans. **1.17 to 1.19**

Sol. For Diffusing A through Non-Diffusing B.

$$(N_A)_{DANB} = \frac{CD_{AB}}{Z}\left(\frac{y_{A_1} - y_{A_2}}{y_{B_{lm}}}\right) \quad \ldots \text{(i)}$$

For Equimolar Counter Diffusion –

$$(N_A)_{EMCD} = \frac{CD_{AB}}{Z}(y_{A_1} - y_{A_2}) \quad \ldots \text{(ii)}$$

$$\frac{(N_A)_{DANB}}{(N_A)_{EMCD}} = \frac{1}{y_{B_{lm}}}$$

$$\frac{(N_A)_{DANB}}{(N_A)_{EMCD}} = \frac{\ln\left(\frac{y_{B_1}}{y_{B_2}}\right)}{y_{B_1} - y_{B_2}}$$

$$\frac{(N_A)_{DANB}}{(N_A)_{EMCD}} = \frac{\ln\left(\frac{0.8}{0.9}\right)}{0.8 - 0.9}$$

$$\frac{(N_A)_{DANB}}{(N_A)_{EMCD}} = 1.176$$

Q. 36 - Q. 65 Carry ONE mark Each

Question 36

An exhibition was held in a hall on 15 August 2022 between 3 PM and 4 PM during which any person was allowed to enter only once. Visitors who entered before 3:40 PM exited the hall exactly after 20 minutes from their time of entry. Visitors who entered at or after 3:40 PM, exited exactly at 4 PM. The probability distribution of the arrival time of any visitor is uniform between 3 PM and 4 PM. Two persons X and Y entered the exhibition hall independent of each other. Which one of the following values is the probability that their visits to the exhibition overlapped with each other?

[Engineering Mathematics, Probability]

(A) $\frac{5}{9}$

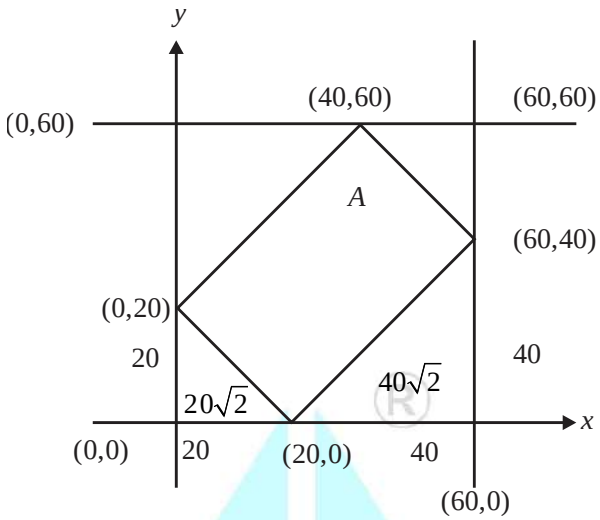
(B) $\frac{4}{9}$

(C) $\frac{2}{9}$

(D) $\frac{7}{9}$

Ans. **(B)**

Sol.



$$A = |x - y| \le 20$$

$$P = \frac{\text{Area of rectangle A}}{\text{Area of square}}$$

$$P = \frac{40\sqrt{2} \times 20\sqrt{2}}{60 \times 60}$$

$$P = \frac{800 \times 2}{3600}$$

$$P = \frac{16}{36}$$

$$P = \frac{4}{9}$$

Question 37

Simpson's one-third rule is used to estimate the definite integral $I = \int_{-1}^{1} \sqrt{(1-x^2)}\, dx$ with an interval length of 0.5. Which one of the following is the CORRECT estimate of I obtained using this rule?

[Engineering Mathematics, Numerical Method]

(A) $\frac{1}{3} - \frac{1}{\sqrt{3}}$ (B) $\frac{1}{3} + \frac{2}{\sqrt{3}}$

(C) $\frac{1}{3} + \frac{1}{\sqrt{3}}$ (D) $\frac{1}{3} - -\frac{2}{\sqrt{3}}$

Ans. (B)

Sol. **Given :** $I = \int_{-1}^{1} \sqrt{1-x^2}\, dx$

Let $y = f(x) = \sqrt{1-x^2}$

Also given interval length h = 0.5

For different values of x starting from –1, $f(x)$ can be tabulated as shown below

x	$y = f(x)$

–1	0
–0.5	0.866
0	1
0.5	0.866
1	0

From the above table $y_0 = 0$, $y_1 = 0.866$, $y_2 = 1, y_3 = 0.866$ and $y_4 = 0$.

Using Simpson's $\frac{1}{3}$ rule

$$\int_{-1}^{1} \sqrt{1-x^2}\,dx = \frac{h}{3}\left[(y_0 + y_4) + 2y_2 + 4(y_1 + y_3)\right]$$

$$= \frac{0.5}{3}\left[(0+0) + 2(1) + 4(0.866 + 0.866)\right]$$

$$= \frac{1}{6}\left[2 + (4 \times 2 \times 0.866)\right]$$

$$= \frac{1}{6}\left[2 + \left(\frac{8 \times \sqrt{3}}{2}\right)\right] = \left[\frac{2}{6} + \frac{4\sqrt{3}}{6}\right]$$

$$= \left[\frac{1}{3} + \frac{(2 \times 3)}{3 \times \sqrt{3}}\right]$$

$$= \left[\frac{1}{3} + \frac{2}{\sqrt{3}}\right]$$

Hence, the correct option is (B).

Question 38

Match the products in Group 1 with the manufacturing processes in Group 2 listed in the table below.

Group 1	Group 2
P) Acetaldehyde	I) Sulfate process
Q) Sulfuric acid	II) Electric furnace process
R) Pulp	III) Wacker process
S) Phosphorus	IV) Contact process

[Chemical Technology, 2 Marks]

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

Ans. **(A)**

Sol. Acetaldehyde $\rightarrow$ Wacker process

Sulfuric Acid $\rightarrow$ Contact process

Pulp $\rightarrow$ Sulfate process

Phosphorus $\rightarrow$ Electric Furnace process

Question 39

Match the reactions in Group 1 with the catalyst in Group 2 listed in the table below.

Group 1	Group 2
P) $C_6H_6 + Cl_2 \longrightarrow$ Chlorobenzene $+$ HCl	I) Mixed oxide of Mo and Fe
Q) $H_2C = CH_2 + \frac{1}{2}O_2 \longrightarrow$ Ethylene oxide	II) V_2O_5
R) $CH_3OH + \frac{1}{2}O_2 \longrightarrow$ Formaldehyde $+ H_2O$	III) $FeCl_3$
S) Naphthalene $+ \frac{9}{2}O_2 \longrightarrow$ phthalic Anhydride $+ 2H_2O + 2CO_2$	IV) Ag_2O

[Chemical Technology, 2 Marks]

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

Ans. **(B)**

Sol. $C_6H_6 + Cl_2 \xrightarrow{FeCl_3}$ Chlorobenzene + HCl

$H_2C = CH_2 + \frac{1}{2}O_2 \xrightarrow{Ag_2O}$ Ethylene Oxide

$CH_3OH + \frac{1}{2}O_2 \xrightarrow{\text{Mixed Oxide of MO and Fe}}$ Formaldehyde $+ H_2O$

Naphthaline $+ \frac{9}{2}O_2 \xrightarrow{V_2O_5}$ Pthalic Anhydride $+ 2H_2O + 2CO_2$

Question 40

Water in a container at 290 K is exposed to air containing 3% CO_2 by volume. Air behaves like an ideal gas and is maintained at 100 kPa pressure. The liquid phase comprising of dissolved CO_2 in water behaves like an ideal solution. Use Henry's constant of CO_2 dissolved in water at 290 K as 12 MPa. Under equilibrium conditions, which one of the following is the CORRECT value of the mole fraction of CO_2 dissolved in water?

[Mass Transfer, 2 Marks]

(A) 2.9×10^{-4}
(B) 0.9×10^{-4}
(C) 2.5×10^{-4}
(D) 0.5×10^{-4}

Ans. **(C)**

Sol. Henry Law $\rightarrow$ $pi = Hxi$ … (i)

Rault's Law $\rightarrow$ $pi = y_i P$ … (ii)

$$Hxi = y_i P$$

$$(12\times10^6)x_i = (0.03)(100\times10^3)$$

$$x_i = 2.5\times10^{-4}$$

Question 41

The enthalpy $(H, \text{in J.mol}^{-1})$ of a binary liquid system at constant temperature and pressure is given as

$$H = 40x_1 + 60x_2 + x_1x_2(4x_1 + 2x_2),$$

Where x_1 and x_2 represent the mole fractions of species 1 and 2 in the liquid, respectively. Which one of the following is the CORRECT value of the partial molar enthalpy of species 1 at infinite dilution, $\overline{H}_1^{\infty}$ (in J.mol^{-1})? **[Thermodynamics, 2 Marks]**

(A) 100
(B) 42
(C) 64
(D) 40

Ans. **(B)**

Sol. At infinite Dilution $\rightarrow$ $x_1 = 0, x_2 = 1$

By partial property of Diffusion –

$$\bar{H}_1 = H - x_2\frac{dH}{dx_2}$$

$$x_1 + x_2 = 1 \Rightarrow x_1 = 1 - x_2 \Rightarrow dx_1 = -dx_2$$

$$\bar{H}_1 = H - (1-x_1)\left(\frac{-dH}{dx_1}\right)$$

$$\bar{H}_1 = H + x_2\frac{dH}{dx_1} \quad \text{… (i)}$$

Given $\rightarrow$ $H = 40x_1 + 60x_2 + x_1x_2(4x_1 + 2x_2)$

$$H = 40x_1 + 60(1-x_1) + x_1(1-x_1)\left(4x_1 + 2(1-x_2)\right)$$

$$H = -20x_1 + 60 + 2x_1 - 2x_1^3 \quad \text{… (ii)}$$

$$\frac{dH}{dx_1} = -20 + 0 + 2 - 6x_1^2$$

$$\frac{dH}{dx_1} = -18 - 6x_1^2$$

$$\frac{dH}{dx_1} = -(6x_1^2 + 18) \qquad \ldots \text{(iii)}$$

By equation (i) and equation (iii) –

$$\bar{H}_1 = H + x_2\left(-(6x_1^2 + 18)\right)$$

$$\bar{H}_1 = \left(-20x_1 + 60 + 2x_1 - 2x_1^3\right) - 6x_1^2x_2 - 18x_2$$

at infinite dilution $\rightarrow$ $x_1 = 0, x_2 = 1$

$$\overline{H_1^{\infty}} = 60 - 18$$

$$\overline{H_1^{\infty}} = 42$$

Question 42

Which one of the following represents the CORRECT effects of concentration polarization in a reverse osmosis process? **[Mass Transfer, 2 Marks]**

(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

Ans. **(A)**

Sol. Reduced water flux and reduced solute rejection is the correct effect of concentration polarization in a reverse osmosis process.

Question 43

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, H2 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 $(\text{in mol.(g cat)}^{-1})$. 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? **[Chemical Reaction Engineering, 2 Marks]**

(A) $\dfrac{K_{CO}\,p_{CO}}{\sqrt{K_{H_2}\,p_{H_2}}}$

(B) $\frac{K_{CO}}{\sqrt{K_{H_2}}}$

(C) $\frac{p_{CO}}{\sqrt{p_{H_2}}}$

(D) $\frac{K_{CO}\,p_{CO}}{\sqrt{K_{H_2}\,p_{H_2}}}$

Ans. **(A)**

Sol. (1) $CO(g) \rightarrow CO \cdot S$

$$K_{CO} = \frac{K}{K_{-1}} = \frac{[CO \cdot S]}{[S]_{P_{CO}}}$$

$$[CO \cdot S] = K_{CO} - P_{CO}[S] \qquad \ldots (i)$$

(2) $H_2(g) + 2S \rightarrow 2H.S$

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

$$[H \cdot S]^2 = KH_2 \cdot P_{H_2}[S]^2$$

$$[H \cdot S] = \sqrt{KH_2\,P_{H_2}}[S] \qquad \ldots (ii)$$

From equation (i) and (ii)

$$\frac{[CO \cdot S]}{[H \cdot S]} = \frac{K_{CO}P_{CO}[S]}{\sqrt{K_H P_{H_2}}[S]} = \frac{K_{CO}P_{CO}}{\sqrt{K_H P_{H_2}}}$$

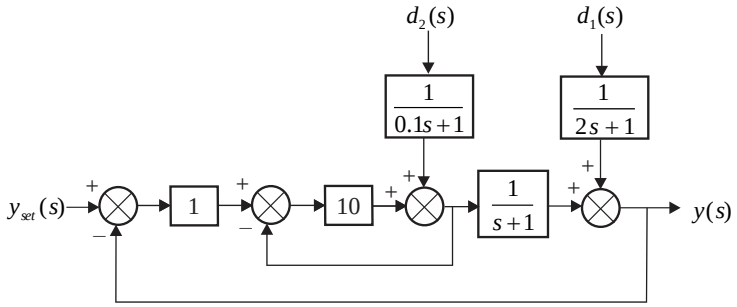
Question 44

A cascade control strategy is shown in the figure below. The transfer function between the output (y) and the secondary disturbance (d_2) is defined as

$$G_{d_2}(s) = \frac{y(s)}{d_2(s)}.$$

Which one of the following is the CORRECT expression for the transfer function $G_{d_2}(s)$?

[Instrumentation and process control, 2 Marks]



(A) $\dfrac{1}{(11s+21)(0.1s+1)}$

(B) $\dfrac{1}{(s+1)(0.1s+1)}$

(C) $\dfrac{(s+1)}{(s+2)(0.1s+1)}$

(D) $\dfrac{(s+1)}{(s+1)(0.1s+1)}$

Ans. **(A)**

Sol. $$d_2(S)\times\frac{1}{(0.1S+1)}\times\frac{1}{(S+1)}=Y(S)\left[1+1\times\frac{10}{11}\times\frac{1}{(S+1)}\right]$$

$$\frac{Y(S)}{d_2(S)}=\frac{\dfrac{1}{(0.1S+1)}\times\dfrac{1}{(S+1)}}{1+\dfrac{10}{11(S+1)}}$$

$$\frac{Y(S)}{d_2(S)}=\frac{1}{\left[11(S+1)+10\right](0.1S+1)}$$

$$\frac{Y(S)}{d_2(S)}=\frac{1}{(11S+11+10)(0.1S+1)}$$

$$\frac{Y(S)}{d_2(S)}=\frac{1}{(11S+21)(0.1S+1)}$$

Question 45

Level (h) in a steam boiler is controlled by manipulating the flow rate (F) of the make-up (fresh) water using a proportional (P) controller. The transfer function between the output and the manipulated input is

$$\frac{h(s)}{F(s)}=\frac{0.25(1-s)}{s(2s+1)}.$$

The measurement and valve transfer functions are both equal to 1. A process engineer wants to tune the controller so that the closed-loop response gives decaying oscillations under servo mode. Which one of the following is the CORRECT value of the controller gain to be used by the engineer?

[Instrumentation and process control, 2 Marks]

(A) 0.25
(B) 2
(C) 4
(D) 6

Ans. **(B)**

Sol. $\frac{h(S)}{F(S)} = \frac{0.25(1-S)}{S(2S+1)}$

$$\frac{h(S)}{h_{SP}(S)} = \frac{K_C \times \frac{0.25(1-S)}{S(2S+1)}}{1+K_C \times \frac{0.25(1-S)}{S(2S+1)} \times 1 \times 1}$$

$$\frac{h(S)}{h_{SP}(S)} = \frac{0.25K_C(1-S)}{2S^2+S+K_C \times 0.2 - K_C \times 0.25S}$$

$$\frac{h(S)}{h_{SP}(S)} = \frac{0.25K_C(1-S)}{\left[2S^2+S(1-0.25K_C)\times 0.25K_C\right]}$$

$$\tau_P = \sqrt{\frac{2}{0.25K_C}}$$

$$2\xi\tau_P = \frac{1-0.25K_C}{0.25K_C}$$

$$\xi = \frac{1-0.25K_C}{2\times 0.25K_C} \times \sqrt{\frac{0.25K_C}{2}}$$

$$\xi = \frac{1-0.25K_C}{2\sqrt{2}\times\sqrt{0.25}K_C}$$

When $K_C = 0.25, \xi = \frac{1-0.0625}{2\sqrt{2}\times 0.25} > 1$

When $K_C = 2, \xi = \frac{0.5}{2\sqrt{2}\sqrt{0.5}}$

$$\xi = \frac{0.5}{2}$$

$$\xi = 2.25$$

Question 46

Which of the following statements is/are CORRECT?

[Heat transfer and Fluid Mechanics, 2 Marks]

(A) Bond number includes surface tension.
(B) Jakob number includes latent heat.
(C) Prandtl number includes liquid-vapor density difference.
(D) Biot number includes gravity.

Ans. **(A), (B)**

Sol.

- Bond number includes Surface Tension
- Jacob number included Latent Heat

Question 47

If a matrix M is defined as $M = \begin{bmatrix} 10 & 6 \\ 6 & 10 \end{bmatrix}$, the sum of all the eigenvalues of M^3 is equal to _____ (in integer).

[Engineering Mathematics, Linear Algebra]

Ans. **4160 to 4160**

Sol. **Method 1 :**

Given : $M = \begin{bmatrix} 10 & 6 \\ 6 & 10 \end{bmatrix}$

Eigen Values of M can be found from the equation $|M - \lambda I| = 0$

$$\begin{vmatrix} 10-\lambda & 6 \\ 6 & 10-\lambda \end{vmatrix} = 0$$

$$(10-\lambda)^2 - 36 = 0$$

$$100 + \lambda^2 - 20\lambda - 36 = 0$$

$$\lambda^2 - 20\lambda + 64 = 0$$

$$\lambda^2 - 16\lambda - 4\lambda + 64 = 0$$

$$\lambda(\lambda - 16) - 4(\lambda - 16) = 0$$

$$(\lambda - 4)(\lambda - 16) = 0$$

$\lambda = 4$ and 16 are the eigen values of M.

So, the eigen values of M^3 will be $(4)^3$ and $(16)^3$ that is 64 and 4096.

$\therefore$ Sum of the eigen values of M^3 will be 64 + 4096 = 4160.

Hence, the correct answer is 4160.

Method 2 :

Given : $M = \begin{bmatrix} 10 & 6 \\ 6 & 10 \end{bmatrix}$

Let λ_1 and λ_2 be the eigen values of M

$$\lambda_1 + \lambda_2 = tr\,(M) = 10 + 10 = 20$$

$$\lambda_1\lambda_2 = |M| = 100 - 36 = 64$$

$$\therefore \quad (\lambda_1 - \lambda_2)^2 = (\lambda_1 + \lambda_2)^2 - 4\lambda_1\lambda_2$$

$$= (20)^2 - 4\times(64)$$

$$= 400 - 256 = 144$$

$$\lambda_1 - \lambda_2 = \sqrt{144} = 12$$

$$\therefore \quad \lambda_1 = \frac{(\lambda_1 + \lambda_2) + (\lambda_1 - \lambda_2)}{2} = \frac{20+12}{2} = 16$$

$$\lambda_2 = \frac{(\lambda_1 + \lambda_2) - (\lambda_1 - \lambda_2)}{2} = \frac{20-12}{2} = 4$$

Eigen values of M^3 will be $(16)^3$ and $(4)^3$ that is 4096 and 64.

Sum of the eigen values of M^3 is 4096 + 64 = 4160.

Hence, the correct answer is 4160.

Question 48

The first derivative of the function $U(r) = 4\left[\left(\frac{1}{r}\right)^{12} - \left(\frac{1}{r}\right)^{6}\right]$ evaluated at $r = 1$ is _____ (in integer).

[Engineering Mathematics, Integral and Differential Calculus]

Ans. (–24)

Sol. **Given :** $U(r) = 4\left[\left(\frac{1}{r}\right)^{12} - \left(\frac{1}{r}\right)^{6}\right]$

$$\frac{dU(r)}{dr} = 4\left[12\left(\frac{1}{r}\right)^{11} \times \frac{-1}{r^2} - 6\left(\frac{1}{r}\right)^{5} \times \frac{-1}{r^2}\right]$$

$$\frac{dU(r)}{dr} = \frac{-4}{r^2}\left[12\left(\frac{1}{r}\right)^{11} - 6\left(\frac{1}{r}\right)^{5}\right]$$

$$\left.\frac{dU(r)}{dr}\right|_{r=1} = -4[12-6] = -24$$

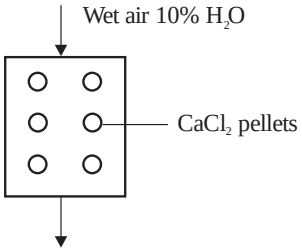
Hence, the correct answer is – 24.

Question 49

Wet air containing 10 mole percent water vapor is dried by continuously passing it through a column of $CaCl_2$ pellets. The pellets remove 50 percent of water from wet air entering the column. The mole percent of water vapor in the product stream exiting the column is _____ (rounded off to two decimal places). **[Mass Transfer, 2 Marks]**

Ans. 5.20 to 5.30

Sol.



Let 100 mol of wet air entering the bed

At inlet –

mol of dry air $= 90$ mol

mol of water $= 10$ mol

At exit –

mol of dry air $= 90$ mol

mol of water $= 5$ mol

mol% of water vapor in product $= \frac{5}{95} \times 100$

$= 5.26\%$

Question 50

Orsat analysis showing the composition (in mol%, on a dry basis) of a stack gas is given in the table below. The humidity measurement reveals that the mole fraction of H_2O in the stack gas is 0.07. The mole fraction of N_2 calculated on a wet basis is _____ (rounded off to two decimal places).

[Process Calculation, 2 Marks]

Species	N_2	CO_2	CO	O_2
mol%	65	15	10	10

Ans. **0.59 to 0.62**

Sol. Let 100 mol of stack Gas

$N_2 = 65$ mol

$CO_2 = 15$ mol

$CO = 10$ mol

$O_2 = 10$ mol

Let x mols of H_2O

Total mols of wet Gas $= 100 + x$

Given $\rightarrow \quad \dfrac{x}{100+x} = 0.07$

$$x = 7 + 0.07x$$

$$x = 7.5268$$

$$\text{mol fraction of } H_2 = \frac{65}{100 + 7.5268}$$

$$= 0.6045$$

Question 51

A pump draws water $(\text{density} = 1000\,\text{kg.m}^{-3})$ at a steady rate of $10\ \text{kg.s}^{-1}$. The pressures at the suction and discharge sides of the pump are -20 kPa (gauge) and 350 kPa (gauge), respectively. The pipe diameters at the suction and discharge side are 70 mm and 50 mm, respectively. The suction and discharge lines are at the same elevation, and the pump operates at an efficiency of 80 %. Neglecting frictional losses in the system, the power (in kW) required to drive the pump is _____ (rounded off to two decimal places).

[Fluid Mechanics, 2 Marks]

Ans. **4.70 to 4.78**

Sol. At Suction point

$$\text{Velocity } v_s = \frac{\dot{M}}{\rho A} = \frac{10}{10^3 \times \frac{\pi}{4} \times (0.07)^2} = 2.60 \text{ m/s}$$

At Discharge point

$$\text{Velocity } v_d = \frac{\dot{M}}{\rho A} = \frac{10}{10^3 \times \frac{\pi}{4} \times (0.05)^2} = 5.095 \text{ m/s}$$

$$\frac{\rho_s}{\rho g} + \frac{v_s^2}{2g} + Z_s + \eta \Delta H_P = \frac{P_d}{\rho g} + \frac{v_d^2}{2g} + z_d + h_{fs}$$

$$\eta \Delta H_P = \frac{P_d - P_s}{\rho g} + \frac{V_d^2 - V}{2g}$$

$$\frac{(350 + 20) \times 10^3}{10^3 \times 9.8} + \frac{(5.095)^2 - (2.60)^2}{2 \times 9.8} = \eta \Delta H_P$$

$$\eta \Delta H_P = \frac{379.59}{9.8}$$

$$\Delta H_P = \frac{379.59}{9.8 \times 0.8}$$

$$\Delta H_P = \frac{474.499}{9.8} \text{ m}$$

We know that –

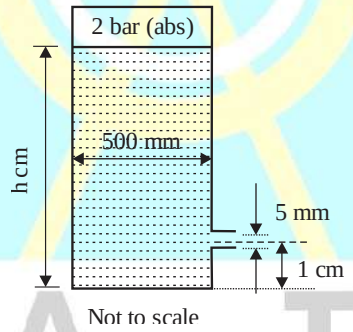
$$P = mg\Delta H_P$$

$$P = 10 \times 9.8\left(\frac{474.499}{9.8}\right)$$

$$P = 4.744 \text{ kW}$$

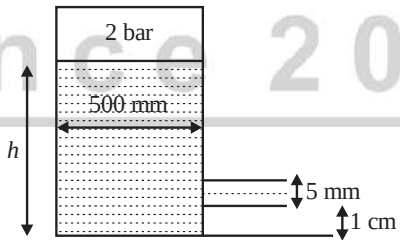
Question 52

A cylindrical tank with a diameter of 500 mm contains water $(\text{density} = 1 \text{ g.cm}^{-3})$ upto a height h. A 5 mm diameter round nozzle, whose center is 1 cm above the base of the tank, has its exit open to the atmosphere as shown in the schematic below. The pressure above the water level in the tank is maintained at 2 bar (absolute). Neglect all frictional and entry/exit losses. Use acceleration due to gravity as 10 m.s^{-2} and atmospheric pressure as 1 bar. The absolute value of initial $\frac{dh}{dt}$ (in mm.s^{-1}) when h = 51 cm is equal to _____ (rounded off to two decimal places). **[Fluid Mechanics, 2 Marks]**



Ans. **1.40 to 1.50**

Sol.



Applying Bernoulli's equation point (i) and (ii)

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

$$(P_1 - P_2) + \rho g(h-1) = \frac{1}{2}\rho v_2^2$$

$$(1\times10^5) + \frac{10^3\times10\times(h-1)}{100} = \frac{1}{2}\times10^3 v_2^2$$

$$100 + \frac{(h-1)}{10} = \frac{1}{2}v_2^2$$

$$v_2 = \sqrt{200 + \frac{(h-1)}{5}} = \sqrt{200 + \frac{50}{5}}$$

$$v_2 = \sqrt{210}$$

Mass balance between point (i) and (ii)

$$m_{in} - m_{out} = \frac{dm}{dt}$$

$$0 - \rho\frac{\pi}{4}(5\times10^{-3})^2\sqrt{210} = \rho\times\frac{\pi}{4}(0.5)^2\frac{dh}{dt}$$

$$\left.\frac{dh}{dt}\right|_{t=0} = \frac{(5\times10^{-3})^2\sqrt{210}}{(0.5)^2} = 1.44\times10^{-3}\ \text{m/s}$$

$$\left.\frac{dh}{dt}\right|_{t=0} = 1.44\ \text{m/s}$$

Question 53

A large tank is filled with water $(\text{density} = 1\ \text{g.cm}^{-3})$ upto a height of 5 m. A 100 μm diameter solid spherical particle $(\text{density} = 0.8\ \text{g.cm}^{-3})$ is released at the bottom of the tank. The particle attains its terminal velocity (v_t) after traveling to a certain height in the tank. Use acceleration due to gravity as 10 m.s−2 and water viscosity as 10^{-3} Pa.s. Neglect wall effects on the particle. If Stokes law is applicable, the absolute value of v_t (in mm.s^{-1}) is _____ (rounded off to two decimal places).

[Mechanical Operation, 2 Marks]

Ans. **1.00 to 1.20**

Sol. For Stoke's Law regime –

Terminal settling velocity

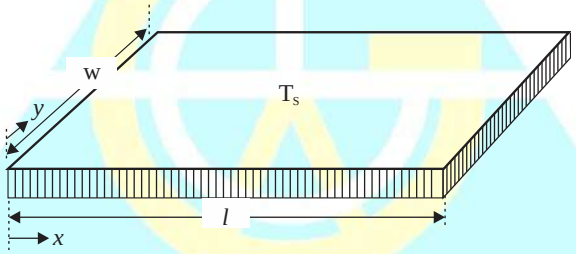
$$v_t = \frac{d_p^2(\rho_p - \rho_f)g}{18\mu}$$

$$v_t = \frac{(100\times10^{-6})^2(1000-800)9.81}{18\times10^{-3}} \Rightarrow v_t = (1.11\times10^{-3})\ \text{m/s}$$

$$v_t = 1.11\ \text{mm/s}$$

Question 54

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 $T\infty$, 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 $\text{Nu} = 0.332(\text{Re})^{1/2}(\text{Pr})^{1/3}$ 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 $h_l = \frac{1}{l}\int_0^l h_x\,dx$ and $h_w = \frac{1}{w}\int_0^w h_y\,dy$. If $w = 1$ m and $l = 4$ m, the value of the ratio of $\bar{h}_w$ to $\bar{h}_l$ is _____ (in integer). **[Heat Transfer, 2 Marks]**



Ans. 2 to 2

Sol. $\text{Nu} = 0.332(\text{Re})^{1/2}(\text{Pr})^{1/3}$

In x-direction –

$$\frac{h_x x}{K} = 0.332\left(\frac{xv\rho}{\mu}\right)^{1/2}\left(\frac{c_p\mu}{k}\right)^{1/3}$$

$$h_x \propto (x)^{-1/2} \quad \ldots (i)$$

Similarly for y-direction

$$\frac{h_y y}{K} = 0.332\left(\frac{yv\rho}{\mu}\right)^{1/2}\left(\frac{c_p\mu}{k}\right)^{1/3}$$

$$h_y \propto (y)^{-1/2} \quad \ldots (ii)$$

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

$$\bar{h}_\ell = \frac{1}{4}\left[\frac{x^{1/2}}{\frac{1}{2}}\right]_0^4$$

$$\bar{h}_\ell = 1$$

Similarly –

$$\bar{h}_y = \frac{1}{W}\int_0^W h_y\, dy$$

$$\bar{h}_y = \frac{1}{W}\int_0^W y^{-1/2}\, dy$$

$$\bar{h}_y = \frac{1}{W}\left[\frac{y^{1/2}}{\frac{1}{2}}\right]_0^W$$

$$\bar{h}_y = \frac{1}{1}\times 2[1]^{1/2}$$

$$\bar{h}_y = 2$$

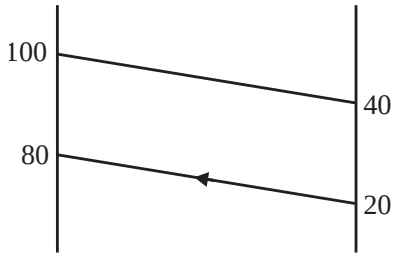
$$\frac{\bar{h}_y}{\bar{h}_\ell} = \frac{2}{1} = 2$$

Question 55

A perfectly insulated, concentric tube countercurrent 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 $2\ \text{kg.s}^{-1}$ with a temperature of 100^0C and leaves at 40^0C. Water enters the inner tube at a mass flow rate of $1\ \text{kg.s}^{-1}$ with a temperature of 20^0C and leaves at 80^0C. 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). **[Heat Transfer, 2 Marks]**

Ans. 3 to 3

Sol.



$$Q = mc_P\Delta T = 2\times 2089\times(100-40)$$

$$Q = 2\times 2089\times 60 \qquad \ldots \text{(i)}$$

$$Q = UA(\Delta T_{\ell m})$$

Here $\Delta T_{\ell m} = \text{AMTD} = 20$

$$Q = UA(20) \qquad \ldots \text{(ii)}$$

By equation (i) and (ii)

$$2\times 2089\times 60 = UA(20)$$

$$(UA) = 12534$$

$$\text{NTU} = \frac{UA}{C_{\min}} \qquad \ldots \text{(iii)}$$

$$C_h = \dot{m}_h C_{P_h} = 2\times 2089 = 4178$$

$$C_c = \dot{m}_c C_{P_c} = 1\times 4178 = 4178$$

As both the fluids have same heat capacity

thus $C_{\min} = C_{\max} = 4178$

$$\text{NTU} = \frac{12534}{4178}$$

$$\text{NTU} = 3$$

Question 56

Partially saturated air at 1 bar and 50^0C is contacted with water in an adiabatic saturator. The air is cooled and humidified to saturation, and exits at 25^0C with an absolute humidity of 0.02 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 kJ.kg^{-1}K^{-1} and 4.18 kJ.kg^{-1}K^{-1}. If the absolute humidity of air entering the adiabatic saturator is $H\times 10^{-3}$kg water per kg dry air, the value of $\mathcal{H}$ is _____ (rounded off to two decimal places). **[Mass Transfer, 2 Marks]**

Ans. **9.10 to 9.50**

Sol.

$\lambda_w = 2450$ kJ/kg

$C_{P_B} = 1.01$ kJ/kg K

$C_{P_A} = 4.18$ kJ/kg K

$h_1 = h_2$

$$T_G - T_{as} = \frac{(Y_s - Y)\lambda_w}{C_s}$$

$C_s = 1.01 + 0.02(4.18) = 1.0936$ kJ/kg K

$$(50 - 25) = \frac{(0.02 - Y')(2450)}{1.0936}$$

$$\frac{25 \times 1.0936}{2450} = 0.02 - Y'$$

$Y' = 8.8491 \times 10^{-3}$

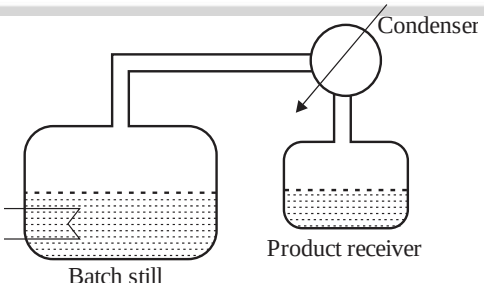
$Y' = H \times 10^{-3}$

$H = 8.84$

Question 57

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).

[Mass Transfer, 2 Marks]



Ans. **0.982**

Sol. By solution of Rayleigh Equation

$$\ln\left(\frac{Fx_F}{Wx_w}\right)=\alpha\ln\left(\frac{F(1-x_F)}{W(1-x_w)}\right)$$

$$\ln\left(\frac{1\times0.1}{W\left(\frac{0.01}{W}\right)}\right)=4.5\ln\left(\frac{F(1-0.1)}{W\left(1-\frac{0.01}{W}\right)}\right)$$

$$1.668=\frac{0.9}{W-0.01}$$

$$W=0.549$$

$$x_w=\frac{0.01}{0.549}$$

$$x_w=0.0182 \qquad \{\text{mol fraction of } A$$

mol fraction of B

$$(x_w)_B=1-0.0182=0.982$$

Question 58

Fresh catalyst is loaded into a reactor before the start of the following catalytic reaction.

$$A\longrightarrow \text{products}$$

The catalyst gets deactivated over time. The instantaneous activity $a(t)$, at time t, is defined as the ratio of the rate of reaction $-r_A'(t)(\text{mol.(g cat}^{-1}\text{hr}^{-1})$ 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).

[Chemical Reaction Engineering, 2 Marks]

Ans. **0.5 to 0.5**

Sol. Activity $(a)=\dfrac{-r_A'}{-r_A}$

Given $\rightarrow$ $-r_A'=-0.5t+10$

Rate of reaction with fresh catalyst i.e.

at $t=0$

$$-r_A=-(0.5)\times0+10$$

$$-r_A=10$$

Activity at $t = 10$ hr

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

$$a\big|_{t=10\text{ hr}} = 0.5$$

Question 59

A unimolecular, irreversible liquid-phase reaction

$$A \longrightarrow \text{products}$$

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 $1\ \text{mol.m}^{-3}$, under steady-state conditions. For a conversion of 0.8, the space time (in s) of the CSTR is (in integer).

[Chemical Reaction Engineering, 2 Marks]

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

Ans. **16 to 16**

Sol. $A \longrightarrow P$

$$C_{A_0} = 1\ \text{mol/m}^3$$

$$X_A = 0.8$$

$$\frac{V}{F_{A_0}} = \frac{X_A}{-r_A}$$

$$\frac{V}{F_{A_0}} = \frac{\tau}{C_{A_0}} = \frac{X_A}{-r_A}$$

$$\frac{\tau}{1} = \frac{0.8}{0.05}$$

$$\tau = 16\ \text{sec}$$

Question 60

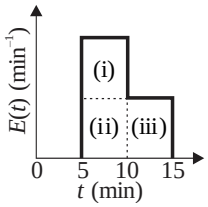
An irreversible liquid-phase second-order reaction

$$A \xrightarrow{k} B$$

with rate constant $k = 0.2\ \text{litre, mol}^{-1}\ \text{min}^{-1}$, 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

mol.liter−1 is fed to the reactor. The segregated model mimics the nonideality of this reactor. The percentage conversion of A at the exit of the reactor is _____ (rounded off to the nearest integer).

[Chemical Reaction Engineering, 2 Marks]



Ans. **71 to 73**

Sol. Area under E – Curve

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

$$A_1 + A_2 + A_3 = 1$$

as $A_1 = A_2 = A_3 = A$

$$3A = 1 \quad \Rightarrow \quad A = \frac{1}{3}$$

$A \rightarrow$ Area of Rectangle $(l \times b)$

$$l \times 5 = \frac{1}{3}$$

$$l = \frac{1}{15}$$

$$2l = \frac{2}{15}$$

For $n = 2$

$$KC_{A_0} t = \frac{X_A}{1 - X_A}$$

$$X_A = \frac{KC_{A_0} t}{1 + KC_{A_0} t}$$

Given $\rightarrow$ $\quad K = 0.2, C_{A_0} = 1.5$

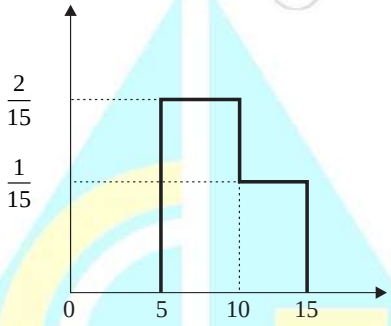
$$X_A = \frac{0.2 \times 1.5 \times t}{1 + (0.2 \times 1.5 \times t)}$$

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

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

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

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



$$X_A = \int_5^{10} \frac{KC_{A_0}t}{1+KC_{A_0}t} \times \left(\frac{2}{15}\right)dt + \int_{10}^{15} \frac{KC_{A_0}t}{1+KC_{A_0}t}\left(\frac{1}{15}\right)dt$$

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

$$X_A = 0.72$$

$$X_A = 72\%$$

Question 61

The outlet concentration C_A of a plug flow reactor (PFR) is controlled by manipulating the inlet concentration $CA0$. The following transfer function describes the dynamics of this PFR.

$$\frac{C_A(s)}{C_{A_0}(s)} = \exp\left[-\left(\frac{V}{F}\right)(k+s)\right]$$

In the above equation, $V = 1\ \text{m}^3, F = 0.1\ \text{m}^3\text{min}^{-1}$ and $V = 1\ \text{m}^3, F = 0.1\ \text{m}^3\text{min}^{-1}$ and $k = 0.5\ \text{min}^{-1}$ The measurement and valve transfer functions are both equal to 1. The ultimate gain, defined as the proportional controller gain that produces sustained oscillations, for this system is _____ (rounded off to one decimal place). **[Instrumentation and Process Control, 2 Marks]**

Ans. **148.0 to 148.8**

Sol. $\frac{C_A}{C_{A_0}} = e^{\frac{V}{F}(K+S)}$

$$G_P = e^{\frac{V}{F}K} \cdot e^{\frac{V}{F}S}$$

$$G_C = K_C$$

$$G_m = G_f = 1$$

$$G_{OL} = G_P G_C G_m G_f$$

$$G_{OL} = K_C \cdot e^{\frac{V}{F}K} \cdot e^{\frac{V}{F}S}$$

$$AR = K_C\, e^{\frac{V}{F}K}$$

For Ultimate gain $\rightarrow$ $AR = 1$

$$K_C = \frac{1}{e^{\frac{V}{F}\cdot K}} = e^{\frac{V}{F}K}$$

$$V = 1\ \text{m}^3$$

$$F = 0.1\ \text{m}^3/\text{min}$$

$$K_C = e^{\frac{1}{(0.1)}(0.5)}$$

$$K_C = e^5$$

$$K_C = 148.41$$

Question 62

The transfer function of a measuring instrument is

$$G_m(s) = \frac{1.05}{2s+1}\exp(-s)$$

At time t = 0, a step change of +1 unit is introduced in the input of this instrument. The time taken by the instrument to show an increase of 1 unit in its output is _____ (rounded off to two decimal places).

[Instrumentation and Process Control, 2 Marks]

Ans. **6.99 to 7.19**

Sol. $$G_m(S) = \frac{Y(S)}{X(S)} = \frac{1.05e^{-S}}{2S+1}$$

Since step response of first order plus delay system is –

$$Y(t) = MK_P\left[1 - e^{-\left(\frac{t-\tau_d}{\tau_p}\right)}\right]$$

Where τ_d = dead time constant

$$Y(t) = 1.0 = 1.05\left[1 - e^{\left(\frac{t-1}{2}\right)}\right]$$

$$\frac{1.0}{1.05} - 1 = -e^{\frac{-(t-1)}{2}}$$

$$\frac{-0.05}{1.05} = -e^{-\left(\frac{t-1}{2}\right)}$$

$$\ln\left(\frac{5}{105}\right) = -\left(\frac{t-1}{2}\right)$$

$$t = 7.089$$

$$t = 7.1$$

Question 63

A design engineer needs to purchase a membrane module (M) for a plant. Details about the two available options, M_1 and M_2, are given in the table below. The overall plant has an expected life of 7 years. If the interest rate is 8 % per annum, compounded annually, the difference in the net present value (NPV) of these two options, in lakhs of rupees, is _____ (rounded off to one decimal place).

[Plant design and economic, 2 Marks]

	M_1	M_2
Purchase cost (in lakhs of rupees)	10	5
Expected life (years)	5	3

Ans. **4.6 to 4.8**

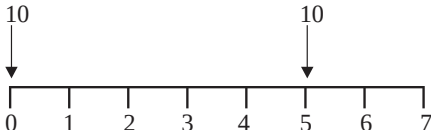
Sol. On considering purchasing over the plant life of 7 years.

Overall plant life $= 7$ years, $i = 8\% = 0.08$ per anum

- M_1 then you have to replace the module at the end of every 5 years till the end of the plant life (7 year).
- M_2 then you have to replace the module at the end of every 3 years till the end of the plant life (7 years).

Option (1) : $C_{O_1} = 10$ Lakh, $n_1 = 5$ year

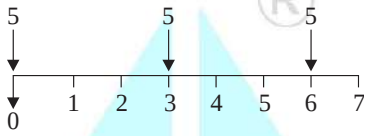
Cash flow diagrams for the overall plant life



$$NPV_1 = -10 - \frac{10}{(1+0.08)^5}$$

$$NPV_1 = -16.806 \text{ Lakh}$$

Option (2) : $C_{O_2} = 5$ Lakh, $n_2 = 3$ year



$$NPV_2 = -5 - \frac{5}{(1+0.08)^3} - \frac{5}{(1+0.08)^6}$$

$$NPV_2 = -12.120 \text{ Lakh}$$

$$NPV_2 - NPV_1 = 4.68 \text{ Lakh}$$

$$(NPV)_{Net} = 4.7 \text{ Lakh}$$

Question 64

The purchase cost of a new distillation column is Rs.10 lakhs with an installation factor of 5.8. The cost of the capital is to be annualized over a period of 6 years at a fixed rate of interest of 5 % per annum, compounded annually. The annual cost (in lakhs of rupees) of the installed capital is _____ (rounded off to one decimal place). **[Plant Design and Economic, 2 Marks]**

Ans. **11.0 to 11.8**

Sol. $C_O = 10$ Lakh

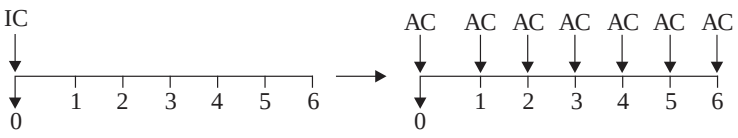
$f = 5.8$

$n = 6$ years

$i = 5\%$ per anum $= 0.05$ per anum

Installation Capital (IC) $= 10 \times 5.8 = 58$ Lakh

Annualizing IC over the period of 6 years.



$$\text{Annual Cost (AC)} = \text{IC} \times \left[\frac{(1+\text{i})^6 \times i}{(1+i)^6 - 1}\right]$$

$$AC = 58 \times \left[\frac{(1.05)^6 \times 0.05}{(1.05)^6 - 1} \right]$$

$$AC = 11.43 \text{ Lakh}$$

Question 65

Pumps *A* and *B* are being considered for purchase in a chemical plant. Cost details for these two pumps are given in the table below. The interest rate is 10 % per annum, compounded annually. For both the pumps to have the same capitalized cost, the salvage value (in Rs.) of pump B should be _____ (rounded off to the nearest integer). **[Plant Design and Economic, 2 marks]**

Item	Pump *A*	Pump *B*
Installed cost (Rs.)	16000	32000
Uniform end of year maintenance (Rs.)	2400	1600
Salvage value (Rs.)	1000	?
Service life (year(s))	1	2

Ans. **2080 to 2300**

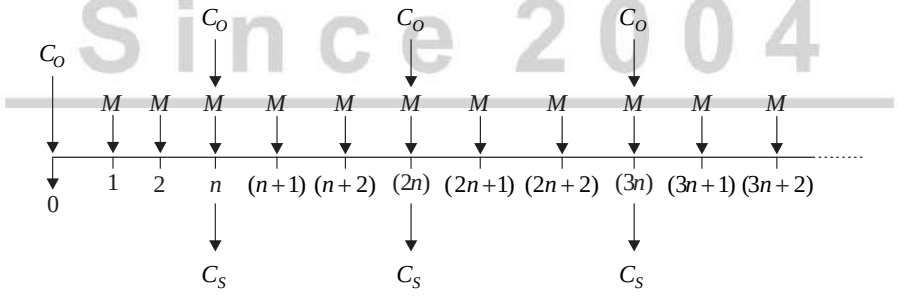
Sol. $i = 10\%$ per anum $= 0.1$ per anum

Both pumps have same capitalized cost

$$CC_A = CC_B$$

Pump A	Pump B
$C_O = 16000$	32000
$M = 2400$	1600
$C_S = 1000$	?
$h = 1$	2

Cash Flow Diagram for perpetual service by replacement



$$\text{Capitalized Cost (CC)} = C_O + \frac{C_O - C_S}{(1+i)^n - 1} + \frac{M}{i}$$

But $CC_A = CC_B$

$$\left[C_{O_A} + \frac{C_{O_A} - C_{S_A}}{(1+i)^{n_A} - 1} + \frac{M_A}{i}\right] = \left[C_{O_B} + \frac{C_{O_B} - C_{S_B}}{(1+i)^{n_B} - 1} + \frac{M_B}{i}\right]$$

$$16000 + \frac{16000 - 1000}{(1\cdot 1)^1 - 1} + \frac{2400}{0.1} = 32000 + \frac{32000 - C_S B}{(1\cdot 1)^2 - 1} + \frac{1600}{0.1}$$

$$C_{S_B} = 2180 \text{ Rs}$$