MADE EASY

GATE 2023

CHEMICAL ENGINEERING

Questions & Solutions

Exam held on 11th Feb, 2023 Afternoon Session

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SECTION - A GENERAL APTITUDE

Q.1 "You are delaying the completion of the task. Send _______ contributions at the earliest."

(a) you are (b) your
(c) you're (d) yore

Ans. (b)

End of Solution

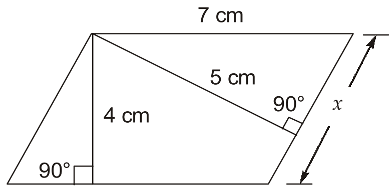
Q.2 References : ______ : : Guidelines : Implement (By word meaning)

(a) Sight (b) Site
(c) Cite (d) Plagiarise

Ans. (c)

End of Solution

Q.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.)



(a) $\frac{20}{7}$ (b) $\frac{28}{5}$
(c) $\frac{9}{2}$ (d) $\frac{35}{4}$

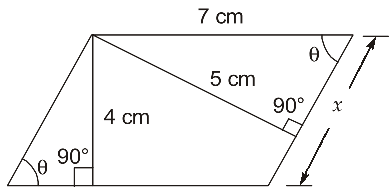
Ans. (b)

$$\text{Area of parallelogram} = \text{Base} \times \text{Height}$$

So,
$$4 \times 7 = 5 \times x$$

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

Alternate Method:



$$\sin\theta = \frac{5}{7} = \frac{4}{x}$$

$$\Rightarrow \quad x = \frac{28}{5} \text{ cm}$$

End of Solution

Q.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*?

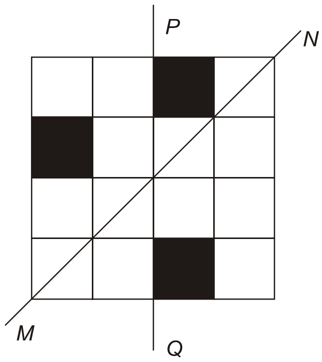
(a) Every Fields medalist has won a medal in an International Mathematics Olympiad.
(b) Everyone who has dropped out of college has won the Fields medal.
(c) All Fields medalists are part-time poets.
(d) Some Fields medalists have dropped out of college.

Ans. (d)

End of Solution

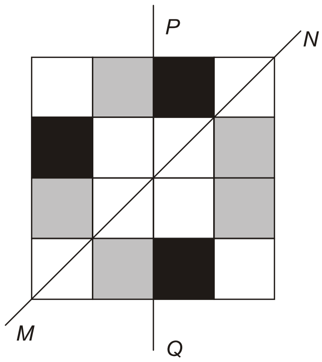
Q.5 A line of symmetry is defined as a line that divides a figure into two parts in a way such that each part is a mirror image of the other part about that line.

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)



(a) 3
(b) 4
(c) 5
(d) 6

Ans. (c)



End of Solution

Q.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?

(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)

End of Solution

Q.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?

(a) 400
(b) 600
(c) 800
(d) 200

Ans. (a)

	Sand	Cement
Quantity	$3x$	x
Cost	y	$2y$
Total cost	$3xy$	$2xy = 1000$

$$\frac{S}{C} = \frac{3xy}{2xy} = \frac{3}{2} = \frac{600}{400}$$

$$C = \frac{4}{10} \times 1000$$

Cost of cement = 400

End of Solution

Q.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.

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)

End of Solution

Q.9 The coefficient of x^4 in the polynomial $(x - 1)^3 (x - 2)^3$ is equal to ______.

(a) 33
(b) –3
(c) 30
(d) 21

Ans. (a)

End of Solution

Q.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.

(a) circle
(b) regular octagon
(c) regular pentagon
(d) rhombus

Ans. (d)

End of Solution

■■■■

SECTION - B TECHNICAL

Q.11 Which one of the following is the CORRECT value of y, as defined by the expression given below?

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

(a) 1 (b) 2
(c) 0 (d) ∞

Ans. (b)

$\therefore$ It is in $\frac{0}{0}$ form so, using L-Hospital's rule

$$\lim_{x \to 0}\left(\frac{2x}{e^x - 1}\right) = \lim_{x \to 0}\left(\frac{2}{e^x}\right) = \frac{2}{e^0} = \frac{2}{1} = 2$$

End of Solution

Q.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 $(x, y, z) = (3, 2, 1)$?

(a) 0 (b) 3
(c) 14 (d) 13

Ans. (d)

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

For divergence, we know

$$\nabla \cdot \vec{v} = \frac{\partial}{\partial x}(zx) + \frac{\partial}{\partial y}(zxy) + \frac{\partial}{\partial z}(zyx)$$

$$\nabla \cdot \vec{v} = z + 2x + 3y \text{ at } [3, 2, 1]$$

$$\nabla \cdot \vec{v} = 1 + 2 \times 3 + 3 \times 2 = 13$$

End of Solution

Q.13 Given that

$$F = \frac{|Z_1 + Z_2|}{|Z_1| + |Z_2|}$$

where $z_1 = 2 + 3i$ and $z_2 = -2 + 3i$ with $i = \sqrt{-1}$ which one of the following options is CORRECT?

(a) $F < 0$
(b) $F < 1$
(c) $F > 0$
(d) $F = 1$

Ans. **(b)**

$$|Z_1| = \sqrt{4+9} = \sqrt{13}$$

$$|Z_2| = \sqrt{(-2)^2 + 9} = \sqrt{13}$$

$$Z_1 + Z_2 = 0 + 6\hat{i}$$

$\Rightarrow$ $$|Z_1 + Z_2| < |Z_1| + |Z_2|$$

Hence, $$F < 1$$

End of Solution

Q.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 $\frac{\partial(\hat{e}_r + \hat{e}_\theta)}{\partial\theta}$?

(a) 1
(b) $\hat{e}_\theta$
(c) $\hat{e}_r + \hat{e}_\theta$
(d) $-\hat{e}_r + \hat{e}_\theta$

Ans. **(d)**

Given:

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

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

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

$$\frac{\partial f(z)}{\partial\theta} = -\sin\theta\hat{i} - \cos\hat{i} + \cos\theta\hat{j} - \sin\theta\hat{j}$$

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

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

$$\frac{\partial f(z)}{\partial\theta} = -\hat{e}_r + \hat{e}_\theta$$

End of Solution

Q.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.

Ans. (a)

End of Solution

Q.16 Which one of the following options represents the major components of oleum?

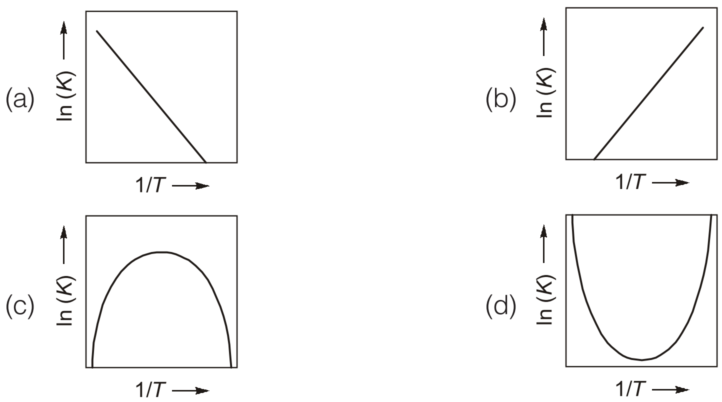
(a) Sulfuric acid and nitric acid
(b) Concentrated sulfuric acid and petroleum jelly
(c) Sulfuric acid and hydrochloric acid
(d) Sulfuric acid and sulfur trioxide

Ans. (d)

Oleum is a term referring to solutions of various compositions of SO_3 in H_2SO_4 having chemical formula of $H_2S_2O_7$.

End of Solution

Q.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*?



Ans. (a)

For reversible endothermic reactions, the value of equilibrium constant (*K*) increases as the value of operating temperature increases, thus

K increases, as *T* increases

K increases, as $\frac{1}{T}$ decreases

Thus, option (a) is the correct one.

End of Solution

Q.18 Nitrile rubber is manufactured via polymerization process. Which one of the following options is the CORRECT pair of monomers used in this process?

(a) Acrylonitrile and styrene
(b) Acrylonitrile and butadiene
(c) Butadiene and styrene
(d) Butadiene and isoprene

Ans. (b)

Nitrile rubber is manufactured via polymerization, the correct monomers are acrylonitrile and butadiene.

Nitrile rubber also known as nitrile butadiene rubber i.e. (BUNA-N) which is composed of acrylonitrile and butadiene.

End of Solution

Q.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 ΔS_{rev}. Jane performed the experiment under irreversible conditions, for which the change in entropy of the system was ΔS_{irr}. Which one of the following relationships is CORRECT?.

(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)

Since entropy is a point function so that is why, it only depends on the initial and final state either performed by reversible path or irreversible path. Therefore the change in entropy in both the cases will be same.

End of Solution

Q.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 $Re_p < 1$. Under this condition, minimum fluidization velocity is proportional to D_p^n. Which one of the following is the CORRECT value of exponent n?

(a) 2
(b) –1
(c) –2
(d) 1

Ans. (a)

From Carman-Kozeny equation, we have

$$\frac{\Delta P}{L} = \frac{150\mu_f V_0 (1-\epsilon)^2}{(\phi_s d_p)^2 \epsilon^3} \quad \{\text{when } Re_p < 1\}$$

V_0 = Fluidization velocity

Under minimum fluidization condition, we have

$$g(\rho_p - \rho_f)(1-\epsilon) = \frac{150\mu_f V_0 (1-\epsilon)^2}{(\phi_s d_p)^2 \epsilon^3}$$

i.e. $V_0 \propto (D_p)^2$

$n = 2$

End of Solution

Q.21 Match the quantities in Group 1 with their units in Group 2 listed in the table below.

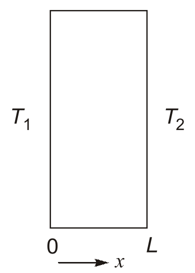
Group 1	Group-2
P. Thermal conductivity	I. $W.m^{-2}\ K^{-1}$
Q. Convective heat transfer coefficient	II. $W.m^{-1}\ K^{-1}$
R. Stefan-Boltzmann constant	III. $W.K^{-1}$
S. Heat capacity rate	IV. $W.m^{-2}\ K^{-4}$

(a) P - II, Q - I, R - IV, S - II
(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 - IV

Ans. (a)

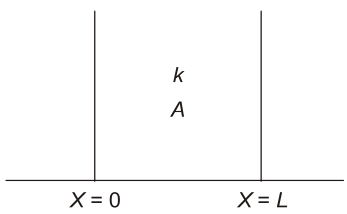
End of Solution

Q.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_1 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?



(a) $\frac{L}{kA}$
(b) $\frac{k}{LA}$
(c) $\frac{kA(T_1 - T_2)}{L}$
(d) $\frac{A}{Lk}$

Ans. (a)



From, conduction we have

$$\Sigma R = \frac{b}{kA}$$

$$R = \frac{L}{kA}, \text{ where } R = \text{Resistance}$$

k = Thermal conductivity
A = Cross-sectional area
L = Thickness of slab

End of Solution

Q.23 Spray dryers have many advantages. Which one of the following is NOT an advantage of a typical spray dryer?
(a) Has short drying time
(b) Produces hollow spherical particles
(c) Has high heat efficiency
(d) Is suitable for heat sensitive materials

Ans. (c)

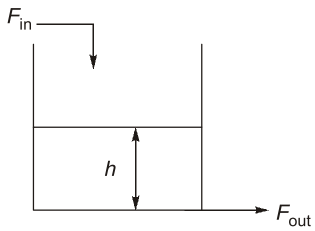
End of Solution

Q.24 Which one of the following quantities of a flowing fluid is measured using a rotameter?
(a) Static pressure
(b) Dynamic pressure
(c) Volumetric flow rate
(d) Viscosity

Ans. (c)

End of Solution

Q.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 cm^2. Density of the liquid is constant everywhere in the system. At steady state, $F_{in} = F_{out}$ = 10 cm^3s^{-1} and h = 16 cm. The variation of h with F_{in} 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?



(a) 20
(b) 32
(c) 64
(d) 128

Ans. (c)

$$F_{in} - F_{out} = A\frac{dh}{dt}$$

$$F_{in} - k\sqrt{h} = A\frac{dh}{dt}$$

$$F_{in} - k\left(\frac{\sqrt{h_0}}{2} + \frac{h}{2\sqrt{h_0}}\right) = A\frac{dh}{dt} \quad ...(i)$$

$$F_{in} - \frac{k\sqrt{h_0}}{2} - \frac{kh}{2\sqrt{h_0}} = A\frac{dh}{dt}$$

$$F_{in} - \frac{k}{2\sqrt{h_0}}.h = A\frac{dh}{dt} + \frac{k\sqrt{h_0}}{2}$$

$$f(x) = s\, f(x_0) + (x - x_0)\frac{\partial t}{\partial x}\bigg|_{x_0}$$

$$\sqrt{h} = \sqrt{h_0} + (h - h_0)\times\frac{1}{2\sqrt{h_0}}$$

$$\sqrt{h} = \sqrt{h_0} + \frac{h}{2\sqrt{h_0}} - \frac{h_0}{2\sqrt{h_0}}$$

$$\sqrt{h} = \sqrt{h_0} + \frac{h}{2\sqrt{h_0}} - \frac{h_0\times\sqrt{h_0}}{2\sqrt{h_0}}$$

$$\sqrt{h} = \sqrt{h_0} - \frac{\sqrt{h_0}}{2} + \frac{h}{2\sqrt{h_0}}$$

$$\sqrt{h} = \frac{\sqrt{h_0}}{2} + \frac{h}{2\sqrt{h_0}}$$

At S.S.

$$(F_{in})_{SS} - k = \left(\frac{\sqrt{h_0}}{2} + \frac{h}{2\sqrt{h_0}}\right) = A\frac{dh_s}{dt} = 0 \qquad \text{...(ii)}$$

(i) – (ii)

$$[F_{in} - (F_{in})_{SS}] - \frac{k(h - h_s)}{2\sqrt{h_0}} = A\frac{d(h - h_s)}{dt}$$

$$\bar{F}_{in} = \frac{k\bar{h}}{2\sqrt{h_0}} = A\frac{d\bar{h}}{dt}$$

As S.S, $F_{in} = F_{out} = 10\ \text{cm}^3/\text{sec}$

$h_s = 16\ \text{cm} = h_0$ $\quad \sqrt{h_0} = 4$

At S.S, $F_{out} = 10$

$k\sqrt{h_s} = 10$

$k = 2.5$

$$F_{in}(s) = \frac{kh(s)}{2\sqrt{h_0}} = As\,h(s)$$

$$F_{in}(s) = As\,h(s) + \frac{k\,h(s)}{2\sqrt{h_0}}$$

$$F_{in}(s) = h(s)\left(As + \frac{h}{2\sqrt{h_0}}\right)$$

$$\frac{h(s)}{F_{in}(s)} = \frac{1}{As+\frac{k}{2\sqrt{h_0}}} = \frac{1}{20s+\frac{2.5}{2\sqrt{16}}} = \frac{1}{20s+\frac{2.5}{8}}$$

$$\frac{h(s)}{F_{in}(s)} = \frac{1}{20s+0.3125} = \frac{1/0.3125}{\frac{20}{0.3125s}+1} = \frac{k_p}{\tau_p s+1}$$

$$\tau_p = \frac{20}{0.3125} = 64$$

End of Solution

Q.26 A packed distillation column, with vapor having an average molecular weight of 45 kg.kmol^{-1}, density of 2 kg.m^{-3} and a molar flow rate of 0.1 kmol.s^{-1}, has a flooding velocity of 0.15 m.s^{-1}. The column is designed to operate at 60% of the flooding velocity. Which one of the following is the CORRECT value for the column diameter (in m)?

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

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

(c) 4π

(d) $\frac{10}{\sqrt{\pi}}$

Ans. (d)

Given:

$$\dot{m}_v = 0.1 \text{ kmol/s}$$

$$M = 45 \text{ kg/kmol}, \quad V_f = 0.15 \text{ m/s}$$

$$\rho_v = 2 \text{ kg/m}^3, \quad V_{operating} = 60\% \text{ of } V_{flooding}$$

Diameter of column = ?

Now,

$$\dot{m}_v = \rho A V_{operating}$$

$$A = \frac{\dot{m}_v}{\rho V_{operating}}$$

Since, $\dot{m}_v$ is in kmol/s, thus expression becomes

$$A = \frac{\dot{m}_v M}{\rho V_{operating}}$$

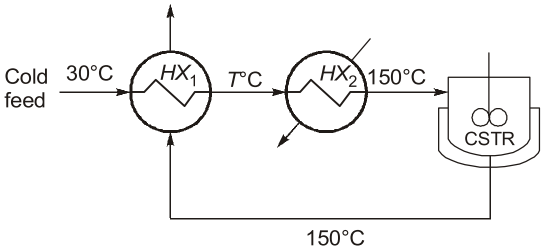
$$\frac{\pi}{4}d^2 = \frac{0.1\times 45}{2\times 0.60\times 0.15}$$

$$d = \sqrt{\frac{100}{3.14}} = 5.64 \text{ m}$$

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

End of Solution

Q.27 An isothermal jacketed continous stirred tank reactor (CSTR) operating at 150°C is shown in the figure below. The cold feed entering the system at 30°C is preheated to a temperature T (T < 150°C) using a heat exchanger HX_1. This preheated feed is further heated to 150°C using the utility heater HX_2. The mass flow rate and heat capacity are same for all the process streams, and the overall heat transfer coefficient is independent of temperature. Which one of the following statements is the CORRECT action to take if it is desired to increase the value of T?



(a) Increase both heat transfer area of HX_1 and heat duty of HX_2.
(b) Decrease both heat transfer area of HX_1 and heat duty of HX_2.
(c) Increase the heat transfer area of HX_1 and decrease the heat duty of HX_2.
(d) Decrease the heat transfer area of HX_1 and increase the heat duty of HX_2.

Ans. (c)

End of Solution

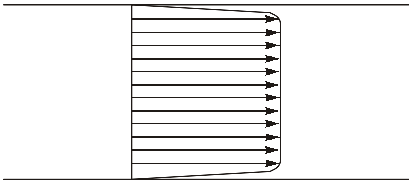
Q.28 Consider a system where a Carnot engine is operating between a source and a sink. Which of the following statements about this system is/are NOT correct?
(a) This engine is reversible.
(b) The engine efficiency is independent of the source and sink temperatures.
(c) This engine has the highest efficiency 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)

End of Solution

Q.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?
(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. (b, d)
For the case of fully developed turbulent flow,



$\overline{v}_{avg}$ is found to be 0.817 times of the centre line velocity.

End of Solution

Q.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?

(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, d)

End of Solution

Q.31 The position $x(t)$ of a particle, at constant ω, is described by the equation

$$\frac{d^2x}{dt^2} = -w^2x$$

The initial conditions are $x(t=0) = 1$ and $\left.\frac{dx}{dt}\right|_{t=0} = 0$ then position of particle at $t = \left(\frac{3\pi}{\omega}\right)$ is _____ (in integer).

Ans. (–1)

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

$$(D^2 + w^2) = 0$$

$$D = \pm wi$$

$$i = C_1 \cos wt + C_2 \cos wt$$

$$\frac{dx}{dt} = -C_1 w \cos wt + C_2 w \cos wt$$

Using Boundary conditions, we get

$$x = 1 \text{ at } t = 0$$

$$[1 = C_1]$$

and $$\frac{dx}{dt} = 0 \text{ at } t = 0$$

$$[0 = C_2]$$

Therefore, $$x = \cos wt$$

Now, at $$t = \left(\frac{3\pi}{w}\right)$$

$$x = \cos w \cdot \frac{3\pi}{w} = -1$$

End of Solution

Q.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).

Ans. **(200)**

$$CH_4 + 2CO_2 \rightarrow CO_2 + 2H_2O$$

$$CH_4 + \frac{3}{2}O_2 \rightarrow CO + 2H_2O$$

Given: CH_4 supply = 100 mol/hr

For theoretical oxygen requirement, complete combustion is only considered, i.e.

For 100 mole $CH_4 \rightarrow$ 200 mole O_2 is require.

End of Solution

Q.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^{3}s^{-1}, the pressure drop across the length of the tube is 1 MPa. If the viscosity of the fluid is $k \times 10^{-3}$ Pa.s, the value of k is _____ (rounded off to two decimal places).

Ans. **(1.02)**

Given:

$$d = 0.5 \text{ mm}, \quad L = 1.5 \text{ m}$$

$$\Delta P = 1 \text{ MPa}, \quad Q = 1 \text{ cm}^3/\text{s}$$

$$\mu = k \times 10^{-3} \text{ Pa.s}$$

Given the flow is laminar, steady and fully developed, thus we have

$$\frac{\Delta P}{L} = \frac{128\mu Q}{\pi d^4}$$

$$\mu = \frac{\Delta P \pi d^4}{128 \times Q \times L}$$

Putting values, we get

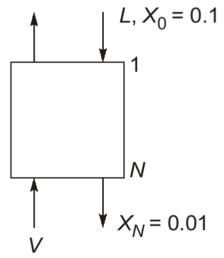
$$\mu = \frac{10^6 \times 3.14 \times (0.5 \times 10^{-3})^4}{128 \times 10^{-6} \times 1.5} = 1.022 \times 10^{-3} \text{ Pa.s}$$

Thus, the value of k is 1.02.

End of Solution

Q.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).

Ans. (3)



$y_{n+1} = 0$ (pure gas), $L = \frac{V}{2}$, $y_e = x_e$

Now, for stripping, we have

$$N_P = \frac{\ln\left[\left(\frac{X_0 - \frac{Y_{N+1}}{m}}{X_N - \frac{Y_{N+1}}{m}}\right)\left(1-\frac{1}{s}\right)+\frac{1}{s}\right]}{\ln s}$$

where, S = Stripping factor = 2

Putting values, we get

$$N_P = \frac{\ln\left[\left(\frac{0.1}{0.01}\right)(1-0.5)+0.5\right]}{\ln 2}$$

$$N_P = 2.46 \cong 3 \text{ stage}$$

End of Solution

Q.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. $N_{A,UMD}$ is the molar flux of A for steady one-component diffusion through stagnant B. Using the mole fraction of A in the bulk of the gas phase as 0.2 and that at the gas-liquid interface as 0.1 for both the modes of diffusion, the ratio of $N_{A,UMD}$ to $N_{A,EMD}$ is equal to _____ (rounded off to two decimal places).

Ans. (1.17)

Now,
$$\frac{(N_A)_{ANB}}{(N_A)_{EMCD}} = \frac{D_{AB}P_T(y_{A_1}-y_{A_2})R_T\Delta z}{R_T\Delta z\, y_{Blm}\cdot D_{AB}P_T(y_{A_1}-y_{A_2})}$$

$$\frac{(N_A)_{ANB}}{(N_A)_{EMCD}} = \frac{1}{y_{Blm}} = \frac{1}{\frac{y_{B_1}-y_{B_2}}{\ln\left|\frac{y_{B_1}}{y_{B_2}}\right|}}$$

$$y_{B_1} = 1 - 0.2 = 0.8$$

$$y_{B_2} = 1 - 0.1 = 0.9$$

$$Y_{Blm} = \frac{0.8 - 0.9}{\ln\left|\frac{0.8}{0.9}\right|} = 0.85$$

$$\therefore \quad \frac{(N_A)_{ANB}}{(N_A)_{EMCD}} = \frac{1}{0.85} = 1.176$$

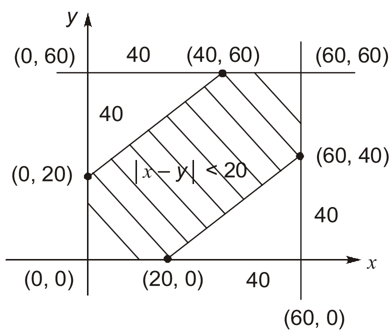
End of Solution

Q.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?

(a) $\frac{5}{9}$ (b) $\frac{4}{9}$

(c) $\frac{2}{9}$ (d) $\frac{7}{9}$

Ans. **(a)**



Let arrival time of two persons be x and y then according to question $|x - y| < 20$

or $-20 < x - y < 20$

Shaded area is favourable area

$$\text{Total area} = 60 \times 60 = 3600$$

$$\text{Unfavourable area} = 2 \times \frac{1}{2}\text{Base} \times \text{Height} = 40 \times 40 = 1600$$

So, $$\text{Favourable area} = 3600 - 1600 = 2000$$

Hence $$P(|x - y| < 20) = \frac{\text{Favourable area}}{\text{Total area}} = \frac{2000}{3600} = \frac{5}{9}$$

End of Solution

Q.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?

(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)

$$f(x) = \int_{-1}^{1} \sqrt{1-x^2}\, dx, \quad h = 0.5$$

From Simpson's $\frac{1}{3}$ rd rule, we have

$$\int f(x)dx = \frac{h}{3}[y_0 + y_n + 2[\text{even terms}] + 4\,(\text{odd terms})]$$

x	-1	-0.5	0	0.5	1
$f(x)$	0	0.87	1	0.87	0
	y_0	y_1	y_2	y_3	y_4

$$\int_{-1}^{1} f(x)dx = \frac{0.5}{3}[2x_1 + 4[0.87 + 0.87]]$$

$$= 1.49 \cong 1.5$$

End of Solution

Q.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. Phosphorous	IV. Contact process

Codes:

(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 - IV, Q - I, R - II, S - III

Ans. (a)

End of Solution

Q.39 Match the reactions in Group 1 with the catalysts in Group 2 listed in the table below.

Group 1	Group 1
P. $C_2H_6 + Cl_2 \rightarrow$ Chlorobenzene + HCl	I. Mixed oxide of Mo and Fe
Q. $H_2C = CH_2 + \frac{1}{2}O_2 \rightarrow$ Ethylene oxide	II. V_2O_5
R. $CH_3OH + \frac{1}{2}O_2 \rightarrow$ Formaldehyde + H_2O	III. $FeCl_3$
S. Naphthalene + $\frac{9}{2}O_2 \rightarrow$ Phthalic anhydride $+2H_2O + 2CO_2$	IV. Ag_2O

Codes:

(a) P - III, Q - IV, R - II, S - 2I
(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)

End of Solution

Q.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?

(a) 2.9×10^{-4}
(b) 0.9×10^{-4}
(c) 2.5×10^{-4}
(d) 0.5×10^{-4}

Ans. (c)

End of Solution

Q.41 The enthalpy (H, 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}) ?

(a) 100
(b) 42
(c) 64
(d) 40

Ans. (b)

For $\overline{H}_1^{\infty}$, we have

$$\overline{H}_1 = H + X_2\frac{dH}{dX_1}$$

$$H = 40X_1 + 60X_2 + X_1X_2\,[4X_1 + 2X_2]$$

$$H = -20X_1 + 60 + 2X_1 - 2X_1^3 \qquad \{\text{In terms of } X_1\}$$

Now,

$$\overline{H}_1 = 40X_1 + 60X_2 + X_1X_2[4X_1 + 2X_2] + X_2\frac{dH}{dX_1}$$

$$\frac{dH}{dX_1} = -20 + 2 - 6X_1^2 = -18 - 6X_1^2$$

$$\therefore \quad \overline{H}_1^{\infty} = 60 - 18 = 42 \qquad \{X_1 \to 0,\ X_2 \to 1\}$$

$$\overline{H}_1^{\infty} = 42$$

End of Solution

Q.42 Which one of the following represents the CORRECT effects of concentration polarization in a reverse osmosis process?

(a) Reduced water flux and reduced solute rejection
(b) Increased water flux and increased solute rejection
(c) Reduced water flux and increased solute rejection
(d) Increased water flux and reduced solute rejection

Ans. (a)

Concentration polarization reduces the flux of water because the increase in osmotic pressure reduces the driving force for water transport and the solute rejection decreases because of lower water flux.

End of Solution

Q.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_{H2}, respectively. While CO undergoes molecular adsorption, H_2 adsorbs via dissociative adsorption, that is, as hydrogen atoms. The equilibrium constants (in atm^{-1}) corresponding to adsorption of CO and H_2 to the catalyst sites are K_{CO} and K_{H2}, respectively. Total molar concentration of active sites per unit mass of the catalyst is C_t (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?

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

(b) $\dfrac{K_{CO}}{\sqrt{K_{H_2}}}$

(c) $\dfrac{p_{CO}}{\sqrt{p_{H_2}}}$

(d) $\dfrac{K_{CO}p_{CO}}{K_{H_2}p_{H_2}}$

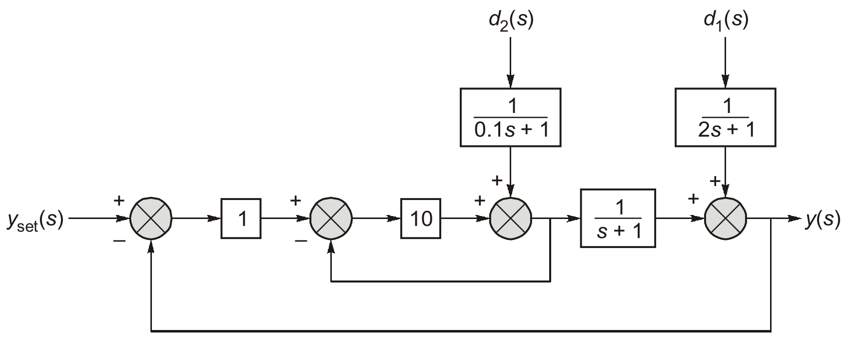
Ans. (a)

End of Solution

Q.44 A cascade control strategy is shown in the figure below. The transfer function between the output (y) and the secondary disturbance (y_2) is defined as

$$G_{d2}(s) = \frac{y(s)}{d_2(s)}$$

Which one of the following is the CORRECT expression for the transfer function $G_{d2}(s)$?



(a) $\frac{1}{(11s+21)(0.1s+1)}$

(b) $\frac{1}{(s+1)(0.1s+1)}$

(c) $\frac{(s+1)}{(s+2)(0.1s+1)}$

(d) $\frac{(s+1)}{(s+1)(0.1s+1)}$

Ans. (a)

$$\left[(y_{sp}-y)(1)-a\right]10+d_s(s).\frac{1}{0.1s+1} = a \quad ...(i)$$

$$a\left(\frac{1}{s+1}\right)+d_1(s)\frac{1}{(2s+1)} = y \quad ...(ii)$$

$$(y_{sp}-y)10-10a+d_2(s).\frac{1}{0.1s+1} = a$$

$$(y_{sp}-y)10+\frac{d_2(s)}{(0.1s+1)} = 11\,a$$

$$(y_{sp}-y)\frac{10}{11}+\frac{d_2(s)}{11(0.1s+1)} = a$$

$$Gd_2(s)=\frac{y(s)}{d_2(s)}$$

$$\left[(y_{sp}-y)\frac{10}{11}+\frac{d_2(s)}{11(0.1s+1)}\right]\frac{1}{(s+1)}+d_1(s)\frac{1}{(2s+1)} = y$$

$$(y_{sp}-y)\frac{10}{11}\times\frac{1}{(s+1)}+\frac{d_2(s).1}{11(0.1s+1)(s+1)}+d_1(s)\frac{1}{(2s+1)} = y$$

$$(0-y)\frac{10}{11}\times\frac{1}{(s+1)}+\frac{d_2(s)}{11(0.1s+1)(s+1)} = y$$

$$\frac{d_2(s)}{11(0.1s+1)(s+1)} = y+\frac{10}{11}y.\frac{1}{(s+1)}$$

$$\frac{d_2(s)}{11(0.1s+1)(s+1)} = y(s)\left(1+\frac{10}{11}.\frac{1}{(s+1)}\right)$$

$$\frac{d_2(s)}{11(0.1s+1)(s+1)} = y(s)\left(\frac{11(s+1)+10}{11(s+1)}\right)$$

$$\frac{d_2(s)}{(0.1s+1)} = y(s)\ [11s + 11 + 10]$$

$$\frac{d_2(s)}{(0.1s+1)} = y(s)\ [11s + 21]$$

$$\frac{d_2(s)}{(0.1s+1)} = y(s)\ [11s + 21]$$

$$\frac{y(s)}{d_s(s)} = \frac{1}{(0.1s+1)(11s+21)}$$

End of Solution

Q.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?

(a) 0.25
(b) 2
(c) 4
(d) 6

Ans. (b)

End of Solution

Q.46 Which of the following statements is/are CORRECT?

(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)

End of Solution

Q.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).

Ans. (4160)

$$A = \begin{bmatrix} 10 & 6 \\ 6 & 10 \end{bmatrix}$$

For eigen values, we have

$$|A - \lambda I| = 0$$

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

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

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

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

$$\lambda = \frac{20 \pm \sqrt{400 - 4 \times 64}}{2}$$

$$\lambda = 16, 4$$

$$\lambda^3 = (16)^3 \text{ and } (4)^3$$

$$\text{Sum of eigen values} = (16)^3 + (4)^3 = 4160$$

End of Solution

Q.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).

Ans. (–24)

Given:

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

$$\frac{du}{dr} = 4[-12r^{-13} + 6r^{-7}]$$

At, $r = 1$

$$\frac{du}{dr} = 4[-12 + 6] = -24$$

End of Solution

Q.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).

Ans. (5.26%)

Basis 100 mole of wet air

Thus, 10 mol = H_2O

90 mol = Dry air

After 50% H_2O removal, at exit we have

5 mol H_2O

90 mol dry air

$$X_{water} = \frac{5}{95} = 0.053 = 5.3\%$$

End of Solution

Q.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).

Species	N_2	CO_2	CO	O_2
mol %	65	15	10	10

Ans. (0.61)

Let Moles = 100

N_2 = 65%

O_2 = 10%

CO_2 = 15%

CO = 10%

Moles of N_2 = 65

CO_2 = 15

CO = 10

O_2 = 10

Let m = moles of H_2O

$$\frac{m}{100 + m} = 0.07$$

m = 7.527 moles

$$N_2 = \text{on wet bases}$$

$$\frac{65}{100+7.527} = 0.6045 \approx 0.61$$

End of Solution

Q.51 A pump draws water (density = 1000 kg.m^{-3}) at a steady rate of 10 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).

Ans. (4.74)

Given:

$$\dot{m} = 10 \text{ kg/s}, \quad \rho_w = 1000 \text{ kg/m}^3$$

$$P_S = -20 \text{ kPa (gauge)}, \quad P_D = 350 \text{ kPa (gauge)}$$

$$Z_1 = Z_2 \text{ (same)}, \quad g = 9.81 \text{ m/s}^2$$

$$d_S = 70 \text{ mm}, \quad d_D = 50 \text{ mm}, \quad \eta = 80\%$$

Now, from continuity, we have

$$\dot{m} = \rho AV, \quad A_1V_1 = A_2V_2$$

$$Q = \frac{10}{1000} = 0.01 \text{ m}^3/\text{s}$$

$$0.01 = \frac{\pi}{4}(0.07)^2 V_s \rightarrow V_s = 2.6 \text{ m/s}$$

$$0.01 = \frac{\pi}{4}(0.05)^2 \cdot V_D \rightarrow V_D = 5.1 \text{ m/s}$$

Now, applying Bernoulli's theorem between suction and discharge, we get

$$\frac{P_S}{\rho g}+\frac{V_S^2}{2g}+Z_1+H_P = \frac{P_D}{\rho g}+\frac{V_D^2}{2g}+Z_2+h_f$$

$$h_f \cong 0 \text{ (given)}$$

$$(Z_1 = Z_2)$$

Putting values, we get

$$\frac{-20\times 10^3}{10^3\times g}+\frac{(2.6)^2}{2\times g}+H_P = \frac{35\times 10^3}{10^3\times g}+\frac{(5.1)^2}{2\times g}$$

$$-20+\frac{(2.6)^2}{2}+gH_P = 350+\frac{(5.1)^2}{2}$$

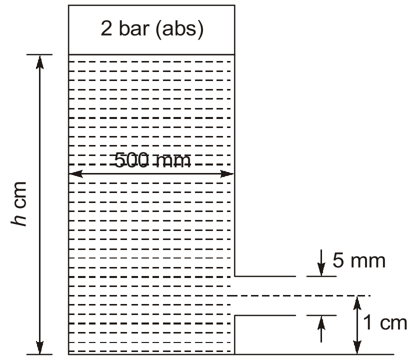
$$gH_P = 383.005-\frac{(2.6)^2}{2} = 379.625$$

$$\text{Power} = \frac{\rho g H_P \cdot Q}{\eta} = \frac{1000\times 379.625\times 0.01}{1000\times 0.8}$$

$$P = 4.74 \text{ kW}$$

End of Solution

Q.52 A cylindrical tank with a diameter of 500 mm contains water (density =1 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).



Not to scale

Ans. (1.45)

From mass balance, we get

$$\rho A_N V_N = \frac{dm}{dt} = \rho A_T \frac{dh}{dt}$$

$$\left(\frac{A_N}{A_T}\right) V_N = \frac{dh}{dt}$$

$$\frac{dh}{dt} = \left(\frac{d_N}{d_T}\right)^2 V_N \quad \text{...(i)}$$

where, d_N = Nozzle diameter, d_T = Tank diameter

V_N = Nozzle velocity

Applying Bernoulli's between tank water surface and nozzle exit, we get

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + \frac{h}{100} = \frac{P_2}{\rho g} + \frac{V_N^2}{2g} + \frac{1}{100}$$

$$V_1 \cong 0 \text{ (surface velocity)}$$

$$\frac{2 \times 10^5}{10^3 \times 10} + \frac{h}{100} = \frac{10^5}{10^4} + \frac{(V_N)^2}{20} + \frac{1}{100}$$

$$20 + \frac{h}{100} - \frac{1}{100} = 10 + \frac{(V_N)^2}{20}$$

$$10 + \frac{h-1}{100} = \frac{V_N^2}{20}$$

$$V_N = \sqrt{20\left[10+\frac{h-1}{100}\right]}$$

Putting V_N in equation (i), we get

$$\frac{dh}{dt} = \left(\frac{5}{500}\right)^2 \sqrt{20\left[10+\frac{51-1}{100}\right]}$$

$$\frac{dh}{dt} = 1.45 \times 10^{-3} \text{ m/s} = 1.45 \text{ mm/sec}$$

End of Solution

Q.53 A large tank is filled with water (density =1 g.cm^{-3}) upto a height of 5 m. A 100 ƒÊm diameter solid spherical particle (density = 0.8 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).

Ans. (1.11)

Given:

$\rho_f = 1$ g/cm^3

$\rho_p = 0.8$ g/cm^3

$R_{ep} < 1$ (Stokes regime)

$d_p = 100$ μm

$\mu = 10^{-3}$ Pa.s

$V_t = ?$

From Stokes regime, we have

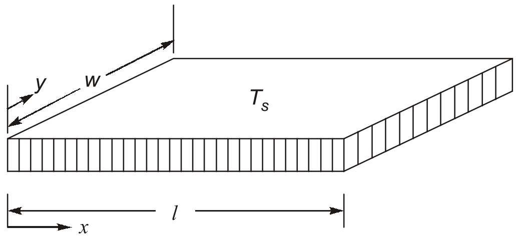
$$V_t = \frac{d_p^2(\rho_p - \rho_f)g}{18\mu_f}$$

$$V_t = \frac{(100\times10^{-6})^2(1000-800)\times 9.81}{18\times10^{-3}}$$

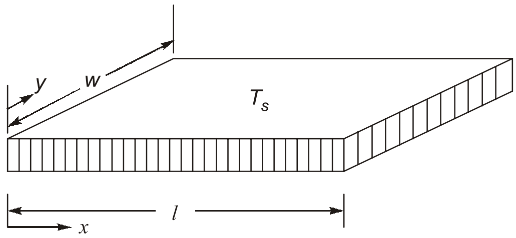
$$V_t = \frac{10^{-8}\times200\times9.81}{18\times10^{-3}} = 1.09 \text{ mm/s} = 1.1 \text{ mm/s}$$

End of Solution

Q.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_∞, respectively. When the fluid flow is only in the x-direction, h_x is the local heat transfer coefficient. Similarly, when the fluid flow is only in the y-direction, h_y is the corresponding local heat transfer coefficient. Use the correlation Nu = 0.332 (Re)$^{1/2}$ (Pr)$^{1/3}$ for the local heat transfer coefficient, where, Nu, Re, and Pr, respectively are the appropriate Nusselt, Reynolds and Prandtl numbers. The average heat transfer coefficients are defined as $\bar{h}_l = \frac{1}{l}\int_0^l h_x\,dx$ and $\bar{h}_w = \frac{1}{w}\int_0^w h_y\,dy$. If w = 1 and l = 4 m, the value of the ratio of $\bar{h}_l$ is _____ (in integer).



Ans. (2)



Steady flow
Laminar flow

$$Nu_x = 0.332\, Re_x^{1/2}\, Pr^{1/3}$$

$$\frac{h_x x}{k} = 0.332\left(\frac{V_\infty x}{\nu}\right)^{1/2} Pr^{1/3}$$

$$h_x = \frac{\text{constant}}{\sqrt{x}}$$

$$h_x = \frac{C}{\sqrt{x}}$$

$$\bar{h}_x = \frac{1}{x}\int_0^x h_x\, dx = \frac{1}{x}\int_0^x \frac{C}{\sqrt{x}}\, dx$$

$$= \frac{1}{x} \times C \times \frac{x^{1/2}}{1/2} = \frac{1}{x} \times 2C \times x^{1/2}$$

$$= 2\frac{C}{\sqrt{x}}$$

$$w = 1 \text{ m}$$

$$l = s$$

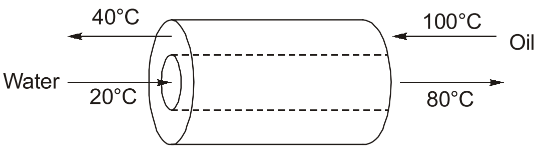
$$\bar{h}_l = 2 \times \frac{C}{\sqrt{x_l}} = \frac{2 \times C}{\sqrt{4}}$$

$$\bar{h}_w = 2 \times \frac{C}{\sqrt{x_w}} = \frac{2 \times C}{\sqrt{4}}$$

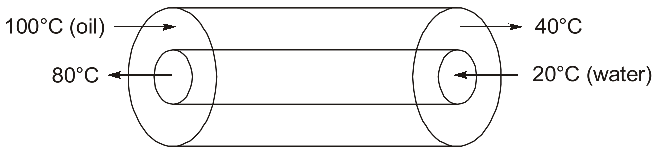
$$\frac{\bar{h}_w}{\bar{h}_l} = \frac{\frac{2 \times C}{\sqrt{1}}}{\frac{2 \times C}{\sqrt{4}}} = 2$$

End of Solution

Q.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 kg.s^{-1} with a temperature of 100 °C and leaves at 40 °C. Water enters the inner tube at a mass flow rate of 1 kg.s^{-1} with a temperature of 20 °C and leaves at 80 °C. Use specific heats of oil and water as 2089 J.kg^{-1}K^{-1} and 4178 J.kg^{-1}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).



Ans. (3)



Given: $\dot{m}_w = 1$ kg/s

$C_{pw} = 4178$ J/kg.K

For NTU, we have,

$$\text{NTU} = \frac{U \cdot A}{(mC_p)_{min}}$$

From energy balance,

$$(\dot{m}C_p)_{hot}[100-40] = (\dot{m}C_p)_{cold}[80-20]$$

$$(\dot{m}C_p)_{hot} = (\dot{m}C_p)_{cold}$$

Again, $1 \times 4178 \times (80 - 20) = U \cdot A\, \Delta T_{lmtd}$

$\because$ $\Delta T_{lmtd} = 20°C \quad \{\Delta T_1 = \Delta T_2 = 20°C\}$

$$UA = \frac{4178 \times 60}{20}$$

$$\therefore \quad (\text{NTU}) = \frac{UA}{(mC_p)_{min}} = \frac{4178 \times 60}{20 \times 1 \times 4178} = 3$$

End of Solution

Q.56 Partially saturated air at 1 bar and 50 °C is contacted with water in an adiabatic saturator. The air is cooled and humidified to saturation, and exits at 25 °C with an absolute humidity of 0.02 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 $H \times 10^{-3}$ water per kg dry air, the value of H is __________ (rounded off to two decimal places).

Ans. (9.3)

Given:

$$T_{DB} = 50°C$$
$$T_W = 25°C$$
$$L = 2450 \text{ kJ/kg}$$
$$C_{Pw} = 4.18 \text{ kJ/kgK}$$
$$(C_P)_{air} = 1.01 \text{ kJ/kgK}$$
$$\tau_w = 0.02 \text{ kg } H_2O/\text{kg dry air}$$

For the humid heat, we have

$$C_S = [(C_P)_{air} + \gamma(C_P)_{water}]$$
$$C_S = 1.01 + 4.18\,\gamma' \quad ...(i)$$

From the energy balance, we have

$$T_D - T_w = \frac{\lambda(\gamma_W' - \gamma')}{C_S}$$

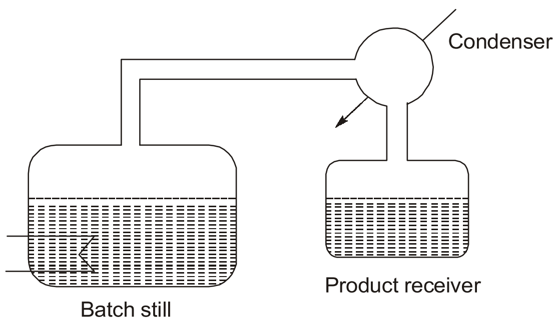
$$(50 - 25) = \frac{2450[0.02 - \gamma']}{1.01 + 4.18\gamma'}$$

Solving, we get $\gamma' = 9.29 \times 10^{-3}$

Thus, $H = 9.29$

End of Solution

Q.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).



Ans. **(0.982)**

Given:

$$F = 1 \text{ kmol}$$
$$X_{FF} = 0.1 \text{ kmol}$$
$$X_{ww} = 0.01 \text{ kmole}$$
$$\alpha_{AB} = 4.5$$

From batch distillation, we have

$$\ln\left|\frac{FX_F}{W \times W}\right| = \alpha_{AB}\ln\left|\frac{F(1-X_F)}{w(1-X_w)}\right|$$

$$\ln\left|\frac{0.1}{0.01}\right| = 4.5\ln\left|\frac{1\times 0.9}{w-0.01}\right|$$

$$\frac{2.3026}{4.5} = \ln\left|\frac{0.9}{w-0.01}\right|$$

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

$$w - 0.01 = 0.539$$
$$w = 0.549$$

$\because$ $$w \times X_w = 0.01$$

$$X_w = \frac{0.01}{0.549} = 0.0182$$

$$X_B = 1 - X_w = 0.982$$

End of Solution

Q.58 Fresh catalyst is loaded into a reactor before the start of the following catalytic reaction.

$$A \rightarrow \text{products}$$

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

Ans. **(0.5)**

Given: A - DP

$$-r_A' = -0.5\ t + 10 \text{ mol.(g cat)}^{-1}\text{ hr}^{-1})$$

$$a = \frac{-r_A'}{-r_0} = \frac{+-0.5t+10}{10}$$

$\because \quad -r_0' = 10 \quad \{\text{at } t = 0\}$

Thus activity of catalyst at time t = 10 hr

$$a = \frac{-0.5 \times 10 + 10}{10} = \frac{5}{10} = 0.5$$

End of Solution

Q.59 A unimolecular, irreversible liquid-phase reaction

$$A \rightarrow P$$

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

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

Ans. (16)

For CSTR we have,

$$\frac{\tau}{C_{A0}} = \frac{V}{F_{A0}} = \left.\frac{X_A}{-r_A}\right|_{exit}$$

$$C_{A0} = 1 \text{ mol/}^{m3}$$

$$X_A = 0.8$$

Since in CSTR the rate at exit conversion is only considered, therefore we have,

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

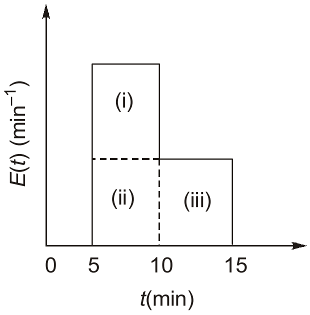
$$\tau = 16$$

End of Solution

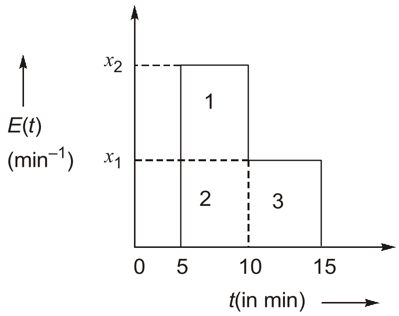
Q.60 An irreversible liquid-phase second-order reaction

$$A \xrightarrow{k} B$$

with rate constant $k = 0.2$ liter.mol^{-1}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).



Ans. (72)



$$\text{Area under E-curve} = 1$$

$$3 \times (10 - 5) \times x_1 = 1$$

$$3 \times 5 \times x_1 = 1 \quad \text{or} \quad x_1 = \frac{1}{15}$$

$$x_2 = \frac{2}{15}$$

For second-order,

$$\frac{X_A}{1 - X_A} = kC_{A0}t$$

or

$$X_A = (1 - X_A)\, kC_{A0}t$$

$$X_A = kC_{A0}t - X_A\, kC_{A0}t$$

$$X_A + X_A kC_{A0}t = kC_{A0}t$$

$$X_A(1 + kC_{A0}t) = kC_{A0}t$$

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

$$X_A = \frac{kC_{A0}t}{1+kC_{A0}t} = \frac{0.2\times 1.5t}{1+0.2\times 1.5\times t}$$

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

$$\bar{X} = \int_5^{10} \frac{2}{15}\times\frac{0.3t}{1+0.3t}dt + \int_5^{10}\frac{1}{15}\times\frac{0.3t}{1+0.3t}dt$$

$$\bar{X} = \int_5^{10} 2\times 0.02\frac{t}{1+0.3t}dt + \int_5^{10}\frac{1}{15}\times\frac{0.3t}{1+0.3t}dt$$

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

$$\bar{X} = \frac{2}{15}\int_5^{10}\frac{0.3t+1-41}{1-0.3t}dt + \frac{1}{15}\int_{10}^{15}\frac{0.3t+1-1}{1+0.3t}dt$$

$$\bar{X} = \frac{2}{15}\int_5^{10}\left(1-\frac{1}{1+0.3t}\right)dt + \frac{1}{15}\int_{10}^{15}\left(1-\frac{1}{1+0.3t}\right)dt$$

$$\bar{X} = \frac{2}{15}\left[t-\frac{1}{0.3}\ln|1+0.3t|\right]_5^{10} + \frac{1}{15}\left[t-\frac{1}{0.3}\ln[1+0.3t]\right]_{10}^{15}$$

$$\bar{X} = \frac{2}{15}[5.38-1.945]+\frac{1}{15}[9.32-5.38]$$

$$\bar{X} = 0.7206 \cong 72\%$$

End of Solution

Q.61 The outlet concentration C_A of a plug flow reactor (PFR) is controlled by manipulating the inlet concentration C_{A0}. The following transfer function describes the dynamics of this PFR.

$$\frac{C_A(s)}{C_{A0}(s)} = \exp\left[-\left(\frac{V}{F}\right)(k+s)\right]$$

In the above equation, $V = 1\ m^3$, $F = 0.1\ m^3 min^{-1}$ and $k = 0.5\ min^{-1}$. 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).

Ans. (148.4)

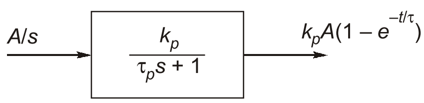
End of Solution

Q.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).

Ans. (7.1)



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

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

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

$$y(t) = k_pA[1 - e^{-(t-1)/\tau}]$$

$$1 = 1.05 \times 1 \times [1 - e^{-(t-1)/2}]$$

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

$$0.952 = 1 - e^{-(t-1)/2}$$

$$e^{-(t-1)/2} = 0.048$$

$$\frac{-(t-1)}{2} = \ln 0.048$$

$$\frac{-(t-1)}{2} = -3.0365$$

$$t - 1 = 6.073$$

$$t = 1 + 6.073$$

$$t = 7.073$$

End of Solution

Q.63 A design engineer needs to purchase a membrane module (M) for a plant. Details about the two available options, M1 and M2, 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).

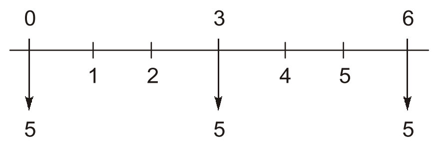
	M1	M2
Purchase cost (in lakhs of rupees)	10	5
Expected life (years)	5	3

Ans. (4.7) [4.6 to 4.8]

$$10+\frac{10}{(1+0.08)^5} = 16.80$$

$$5+\frac{5}{(1.08)^3}+\frac{5}{(1.08)^6} = 12.12$$

$$NPV_1 - NPV_2 = 4.67$$



End of Solution

Q.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).

Ans. (11.4) [11.0 to 11.9]

End of Solution

Q.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).

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

Ans. (2180)

	A	*B*
Installed cost	16000 Rs.	32000 Rs.
Maintenance	2400 Rs.	1600 Rs.
Salvage value	1000 Rs.	?
Service life	1	2

Salvage of instrument (*B*) = ?

i = 10% per year

Now, given [both the instrument have equal capitalized cost], therefore

$$\left[V_0 + \frac{V_0 - V_s}{(1+i)^n - 1} + \frac{V_m}{i}\right]_A = \left[V_0 + \frac{V_0 - V_s}{(1+i)^n - 1} + \frac{V_m}{i}\right]_B$$

$$16000 + \frac{16000 - 1000}{(1.1)^1 - 1} + \frac{2400}{0.1} = 32000 + \frac{32000 - V_s}{(1.1)^2 - 1} + \frac{1600}{0.1}$$

$$142000 = \frac{32000 - V_s}{(1.1)^2 - 1}$$

$$V_s = 2180 \text{ Rs.}$$

End of Solution

■■■■