General Aptitude Questions
Q.No-1-5 Carry One Mark Each

1. The volume of a sphere of diameter 1 unit is than the volume of a cube of side 1 unit.
   (A) least                      (B) less                        (C) lesser                     (D) low
   Answer:                       (B)
   Exp: Volume of a sphere of diameter 1 unit is \( \frac{4}{3} \pi \left(\frac{1}{2}\right)^3 = \frac{\pi}{6} \) and volume of a cube of side 1 unit is \( 1^3 = 1 \)

2. The unruly crowd demanded that the accused be without trial.
   (A) hanged                  (B) hanging                 (C) hankering              (D) hung
   Answer:                       (A)

3. Choose the statement(s) where the underlined word is used correctly:
   (i) A prone is a dried plum.
   (ii) He was lying prone on the floor.
   (iii) People who eat a lot of fat are prone to heart disease.
   (A) (i) and (iii) only    (B) (iii) only                (C) (i) and (ii) only     (D) (ii) and (iii) only
   Answer:                       (D)

4. Fact: If it rains, then the field is wet.
   Read the following statements:
   (i) It rains
   (ii) The field is not wet
   (iii) The field is wet
   (iv) It did not rain
   Which one of the options given below is NOT logically possible, based on the given fact?
   (A) If (iii), then (iv)                      (B) If (i), then (iii)
   (C) If (i), then (ii)                    (D) If (ii), then (iv)
   Answer:                       (C)

5. A window is made up of a square portion and an equilateral triangle portion above it. The base of the triangular portion coincides with the upper side of the square. If the perimeter of the window is 6 m, the area of the window in m\(^2\) is
   (A) 1.43                       (B) 2.06                       (C) 2.68                       (D) 2.88
   Answer:                       (B)
Q.No-6-10 Carry Two Marks Each

6. Students taking an exam are divided into two groups, P and Q such that each group has the same number of students. The performance of each of the students in a test was evaluated out of 200 marks. It was observed that the mean of group P was 105, while that of group Q was 85. The standard deviation of group P was 25, while that of group Q was 5. Assuming that the marks were distributed on a normal distribution, which of the following statements will have the highest probability of being TRUE?

(A) No student in group Q scored less marks than any student in group P.
(B) No student in group P scored less marks than any student in group Q.
(C) Most students of group Q scored marks in a narrower range than students in group P.
(D) The median of the marks of group P is 100.

Answer: (C)

7. A smart city integrates all modes of transport, uses clean energy and promotes sustainable use of resources. It also uses technology to ensure safety and security of the city, something which critics argue, will lead to a surveillance state.

Which of the following can be logically inferred from the above paragraph?

(i) All smart cities encourage the formation of surveillance states.
(ii) Surveillance is an integral part of a smart city.
(iii) Sustainability and surveillance go hand in hand in a smart city.
(iv) There is a perception that smart cities promote surveillance.

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

Answer: (C)

8. Find the missing sequence in the letter series.

B, FH, LNP, _ _ _ _

(A) SUWY  (B) TUVW  (C) TVXZ  (D) TWXZ

Answer: (C)

9. The binary operation □ is defined as \( a □ b = ab+(a+b) \), where \( a \) and \( b \) are any two real numbers.

The value of the identity element of this operation, defined as the number \( x \) such that \( a □ x = a \), for any \( a \), is_____.

(A) 0  (B) 1  (C) 2  (D) 10

Answer: (A)

Exp: 
\[
a □ x = a \Rightarrow ax + (a + x) = a
\]
\[
\Rightarrow x(1+a) = 0 \Rightarrow x = 0 \text{ is the identity element}
\]
10. Which of the following curves represents the function \( y = \ln\left|e^{\sin(|x|)}\right| \) for \(|x| < 2\pi\)？

Here, \( x \) represents the abscissa and \( \varphi \) represents the ordinate.

(A) 

(B) 

(C) 

(D) 

Answer: (C)
CHEMICAL ENGINEERING
Q.No-1-25 Carry One Mark Each

1. Which one of the following is an iterative technique for solving a system of simultaneous linear algebraic equations?
   (A) Gauss elimination  (B) Gauss-Jordan
   (C) Gauss-Seidel  (D) LU decomposition
   Answer: (C)

2. The Laplace transform of $e^{at} \sin(bt)$ is
   \[
   (A) \frac{b}{(s-a)^2 + b^2}  \quad (B) \frac{(s-a)}{(s-a)^2 + b^2} \\
   (C) \frac{(s-a)}{(s-a)^2 - b^2}  \quad (D) \frac{b}{(s-a)^2 - b^2}
   \]
   Answer: (A)
   Exp: $L\{e^{at} \sin(bt)\} = \frac{b}{(s-a)^2 + b^2}$

3. What are the modulus (r) and argument (θ) of the complex number $3 + 4i$?
   \[
   (A) r = \sqrt{7}, \theta = \tan^{-1}\left(\frac{4}{3}\right)  \quad (B) r = \sqrt{7}, \theta = \tan^{-1}\left(\frac{3}{4}\right)
   \\
   (C) r = 5, \theta = \tan^{-1}\left(\frac{3}{4}\right)  \quad (D) r = 5, \theta = \tan^{-1}\left(\frac{4}{3}\right)
   \]
   Answer: (D)
   Exp: Given, $Z = 3 + 4i$
   \[
   T = |Z| = \sqrt{(3)^2 + (4)^2} = 5
   \]
   \[
   \theta = \tan^{-1}\left(\frac{4}{3}\right)
   \]

4. A liquid mixture of ethanol and water is flowing as inlet stream P into a stream splitter. It is split into two streams, Q and R, as shown in the figure below.
The flow rate of P, containing 30 mass% of ethanol, is 100kg/h. What is the least number of additional specification(s) required to determine the mass flow rates and compositions (mass %) of the two exit streams?

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

Answer: (C)

Exp: Independent material balance equations

Given, \( M_{\text{EtOH,P}} = 0.3 \)

\( P = 100 \text{ kg/h} \)

\[ Q + R = 100 \]  \hspace{1cm} _____(1)

\[ m_{\text{EtOH,Q}} + m_{\text{EtOH,R}} = 30 \]  \hspace{1cm} _____(2)

Now, to solve equations (1) & (2) so as to determine all flow rates and mass compositions, both \( m_{\text{EtOH,Q}} \) and \( m_{\text{EtOH,R}} \) have to be specified.

\[ \therefore \text{ Least no. of additional specifications required} = 2 \]

5. The partial molar enthalpy (in kJ/mol) of species 1 in a binary mixture is given by
\[ h_1 = 2 - 60x_2^2 + 100x_1x_2 \]
where \( x_1 \) and \( x_2 \) are the mole fractions of species 1 and 2, respectively. The partial molar enthalpy (in kJ/mol, rounded off to the first decimal place) of species 1 at infinite dilution is ________

Answer: (-58)

Exp: \[ h_1 = 2 - 60x_2^2 + 100x_1x_2 \]  \hspace{1cm} _____(1)

\[ \therefore \text{ Partial molar enthalpy of species 1 at infinite dilution may be obtained from eqn. (1) by putting} \]
\[ x_1 = 0 \text{ and } x_2 = 1 \]

\[ h_{1 \text{ inf. dilution}} = 2 - 60 = -58.0 \text{kJ/mol} \]

6. For a flow through a smooth pipe, the Fanning friction factor \( f \) is given by \( f = m \text{Re}^{-0.2} \) in the turbulent flow regime, where \( \text{Re} \) is the Reynolds number and \( m \) is a constant. Water flowing through a section of this pipe with a velocity 1m/s results in a frictional pressure drop of 10kPa. What will be the pressure drop across this section (in kPa), when the velocity of water is 2 m/s?

(A) 11.5  (B) 20  (C) 34.8  (D) 40

Answer: (C)

Exp: For Turbulent flow we know that \( \Delta p = \frac{4fL^2V^2\rho}{2D} \)

\[ F \text{ is directly proportional to } \text{Re}^{-0.2} \]

Therefore \( \Delta P \propto V^{1.8} \)

\[ \frac{\Delta p_1}{\Delta p_2} = \frac{V_1^{1.8}}{V_2^{1.8}} = \frac{1}{2^{2.8}} \]
\[ \Delta p_2 = \Delta p_1 \times \frac{V_2^{1.8}}{V_1^{1.8}} = 10 \times \left( \frac{2}{1} \right)^{1.8} = 34.8 \text{kPa} \]

7. In a cyclone separator used for separation of solid particles from a dust laden gas, the separation factor is defined as the ratio of the centrifugal force to the gravitational force acting on the particle. \( S_r \) denotes the separation factor at a location (near the wall) that is at a radial distance \( r \) from the centre of the cyclone. Which one of the following statements is INCORRECT?

(A) \( S_r \) depends on mass of the particle
(B) \( S_r \) depends on the acceleration due to gravity
(C) \( S_r \) depends on tangential velocity of the particle
(D) \( S_r \) depends on the radial location (\( r \)) of the particle

Answer: (A)

8. A vertical cylindrical vessel has a layer of kerosene (of density 800 kg/m³) over a layer of water (of density 1000 kg/m³). L-shaped glass tubes are connected to the column 30 cm apart. The interface between the two layers lies between the two points at which the L-tubes are connected. The levels (in cm) to which the liquids rise in the respective tubes are shown in the figure below.

The distance (\( x \) in cm, rounded off to the first decimal place) of the interface from the point at which the lower L-tube is connected is _________.

Answer: (10)

Exp:
Given condition is \( p_1 = p_2 \)

From given diagram

\[
\begin{align*}
p_1 &= p_g (20 + (30 - x)) + \rho_{\text{water}} gx \\
&= 800 \times 9.81 \times 20 + (30 - x) + 1000 \times 9.81 x \\
&= 392400 + 1962x \\
P_2 &= \rho_{\text{water}} \times g \times 42 = 1000 \times 9.81 \times 42 = 412020 \\
\Rightarrow 412020 &= 392400 + 1962x \\
x &= 10 \text{cm}
\end{align*}
\]
9. A composite wall is made of four different materials of construction in the fashion shown below. The resistance (in K/W) of each of the sections of the wall is indicated in the diagram.

![Diagram of a composite wall](image_url)

The overall resistance (in K/W, rounded off to the first decimal place) of the composite wall, in the direction of heat flow, is_______

Answer: (3.9)

Exp: Total Resistance = \( R_{12} + R_{23} + R_{34} \)

\[
\frac{1}{R_{23}} = \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{0.25} + \frac{1}{1}
\]

\( \Rightarrow R_{23} = 0.3 \)

\( R_{\text{total}} = 3 + 0.2 + 0.7 = 3.9 \text{K/W} \)

10. Steam at 100°C is condensing on a vertical steel plate. The condensate flow is laminar. The average Nusselt numbers are \( N_u_1 \) and \( N_u_2 \), when the plate temperatures are 10°C and 55°C, respectively. Assume the physical properties of the fluid and steel to remain constant within the temperature range of interest. Using Nusselt equations for film-type condensation, what is the value of the ratio \( \frac{N_u_2}{N_u_1} \)?

(A) 0.5  
(B) 0.84  
(C) 1.19  
(D) 1.41

Answer: (C)

Exp: We have average heat transfer coefficient for Laminar flow through vertical plate condensation as

\[
\bar{h} = 0.943 \left[ \frac{\rho_l (\rho_l - \rho_v) \gamma h g}{\mu L (T_{sat} - T_w)} \right]^{\frac{1}{4}}
\]

It is given that, all the physical properties remain constant, so that

\[
\bar{h} \propto \frac{1}{(T_{sat} - T_w)^{\frac{1}{4}}}
\]

Where \( T_{sat} \) = saturation temperature = 100°C

\( T_w = \text{Wall temperature} \)

\( T_{w_1} = 10; T_{w_2} = 50 \)
To find \( \frac{\text{Nu}_2}{\text{Nu}_1} = \frac{\left( \frac{\text{h}_2}{\text{k}} \right)_2}{\left( \frac{\text{h}_1}{\text{k}} \right)_1} = \frac{\text{h}_2}{\text{h}_1} = \left( \frac{\text{T}_{\text{sat}} - \text{T}_{w}}{\text{T}_{\text{sat}} - \text{T}_{w_2}} \right)^{\frac{1}{4}} \). 

\[ \therefore \frac{\text{h}_2}{\text{h}_1} = \left( \frac{100 - 10}{100 - 55} \right)^{\frac{1}{4}} = 1.19 \]

11. A binary liquid mixture of benzene and toluene contains 20 mol% of benzene. At 350 K the vapour pressures of pure benzene and pure toluene are 92 kPa and 35 kPa, respectively. The mixture follows Raoult’s law. The equilibrium vapour phase mole fraction (rounded off to the second decimal place) of benzene in contact with this liquid mixture at 350 K is ______.

Answer: (0.40)

Exp:

\[ x_{\text{Benzene}} = 0.2 \]
\[ x_{\text{Tolerance}} = 0.8 \]
\[ P_{\text{vap.Benzene}} = 92 \text{ KPa} \]
\[ P_{\text{vap.Tolerance}} = 35 \text{ KPa} \]

According to Raoult’s law:

\[ y_{\text{Benzene}} = \frac{x_{\text{Benzene}} P_{\text{vap.Benzene}}}{P_{\text{total}}} \]

\[ y_{\text{B}} = \frac{x_{\text{B}} P_{\text{vap.B}}}{P_{\text{total}}} \]

\[ = \frac{x_{\text{B}} P_{\text{vap.B}}}{x_{\text{B}} P_{\text{vap.B}} + x_{\text{T}} P_{\text{vap.T}}} \]

\[ = 0.3965 \approx 0.40 \]

12. Match the dimensionless numbers in Group-1 with the ratios in Group-2.

<table>
<thead>
<tr>
<th>Group-I</th>
<th>Group-II</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>Buoyancy force</td>
</tr>
<tr>
<td></td>
<td>Viscous force</td>
</tr>
<tr>
<td>Q</td>
<td>Internal thermal resistance of a solid</td>
</tr>
<tr>
<td></td>
<td>Boundary layer thermal resistance</td>
</tr>
<tr>
<td>R</td>
<td>Momentum diffusivity</td>
</tr>
<tr>
<td></td>
<td>Mass diffusivity</td>
</tr>
</tbody>
</table>

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

Answer: (D)
13. For what value of Lewis number, the wet-bulb temperature and adiabatic saturation temperature are nearly equal?

(A) 0.33  (B) 0.5  (C) 1  (D) 2

Answer: (C)

Exp: When lewis number is unity, the wet-bulb temperature and adiabatic saturation temperature are equal.

14. For a non-catalytic homogeneous reaction $A \rightarrow B$, the rate expression at 300 K is $-r_A (\text{mol} \text{ m}^{-3} \text{s}^{-1}) = \frac{10C_A}{1+5C_A}$, where $C_A$ is the concentration of $A$ (in mol/m$^3$). Theoretically, the upper limit for the magnitude of the reactor rate ($-r_A$ in mol m$^{-3}$ s$^{-1}$, rounded off to the first decimal place) at 300 K is __________

Answer: (2.0)

Exp: $-r_A = \frac{10C_A}{1+5C_A} = \frac{10}{\left(\frac{1}{C_A}\right)+5}$

Now, theoretically the upper limit for $(-r_A)$ is reached when $\left(\frac{1}{C_A}\right) \rightarrow 0$, i.e., $C_A \rightarrow \infty$

In that case, $(-r_A) = \frac{10}{5} = 2.0$

15. The variations of the concentrations ($C_A$, $C_R$ and $C_S$) for three species ($A$, $R$ and $S$) with time, in an isothermal homogeneous batch reactor are shown in the figure below.

Select the reaction scheme that correctly represents the above plot. The numbers in the reaction schemes shown below, represent the first order rate constants in unit of s$^{-1}$. 
16. Hydrogen iodide decomposes through the reaction \(2\text{HI} \rightleftharpoons \text{H}_2 + \text{I}_2\). The value of the universal gas constant \(R\) is 8.314 J mol\(^{-1}\)K\(^{-1}\). The activation energy for the forward reaction is 184000 J mol\(^{-1}\). The ratio (rounded off to the first decimal place) of the forward reaction rate at 600 K to that at 550 K is ___________

Answer: (28.6)

Exp: 

\[T_1 = 600 \text{ K}, \quad T_2 = 550 \text{ K}\]

Activation Energy, \(\Delta E_A = 184000 \text{ J/mol}\)

Now, according to Ampere's equation:

\[k = k_0 e^{-\Delta E_A / RT}\]

Then,

\[\frac{k_1}{k_2} = e^{\frac{-\Delta E_A}{R} \left(\frac{1}{T_1} - \frac{1}{T_2}\right)}\]

\[= e^{\frac{-184000}{8.314} \left(\frac{1}{600} - \frac{1}{550}\right)}\]

\[= 28.5951 \approx 28.6\]
17. Match the instruments in Group-1 with process variables in Group-2.

<table>
<thead>
<tr>
<th>Group-1</th>
<th>Group-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>P Conductivity meter</td>
<td>I Flow</td>
</tr>
<tr>
<td>Q Turbine meter</td>
<td>II Pressure</td>
</tr>
<tr>
<td>R Piezoresistivity element</td>
<td>III Composition</td>
</tr>
</tbody>
</table>

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

Answer: (D)

18. What is the order of response exhibited by a U-tube manometer?

(A) Zero order  (B) First order  (C) Second order  (D) Third order

Answer: (C)

19. A system exhibits inverse response for a unit step change in the input. Which one of the following statement must necessarily be satisfied?

(A) The transfer function of the system has at least one negative pole  
(B) The transfer function of the system has at least one positive pole  
(C) The transfer function of the system has at least one negative zero  
(D) The transfer function of the system has at least one positive zero

Answer: (D)

20. Two design options for a distillation system are being compared based on the total annual cost. Information available is as follows:

<table>
<thead>
<tr>
<th></th>
<th>Option P</th>
<th>Option Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed cost of the system (Rs in lakhs)</td>
<td>150</td>
<td>120</td>
</tr>
<tr>
<td>Cost of cooling water for condenser (Rs in lakhs/year)</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Cost of steam for reboiler (Rs in lakhs/year)</td>
<td>16</td>
<td>20</td>
</tr>
</tbody>
</table>

The annual fixed charge amounts to 12% of the installed cost. Based on the above information, what is the total annual cost (Rs in lakhs/year) of the better option?

(A) 40  (B) 42.4  (C) 92  (D) 128

Answer: (A)

Exp: Option P: Annual fixed charge = 12% of Rs 150 lakh  
= 0.12 × 150  
= Rs 18 lakh  
Then, total annual cost (in lakhs/year)  
= 18 + 6 + 16 = 40  
Option Q: Annual fixed charge = 12% of Rs 120 lakhs

* India’s No.1 institute for GATE Training  ¦ 1 Lakh+ Students trained till date  ¦ 65+ Centers across India
\[ = 0.12 \times 120 \]
\[ = \text{Rs 14.4 lakh} \]
Then, total annual cost = \(14.4 + 8 + 20 = 42.4\) (in lakh/year)
Thus, option P is better, with lesser annual cost of Rs 40 lakh/year.

21. Standard pipes of different schedule numbers and standard tubes of different BWG numbers are available in the market. For a pipe / tube of a given nominal diameter, which one of the following statements is TRUE?
(A) Wall thickness increases with increase in both the schedule number and the BWG number
(B) Wall thickness increases with increase in the schedule number and decreases with increase in the BWG number
(C) Wall thickness decreases with increase in both the schedule number and the BWG number
(D) Neither the schedule number, nor the BWG number has any relation to wall thickness
Answer: (B)

22. Terms used in engineering economics have standard definitions and interpretations. Which one of the following statements is INCORRECT?
(A) The profitability measure ‘return on investment’ does not consider the time value of money
(B) A cost index is an index value for a given time showing the cost at that time relative to a certain base time
(C) The ‘six-tenths factor rule’ is used to estimate the cost of an equipment from the cost of similar equipment with a different capacity
(D) Payback period is calculated based on the payback time for the sum of the fixed and the working capital investment
Answer: (D)
Exp: Payback period is calculated based on the payback time to cover up the fixed capital investment only. So, statement (D) is false.

23. India has no elemental sulphur deposits that can be economically exploited. In India, which one of the following industries produces elemental sulphur as a by-product?
(A) Coal carbonisation plants
(B) Petroleum refineries
(C) Paper and pulp industries
(D) Iron and steel making plants
Answer: (B)
Exp: In petroleum refineries, elemental sulphur is recovered from \(H_2S\) and other gaseous streams in the Sulphur Recovery Unit (SRU).

24. Two paper pulp plants P and Q use the same quality of bamboo as a raw material. The chemicals used in their digester are as follows:
Which one of the following statements is CORRECT?
(A) Plant P and Plant Q both use the Sulfite process
(B) Plant P and Plant Q both use the Kraft process
(C) Plant P uses Sulfite process
(D) Plant P uses Kraft process

Answer: (D)

Exp: In Kraft process for manufacturing of paper, NaOH and Na₂S are used in the digester

∴ Plant P uses Kraft process.

25. Match the industrial processes in Group-1, with the catalyst materials in Group-2.

<table>
<thead>
<tr>
<th>Group-1</th>
<th>Group-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>P Ethylene polymerisation</td>
<td>I Nickel</td>
</tr>
<tr>
<td>Q Petroleum feedstock cracking</td>
<td>II Vanadium pentoxide</td>
</tr>
<tr>
<td>R Oxidation of SO₂ to SO₃</td>
<td>III Zeolite</td>
</tr>
<tr>
<td>S Hydrogenation of oil</td>
<td>IV Aluminium triethyl with titanium chloride promoter</td>
</tr>
</tbody>
</table>

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

Answer: (A)

Exp: In ethylene polymerization, aluminium triethyl with TiCl₃ promoter is used.
Cracking of petroleum feedstock requires zeolite as a catalyst material.
In the DCDA process for sulphuric acid manufacture, there is an oxidation step of SO₂ to SO₃, where V₂O₅ (Vanadium pentoxide) is the catalyst.
Hydrogenation of oil uses Nickel as catalyst

∴  P – IV, Q – III, R – II, S – I

Q.No-26-55 Carry Two Marks Each

26. A set of simultaneous linear algebraic equations is represented in a matrix form as shown below.
The value (rounded off to the nearest integer) of x₃ is
The value (rounded off to the nearest integer) of $x_3$ is ________.

Answer: (15)

Exp: Augmented matrix of the given system is

$$\begin{bmatrix} 0 & 0 & 0 & 4 & 13 & x_1 \\ 2 & 5 & 5 & 2 & 10 & x_2 \\ 0 & 0 & 2 & 5 & 3 & x_3 \\ 0 & 0 & 0 & 4 & 5 & x_4 \\ 2 & 3 & 2 & 1 & 5 & x_5 \end{bmatrix} = \begin{bmatrix} 46 \\ 161 \\ 61 \\ 30 \\ 81 \end{bmatrix}$$

$R_2 \leftrightarrow R_1$

$$\begin{bmatrix} 0 & 0 & 0 & 4 & 13 & 46 \\ 2 & 5 & 5 & 2 & 10 & 161 \\ 0 & 0 & 2 & 5 & 3 & 61 \\ 0 & 0 & 0 & 4 & 5 & 30 \\ 2 & 3 & 2 & 1 & 5 & 81 \end{bmatrix}$$

$R_2 \leftrightarrow R_3$

$$\begin{bmatrix} 0 & 0 & 0 & 4 & 13 & 46 \\ 2 & 5 & 5 & 2 & 10 & 161 \\ 0 & 0 & 2 & 5 & 3 & 61 \\ 0 & 0 & 0 & 4 & 5 & 30 \\ 2 & 3 & 2 & 1 & 5 & 81 \end{bmatrix}$$

$R_2 \leftrightarrow R_2 - R_1$, $R_3 \rightarrow R_3 - R_4$

$$\begin{bmatrix} 2 & 5 & 5 & 2 & 10 & 161 \\ 0 & -2 & -3 & -1 & -5 & -80 \\ 0 & 0 & 2 & 5 & 3 & 61 \\ 0 & 0 & 0 & 4 & 5 & 30 \\ 0 & 0 & 0 & 0 & 8 & 16 \end{bmatrix}$$

$$\begin{bmatrix} 2 & 5 & 5 & 2 & 10 & x_1 \\ 0 & -2 & -3 & -1 & -5 & x_2 \\ 0 & 0 & 2 & 5 & 3 & x_3 \\ 0 & 0 & 0 & 4 & 5 & x_4 \\ 0 & 0 & 0 & 0 & 8 & x_5 \end{bmatrix} = \begin{bmatrix} 161 \\ -80 \\ -61 \\ 30 \\ 16 \end{bmatrix}$$
By solving above equations (Backward substitutions)

\[ x_2 = 2, x_4 = 5, x_3 = 15, x_2 = 10, x_1 = 3 \]

27. What is the solution for the second order differential equation \( \frac{d^2y}{dx^2} + y = 0 \), with the initial conditions \( y|_{x=0} = 5 \) and \( \frac{dy}{dx}|_{x=0} = 10 \)?

(A) \( y = 5 + 10\sin x \)  
(B) \( y = 5\cos x - 5\sin x \)  
(C) \( y = 5\cos x + 10x \)  
(D) \( y = 5\cos x + 10\sin x \)

Answer: (D)

Exp: Given that \( \frac{d^2y}{dx^2} + y = 0 \), \( y(0) = 5 \), \( y'(0) = 10 \).

Auxiliary equation is \( m^2 + 1 = 0 \)

\( m = 0 \pm i \)

\( y_c = c_1\cos x + c_2\sin x \) (Complementary solution)

\( y_p = 0 \) (Particular solution)

General solution \( y = y_c + y_p = c_1\cos x + c_2\sin x \)

\( y(0) = 5 \Rightarrow 5 = c_1 + 0 \Rightarrow c_1 = 10 \)

\( y = -c_1\sin x + c_2\cos x \)

\( y'(0) = 10 \Rightarrow 10 = 0 + c_2 \Rightarrow c_2 = 10 \)

\( y = 5\cos x + 10\sin x \)

28. The model \( y = mx^2 \) is to be fit to the data given below.

<table>
<thead>
<tr>
<th>x</th>
<th>1</th>
<th>( \sqrt{2} )</th>
<th>( \sqrt{3} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>y</td>
<td>2</td>
<td>5</td>
<td>8</td>
</tr>
</tbody>
</table>

Using linear regression, the value (rounded off to the second decimal place) of \( m \) is _______.

Answer: (2.52-2.62)

29. The Lagrange mean-value theorem is satisfied for \( f(x) = x^3 + 5 \), in the interval (1, 4) at a value (rounded off to the second decimal place) of \( x \) equal to ________.

Answer: (2.645)

Exp: \( f(x) = x^3 + 5 \), \( x \in (1, 4) \)

\( f'(x) = 3x^2 \)

By Lagrange’s mean value theorem there exists \( C \) is (1, 4) such that
\[
f'(C) = \frac{f(4) - f(1)}{4 - 1}
\]
\[
3C^2 = \frac{69 - 6}{3}
\]
\[
3C^2 = 21
\]
\[
C^2 = 7
\]
\[
C = \pm \sqrt{7}
\]

Lagrange’s means value theorem satisfied (\(\therefore C = -\sqrt{7} \notin (1, 4)\))

30. Values of \(f(x)\) in the interval [0, 4] are given below.

<table>
<thead>
<tr>
<th>x</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>f(x)</td>
<td>3</td>
<td>10</td>
<td>21</td>
<td>36</td>
<td>55</td>
</tr>
</tbody>
</table>

Using Simpson’s 1/3 rule with a step size of 1, the numerical approximation (rounded off to the second decimal place) of \(\int_{0}^{4} f(x) \, dx\) is \(\underline{\underline{94.67}}\).

Answer: (94.67)

Exp:

<table>
<thead>
<tr>
<th>x</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>f(x)</td>
<td>3</td>
<td>10</td>
<td>21</td>
<td>36</td>
<td>55</td>
</tr>
</tbody>
</table>

Given \(h=1\)

By Simpson’s 1/3 rule

\[
\int_{0}^{4} f(x) \, dx = \frac{h}{3} [\bar{y}_0 + \bar{y}_4 + 2(\bar{y}_2) + 4(\bar{y}_1 + \bar{y}_3)]
\]

\[
= \frac{1}{3} \left[(3 + 55) + 2(21) + 4(10 + 36)\right]
\]

\[
= \frac{1}{3} [58 + 42 + 184] = 94.67
\]

31. A jacketed stirred tank with a provision for heat removal is used to mix sulphuric acid and water in a steady state flow process. \(H_2SO_4(\ell)\) enters at a rate of 4 kg/h at 25°C and \(H_2O(\ell)\) enters at a rate of 6 kg/h at 10°C. The following data are available:

Specific heat capacity of water = 4.2 kJ kg\(^{-1}\) K\(^{-1}\).

Specific heat capacity of aqueous solution of 40 mass% \(H_2SO_4 = 2.8\) kJ (kg solution)\(^{-1}\) K\(^{-1}\).

Assume the specific heat capacities to be independent of temperature.

Based on reference states of \(H_2SO_4(\ell)\) and \(H_2O(\ell)\) at 25°C, the heat of mixing for aqueous solution of 40 mass% \(H_2SO_4 = -650\) kJ (kg \(H_2SO_4\))\(^{-1}\).

If the mixed stream leaves at 40°C, what is the rate of heat removal (in kJ/h)?

(A) 1802 (B) 2558 (C) 5702 (D) 6458

Answer: (A)
32. An ideal gas is adiabatically and irreversibly compressed from 3 bar and 300 K to 6 bar in a closed system. The work required for the irreversible compression is 1.5 times the work that is required for reversible compression from the same initial temperature and pressure to the same final pressure. The molar heat capacity of the gas at constant volume is 30 J mol\(^{-1}\) K\(^{-1}\) (assumed to be independent of temperature); universal gas constant, \(R\) is 8.314 J mol\(^{-1}\)K\(^{-1}\); ratio of molar heat capacities is 1.277. The temperature (in K, rounded off to the first decimal place) of the gas at the final state in the irreversible compression case is __________.

Answer: (373)

Exp: Work done in reversible adiabatic process

\[
\text{Work done in reversible adiabatic process} = \frac{RT}{\gamma - 1} \left[ \left( \frac{P_2}{P_1} \right)^{\frac{\gamma - 1}{\gamma}} - 1 \right]
\]

Then, work done in reversible adiabatic

\[
\text{Process} = \frac{1.5RT}{\gamma - 1} \left[ \left( \frac{P_2}{P_1} \right)^{\frac{\gamma - 1}{\gamma}} - 1 \right]
\]

\[
= \frac{1.5 \times 8.314 \times 300}{(1.277 - 1)} \left[ \left( \frac{6}{3} \right)^{\frac{0.277}{3}} - 1 \right]
\]

\[
= 2191.37 \text{ J/mol}
\]

Now, \(\frac{R(T_2 - T_1)}{\gamma - 1} = 2191.37\)

\[
\Rightarrow T_2 = \frac{2191.37 \times 0.277 + 300}{8.314}
\]

\[
\Rightarrow T_2 = 373.0 \text{ K}
\]

33. A gas obeying the Clausius equation of state is isothermally compressed from 5 MPa to 15 MPa in a closed system at 400 K. The Clausius equation of state is \(P = \frac{RT}{v - b(T)}\) where \(P\) is the pressure, \(T\) is the temperature, \(v\) is the molar volume and \(R\) is the universal gas constant. The parameter \(b\) in the above equation varies with temperature as \(b(T) = b_0 + b_1T\) with \(b_0 = 4 \times 10^{-5} \text{ m}^3\text{mol}^{-1}\) and \(b_1 = 1.35 \times 10^{-7} \text{ m}^3\text{mol}^{-1}\text{K}^{-1}\). The effect of pressure on the molar enthalpy (h) at a constant temperature is given by \(\frac{\partial h}{\partial P} = v - T \left( \frac{\partial v}{\partial T} \right)_p\). Let \(h_i\) and \(h_f\) denote initial and final molar enthalpies, respectively. The change in the molar enthalpy \(h_f - h_i\) (in J mol\(^{-1}\), rounded off to the first decimal place) for this process is __________.

Answer: (400)

Exp: \(P = \frac{RT}{v - b(T)} \Rightarrow \left[ v = \frac{RT}{P} + b(T) \right] \quad -----(1)\)

Now, \(\frac{\partial h}{\partial P} = v - T \left( \frac{\partial v}{\partial T} \right)_p\)

.: Change in molar enthalpy, \(h_f - h_i\)
34. A binary system at a constant pressure with species ‘1’ and ‘2’ is described by the two-suffix Margules equation, \( \frac{g^E}{RT} = 3x_1x_2 \), where \( g^E \) is the molar excess Gibbs free energy, \( R \) is the universal gas constant, \( T \) is the temperature and \( x_1, x_2 \) are the mole fractions of species 1 and 2, respectively. At a temperature \( T \), \( \frac{g_1}{RT} = 1 \) and \( \frac{g_2}{RT} = 2 \), where \( g_1 \) and \( g_2 \) are the molar Gibbs free energies of pure species 1 and 2, respectively. At the same temperature, \( g \) represents the molar Gibbs free energy of the mixture. For a binary mixture with 40 mole % of species 1, the value (rounded off to the second decimal place) of \( \frac{g}{RT} \) is ________.

Answer: (1.63-1.67)

35. Water (density=1000 kg m\(^{-3}\)) is pumped at a rate of 36 m\(^3\)/h, from a tank 2 m below the pump, to an overhead pressurized vessel 10 m above the pump. The pressure values at the point of suction from the bottom tank and at the discharge point to the overhead vessel are 120 kPa and 240 kPa, respectively. All pipes in the system have the same diameter. Take acceleration due to gravity, \( g = 10 \text{ m s}^{-2} \). Neglecting frictional losses, what is the power (in kW) required to deliver the fluid?

(A) 1.2                      (B) 2.4                      (C) 3.6                      (D) 4.8

Answer: (B)

Exp: Given
\[ Q = 36 \text{ m}^3/\text{h} = 0.01 \text{ m}^3/\text{sec} \]
\[ P_1 = 120 \text{kPa} \]
\[ P_2 = 240 \text{ kPa} \]
\[ g = 10, \rho_{\text{water}} = 1000 \text{ kg/m}^3 \]
Frictional losses = 0, \( Z_i = 0 \)
Height if suction point (1)
\[ Z_1 = 12 \]
Bernoulli’s equation is given as
\[ \frac{P}{\rho} + gz_2 = \frac{V_i^2}{2} = \frac{P}{\rho} + gz_i + \frac{V_f^2}{2} + \eta W_p - h_i \]

\[ \therefore \quad \frac{P_2 - P_1}{s} + g(z_2 - z_1) = \eta W_p \]

Power delivered to fluid \( p_t = \dot{m} (np) \)

10^3 \times (240 - 120) + 10(12 - 0) = \eta W_p

10^3 \times 0.12 + 120 = \eta W_p = 240

\[ \therefore \quad P_t = 220 \times 0.01 = 2.4 \text{kW} \]

36 An agitated cylindrical vessel is fitted with baffles and flat blade impellers. The power number for this system is given by

\[ N_p = \frac{p}{\rho n^3 D^5} \]

where \( P \) is the power consumed for the mixing, \( \rho \) is the density of the fluid, \( n \) is the speed of the impeller and \( D \) is the diameter of the impeller. The diameter of the impeller is \( 1/3 \) of the diameter of the tank and the height of liquid level is equal to the tank diameter. The impeller speed to achieve the desired degree of mixing is 4 rpm. In a scaled up design, the linear dimensions of the equipment are to be doubled, holding the power input per unit volume constant. Assuming the liquid to be Newtonian and to be independent of Reynolds number, what is the impeller speed (in rpm) to achieve the same degree of mixing in the scaled up vessel?

(A) 0.13  (B) 1.26  (C) 2.52  (D) 3.82

Answer: (C)

Exp: Given power number = \( N_p = \frac{p}{\rho n^3 D^5} = \text{constant} \)

\[ \therefore \quad p \propto N^i D^k \]

\[ \text{Volume of tank} = \frac{\pi}{4} D^2 h \]

Given the diameter = height for the tank

\[ \therefore \quad D_v = h \]

\[ \therefore \quad \text{Volume} \propto D_v^3 \]

\[ \therefore \quad \frac{P}{V} = \frac{ND_v^i}{D_v^k} \quad (i - \text{impeller}) \]

Given that power input per unit volume is constant

\[ \therefore \quad \frac{ND_v^i}{D_v^k} = \text{constant} \]

Hence

\[ \left( \frac{ND_v^i}{D_v^k} \right)_1 = \left( \frac{ND_v^i}{D_v^k} \right)_2 \]

It is said that the dimension is to be doubled.

Hence, \( \frac{D_v}{D_v^i} = \frac{D_v}{D_v} = 2 \)
37. Consider a rigid solid sphere falling with a constant velocity in a fluid. The following data are known at the conditions of interest: viscosity of the fluid = 0.1 Pa s, acceleration due to gravity = 10 m s\(^{-2}\), density of the particle = 1180 kg m\(^{-3}\) and density of the fluid = 1000 kg m\(^{-3}\). The diameter (in mm, rounded off to the second decimal place) of the largest sphere that settles in the Stokes’ law regime (Reynolds number \(\leq 0.1\)), is_________.

Answer: (2.15)

Exp: Given viscosity = 0.1 pa. s ; \(g = 10\)
Density = 100 0 kg/m\(^3\), density of particle = 1180 kg/m\(^3\)

\[ \therefore \text{Under Stokes law; } Re_p \leq 0.1 \]

\[ Re_p = \frac{d_p u_t \rho_p}{\mu} = 0.1 = \frac{d_p \times (u_t) \times 1000}{0.1} = 0.1 \]

We have to get velocity of the particle from terminal velocity

\[ u_t = \frac{gd_p^2 (\rho_p - \rho_f)}{18\mu} \]
\[ u_t = \frac{1000d_p^2}{18 \times 0.1} \]
\[ d_p \times 1000d_p^2 \times 1000 = 0.1 \]
\[ \therefore d_p = 2.15 \text{ mm} \]

38. The characteristics curve (Head – Capacity relationship) of a centrifugal pump is represented by the equation \(\Delta H_{\text{pump}} = 43.8 - 0.19Q\), where \(\Delta H_{\text{pump}}\) is the head developed by the pump (in m) and \(Q\) is the flow rate (in m\(^3\)/h) through the pump. This pump is to be used for pumping water through a horizontal pipeline. The frictional head loss \(\Delta H_{\text{piping}}\) (in m) is related to the water flow rate \(Q_L\) (in m\(^3\)/h) by the equation \(\Delta H_{\text{piping}} = 0.0135Q_L^2 + 0.045Q_L\). The flow rate (in m\(^3\)/h, rounded off to the first decimal place) of water pumped through the above pipeline, is __________.

Answer: (48.5-49.5)

39. Water flows through a smooth circular pipe under turbulent conditions. In the viscous sub-layer, the velocity varies linearly with the distance from the wall. The Fanning friction factor is defined as,

\[ f = \frac{\tau_w}{\rho \bar{u}^2 / 2} \]

where \(\tau_w\) is the shear stress at the wall of the pipe, \(\rho\) is the density of the fluid and \(\bar{u}\) is the average velocity of 1ms\(^{-1}\) through the pipe. For this flow condition, the friction factor \(f\) is 0.005. At a distance of 0.05 mm from the wall of the pipe (in the viscous sub-layer), the velocity (in ms\(^{-1}\), rounded off to the third decimal place), is __________.

Answer: (0.12)
Exp: It is given as turbulent flow – viscous sublayer and also given that velocity is directly proportional to distance

We have a relation \( u^+ = y^+ \)

Where \( u^+ = \frac{u}{v}, y^+ = \frac{\nu y}{\mu}, u^* = \sqrt{\frac{f}{2}} \)

Hence \( u = \frac{\nu y}{\mu} \left( \frac{f}{2} \right) = 5 \times 10^{-2} \times 10^{-3} \times 10^{4} \times 10^2 \)

\[ \therefore u = 0.125 \text{ m/s} \]

Hence we can written as 0.12 (or) 0.13

40. In a 1-1 pass shell and tube exchanger, steam in condensing in the shell side at a temperature \( T_s \) of 135°C and the cold fluid is heated from a temperature \( T_1 \) of 20°C to a temperature \( T_2 \) of 90°C.

The energy balance equation for this heat exchanger is

\[ \ln \left( \frac{T_3 - T_1}{T_s - T_2} \right) = \frac{UA}{mc_p} \]

Where \( U \) is the overall heat transfer coefficient, \( A \) is the heat transfer area, \( m \) is the mass flow rate of the cold fluid and \( c_p \) is its specific heat. Tube side fluid is in a turbulent flow and the heat transfer coefficient can be estimated from the following equation:

\[ Nu = 0.023 (Re)^{0.8} (Pr)^{1/3} \]

where \( Nu \) is the Nusselt number, \( Re \) is the Reynolds number and \( Pr \) is the Prandtl number. The condensing heat transfer coefficient in the shell side is significantly higher than the tube side heat transfer coefficient. The resistance of the wall to heat transfer is negligible. If only the mass flow rate of the cold fluid is doubled, what is the outlet temperature (in °C) of the cold fluid at steady state?

(A) 80.2  (B) 84.2  (C) 87.4  (D) 88.6

Answer: (B)

41. In an experimental setup, mineral oil is filled in between the narrow gap of two horizontal smooth plates. The setup has arrangements to maintain the plates at desired uniform temperatures. At these temperatures, ONLY the radiative heat flux is negligible. The thermal conductivity of the oil does not vary perceptibly in this temperature range. Consider four experiments at steady state under different experimental conditions, as shown in the figure below. The figure shows plate temperatures and the heat fluxes in the vertical direction.
42. What is the steady state heat flux (in W m\(^{-2}\)) with the top plate at 70°C and the bottom plate at 40°C?
   (A) 26   (B) 39   (C) 42   (D) 63
   Answer: (A)

42. The space between two hollow concentric spheres of radii 0.1 m and 0.2 m is under vacuum. Exchange of radiation (uniform in all directions) occurs only between the outer surface (S\(_1\)) of the smaller sphere and the inner surface (S\(_2\)) of the larger sphere. The fraction (rounded off to the second decimal place) of the radiation energy leaving S\(_2\), which reaches S\(_1\), is ___________.
   Answer: (0.245 - 0.255)

43. A binary distillation column is to be designed using McCabe Thiele method. The distillate contains 90 mol% of the more volatile component. The point of intersection of the q-line with the equilibrium curve is (0.5, 0.7). The minimum reflux ratio (rounded off to the first decimal place) for this operation is __________.
   Answer: (1)

Exp: It is evident from above figure that the operating line for the enriching section, corresponding to the minimum reflux ratio, passes through the point of intersection the equilibrium curve and q-line.

\[ \text{R}_{\text{m}} \rightarrow \text{minimum reflux ratio} \]

Now, \( y = \left( \frac{\text{R}_{\text{m}}}{\text{R}_{\text{m}}+1} \right) x + \left( \frac{\text{X}_{\text{D}}}{\text{R}_{\text{m}}+1} \right) \) \( \ldots (1) \)

(0.5, 0.7) is a point on this line.

Also, \( \text{X}_{\text{D}} = 0.9 \)

Now, from (i),

\[ y(\text{R}_{\text{m}} +1) = \text{R}_{\text{m}} x + \text{X}_{\text{D}} \]

\[ \Rightarrow (y - x) \text{R}_{\text{m}} = \text{X}_{\text{D}} - y \]

\[ \Rightarrow \text{R}_{\text{m}} = \frac{\text{X}_{\text{D}} - y}{y - x} \]

\[ \therefore \text{Minimum reflux ratio, } \text{R}_{\text{m}} = \frac{0.9 - 0.7}{0.7 - 0.5} = 1.0 \]

44. Solute C is extracted in a batch process from its homogenous solution of A and C, using solvent B. The combined composition of the feed and the extracting solvent is shown in the figure below as point M, along with the tie line passing through it. The ends of the tie line are on the equilibrium curve.
What is the selectivity for C?

(A) 3.5  (B) 7  (C) 10.5  (D) 21

Answer: (C)

Exp: Selectivity in liquid-liquid extraction is analogous to relative volatility in distillation. By definition, selectivity for C

\[
\frac{\text{weight fraction of } C \text{ in } E}{\text{weight fraction of } C \text{ in } R} \times \frac{\text{weight fraction of } A \text{ in } E}{\text{weight fraction of } A \text{ in } R}
\]

\[
= \frac{0.3}{0.2} \times \frac{0.1}{0.7}
\]

\[
= \frac{0.3}{0.2} \times \frac{0.1}{0.7}
\]

\[
= 10.5
\]

45. At 30°C, the amounts of acetone adsorbed at partial pressures of 10 and 100 mmHg are 0.1 and 0.4 kg acetone/kg activated carbon, respectively. Assume Langmuir isotherm describes the adsorption of acetone on activated carbon. What is the amount of acetone adsorbed (in kg per kg of activated carbon) at a partial pressure of 50 mmHg and 30°C?

(A) 0.23  (B) 0.25  (C) 0.30  (D) 0.35

Answer: (C)

Exp: Langmuir Isotherm: 

\[
\frac{x}{m} = \frac{ap}{1 + bp}
\]

According to question,

\[
0.1 = \frac{10a}{1 + 10b} \quad \text{... (i)}
\]

\[
0.4 = \frac{100a}{1 + 100b} \quad \text{... (ii)}
\]

From (i), 10a – b = 0.1

From (ii), 10 – 4b = 0.04

On solving, a = 0.012, b = 0.02

Then, at P = 50,
46. Consider the following two cases for a binary mixture of ideal gases A and B under steady state conditions. In Case 1, the diffusion of A occurs through non-diffusing B. In Case 2, equimolal counter diffusion of A and B occurs. In both the cases, the total pressure is 100 kPa and the partial pressures of A at two points separated by a distance of 10 mm are 10 kPa and 5 kPa. Assume that the Fick’s first law of diffusion is applicable. What is the ratio of molar flux of A in Case 1 to that in Case 2?

(A) 0.58  (B) 1.08  (C) 1.58  (D) 2.18

Answer: (B)

Exp:

Case 1: Diffusion of A through non-diffusing B

\[ N_{A1} = \frac{D_{AB}P_1}{RT} \ln \left[ \frac{P_1 - P_{A2}}{P_1 - P_{A1}} \right] \]

Case 2: Equimolar counter-diffusion of A & B

\[ N_{A2} = \frac{D_{AB}}{RT} (P_{A1} - P_{A2}) \]

\[ \frac{N_{A1}}{N_{A2}} = \frac{P_1/n_1 \ln \left[ \frac{P_1 - P_{A2}}{P_1 - P_{A1}} \right]}{P_{A1}/n_1 \frac{100/10}{100/5}} = 1.0813 \]

47. The liquid phase reversible reaction \( A \rightleftharpoons B \) is carried out in an isothermal CSTR operating under steady state conditions. The inlet stream does not contain B and the concentration of A in the inlet stream is 10 mol/lit. The concentrations of A at the reactor exit, for residence times of 1 s and 5 s are 8 mol/lit and 5 mol/lit, respectively. Assume the forward and backward reactions are elementary following the first order rate law. Also assume that the system has constant molar density. The rate constant of the forward reaction (in \( s^{-1} \), rounded off to the third decimal place) is __________.

Answer: (0.267)

Exp:

\[ A \xrightarrow{k_1} B \quad C_{B0} = 0 \]
\[ C_{A0} = 10 \text{ mol/ct} \]

\[ \text{Now, } \left(-r_A\right) = k_1C_A - k_2C_B \quad \ldots \ (i) \]
Now, for CSTR, \[ \frac{\tau}{C_A} = \frac{X_A}{-r_A} \] \( \ldots \) (ii)

Now, \( C_{AO} + C_{BO} = C_A + C_B \)
\[ C_B = C_{AO} - C_A \]

\[ \therefore \text{ From (i), } -r_A = k_1 C_A - k_2 (C_{AO} - C_A) \]

And, \[ X = 1 - \frac{C_A}{C_{AO}} \]

\[ \therefore \text{ From (ii)} \]

\[ \frac{\tau}{C_{AO}} = \frac{1 - \frac{C_A}{C_{AO}}}{k_1 C_A - k_2 (C_{AO} - C_A)} \]
\[ \Rightarrow k_1 C_A - k_2 (C_{AO} - C_A) = \frac{C_{AO}}{\tau} \left( 1 - \frac{C_A}{C_{AO}} \right) \]
\[ \Rightarrow k_1 C_A - k_2 (C_{AO} - C_A) = \frac{C_{AO} - C_A}{\tau} \]

Case 1: \( \tau = 1 \text{ s}, C_A = 8 \text{ mol/L} \)
\[ \therefore 8k_1 - 2k_2 = 2 \] \( \ldots \) (iv)

Case 2: \( \tau = 5 \text{ s}, C_A = 5 \text{ mol/L} \)
\[ \therefore 5k_1 - 2k_2 = 1 \]

On solving (iv) and (v), \( k_1 = 0.267 \text{s}^{-1} \)

48. A liquid phase irreversible reaction \( A \rightarrow B \) is carried out in an adiabatic CSTR operating under steady state conditions. The reaction is elementary and follows the first order rate law. For this reaction, the figure below shows the conversion \( X_A \) of \( A \) as a function of temperature \( T \) for different values of the rate of reaction \( -\gamma_A \text{[moldm}^{-3}\text{s}^{-1}] \) denoted by the numbers to the left of each curve. This figure can be used to determine the rate of the reaction at a particular temperature, for a given conversion of \( A \).
The inlet stream does not contain B and the concentration of A in the inlet stream is \(5\text{mol/m}^3\). The molar feed rate of A is \(100\text{mol/s}\). A steady state energy balance for this CSTR results in the following relation: \(T = 350 + 25X_A\), where \(T\) is the temperature (in K) of the exit stream and \(X_A\) is the conversion of A in the CSTR. For an exit conversion of 80% of A, the volume (in m\(^3\), rounded off to the first decimal place) of CSTR required is______

Answer: (8)

Exp:

\[C_{AO} = 5 \text{ mol/m}^3\]

Flow rate \(F_{AO} = 100 \text{ mol/sec}\)

Given temperature profile \(T=350 + 25X_A\)

We have asked for \(X_A=0.8\)

From given curve at \(X_A=0.8\), the corresponding values are \(T=370^0\text{K}, -r_A = 10 \text{ mol/m}^2\text{s}\)

From MFR, we have

\[
V = \frac{X_A}{F_{AO} \cdot -r_A}
\]

\[
V = \frac{F_{AO} \times X_A}{-r_A} = \frac{100 \times 0.8}{10} = 8 \text{m}^3
\]

49. A porous pellet with Pt dispersed in it is used to carry out a catalytic reaction. Following two scenarios are possible.

Scenario 1: Pt present throughout the pores of the pellet is used for catalyzing the reaction.

Scenario 2: Pt present only in the immediate vicinity of the external surface of the pellet is used for catalyzing the reaction.

At a large value of Thiele modulus, which one of the following statements is TRUE?

(A) Since the reaction rate is much greater than the diffusion rate, Scenario 1 occurs

(B) Since the reaction rate is much greater than the diffusion rate, Scenario 2 occurs

(C) Since the reaction rate is much lower than the diffusion rate, Scenario 1 occurs

(D) Since the reaction rate is much lower than the diffusion rate, Scenario 2 occurs
Answer: (B)

Exp: \[ \text{Thick modulus} = \frac{\text{reaction rate}}{\text{diffusion rate}} \]

So, high thick modulus means reaction rate is much greater than diffusion rate.

Now, since diffusion rate is slow, it would be difficult for reactants to diffuse into the pores of the pellet. It would be beneficial if \( p_i \) is present only in the immediate vicinity of the external surface of the pellet.

50. A CSTR has a long inlet pipe. A tracer is injected at the entrance of the pipe. The E-curve obtained at the exit of the CSTR is shown in the figure below.

Assuming plug flow in the inlet pipe, the ratio (rounded off to the second decimal place) of the volume of the pipe to that of the CSTR is_________.

Answer: (0.23-0.27)

51. A liquid flows through an “equal percentage” valve at a rate of 2\( \text{m}^3/\text{h} \) when the valve is 10% open. When the valve opens to 20% the flow rate increases to 3\( \text{m}^3/\text{h} \). Assume that the pressure drop across the valve and the density of the liquid remain constant. When the valve opens to 50%, the flow rate (in \( \text{m}^3/\text{h} \), rounded off to the second decimal place) is_________.

Answer: (10.3)

Exp: For equal percentage valve \( f = f_0 e^{bx} \)

Given, \( f = 2 \) at \( x = 0.1 \)

\[ f = 3 \text{ at } x = 0.2 \]

\( x \) = % of opening

\( f \) = flow rate
Now at \( x = 0.5 \), what is \( f = 10.3 \text{ m}^3/\text{h} \).

52. A PI controller with integral time constant of 0.1 min is to be designed to control a process with transfer function:

\[
G_p(s) = \frac{10}{s^2 + 2s + 100}
\]

Assume the transfer functions of the measuring element and the final control element are both unity (\( G_m = 1, G_f = 1 \)). The gain (rounded off to the first decimal place) of the controller that will constitute the critical condition for stability of the PI feedback control system is ________

Answer: (2.5)

Exp: We can write the characteristic equations as

\[
1 + G(S) \text{ of open loop} = 0
\]

\[
1 + K_c \left(1 + \frac{1}{0.15}\right) \frac{10}{s^2 + 2s + 100} = 0
\]

For critical stability condition, solve by Routh test

We get \( K_c = 2.5 \)

53. For a unit step input, the response of a second order system is

\[
y(t) = K_p \left[1 - \frac{1}{\sqrt{1 - \zeta^2}} e^\left(-\frac{\zeta}{\tau}t\right) \sin \left(\frac{\sqrt{1 - \zeta^2}}{\tau}t + \phi\right)\right]
\]

where, \( K_p \) is the steady state gain, \( \zeta \) is the damping coefficient, \( \tau \) is the natural period of oscillation and \( \phi \) is the phase lag. The overshoot of the system is \( \exp \left(-\frac{\pi \zeta}{\sqrt{1 - \zeta^2}}\right) \). For a unit step input, the response of the system from an initial steady state condition at \( t = 0 \) is shown in the figure below.
What is the natural period of oscillation (in minutes) of the system?

(A) 15.9  (B) 50  (C) 63.2  (D) 100

Answer: (A)

Exp: From graph, overshoot = \( \frac{80}{100} = \exp\left(\frac{-\pi \varepsilon}{\sqrt{1 - \varepsilon^2}}\right) \)

We can find \( \varepsilon \) from above equation

\[ T - \text{valve can be determined as the period between two peaks as 100} \]

\[ \therefore T_d = \frac{2\pi T}{\sqrt{1 - \varepsilon^2}} \]

\[ \therefore T_d = 15.9 \text{ min.} \]

54. A vertical cylindrical tank with a flat roof and bottom is to be constructed for storing 150m\(^3\) of ethylene glycol. The cost of material and fabrication for the tank wall is Rs 6000 per m\(^2\) and the same for the roof and the tank bottom are Rs 2000 and Rs 4000 per m\(^2\), respectively. The cost of accessories, piping and instruments can be taken as 10% of the cost of the wall. 10% of the volume of the tank needs to be kept free as vapour space above the liquid storage. What is the optimum diameter (in m) for the tank?

(A) 3.5  (B) 3.9  (C) 7.5  (D) 7.8

Answer: (D)

Exp: 10% of tank volume to be kept free as vapour space

\[ \therefore 90\% \text{ of tank volume to be used for liquid storage} \]

\[ h \rightarrow \text{height of tank} \]

\[ r \rightarrow \text{radius of tank} \]

\[ \therefore 90\% \text{ of } \pi r^2 h = 150 \]

\[ \Rightarrow \pi r^2 h = \frac{150}{0.9} \Rightarrow h = \frac{500}{3\pi r^2} \]

Now, total cost = \( 1.1 \times 6000 \times 2\pi rh + \pi r^2 \times 2000 + \pi r^2 \times 4000 \)

\[ = 13200\pi rh + 6000\pi r^2 \]

\[ = 13200\pi r \left( \frac{500}{3\pi r^2} \right) + 6000\pi r^2 \]

\[ = \frac{2200000}{r} + 6000\pi r^2 \]

So, we need to minimize
\[ f(r) = \frac{2200000}{r} + 6000\pi r^2 \]
\[ f'(r) = 0 \]
\[ \Rightarrow \frac{-2200000}{r^2} + 12000\pi = 0 \]
\[ \Rightarrow r = \sqrt{\frac{2200000}{12000\pi}} = 3.8788 \text{m} \]

Then, tank diameter = \(2r = 7.758 \approx 7.8\text{m}\)

55. A catalytic reforming plant produces hydrogen and benzene from cyclohexane by dehydro aromatisation. In order to increase the production of hydrogen, the owner plans to change the process to steam reforming of the same feedstock that produces hydrogen and carbon dioxide. Stoichiometrically, what is the maximum ratio of pure hydrogen produced in the proposed process to that in the existing process?

(A) 1  (B) 2  (C) 5  (D) 6

Answer: (D)

Exp: De-hydro aromatisation of cyclohexane to produce hydrogen and benzene
\[ \text{C}_6\text{H}_12 \rightarrow \text{C}_6\text{H}_6 + 3\text{H}_2 \]

Steam reforming of cyclohexane to form \(\text{CO}_2\) and \(\text{H}_2\)
\[ \text{C}_6\text{H}_12 \rightarrow 12\text{H}_2\text{O} \rightarrow 6\text{CO}_2 + 18\text{H}_2 \]

So, according to stoichiometry, ratio of hydrogen in proposed process to that in existing process
\[ = \frac{18}{3} = 6 \]