

**26** *Years*  
Previous Solved Papers

# GATE 2026

## Chemical Engineering

- ✓ Fully solved with explanations
- ✓ Analysis of previous papers
- ✓ Topicwise presentation





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**GATE - 2026**

**Chemical Engineering**

Topicwise Previous GATE Solved Papers (2000-2025)

*Edition*

1 <sup>st</sup> Edition	: 2021
2 <sup>nd</sup> Edition	: 2022
3 <sup>rd</sup> Edition	: 2023
4 <sup>th</sup> Edition	: 2024
<b>5<sup>th</sup> Edition</b>	<b>: 2025</b>

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# Preface

Over the period of time the GATE examination has become more challenging due to increasing number of candidates. Though every candidate has ability to succeed but competitive environment, in-depth knowledge, quality guidance and good source of study is required to achieve high level goals.



**B. Singh** (Ex. IES)

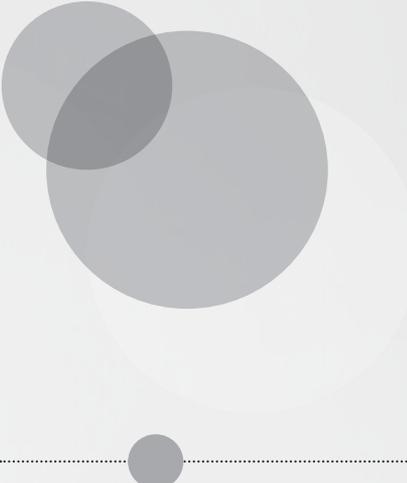
The first edition of **GATE 2026 Solved Papers : Chemical Engineering** has been divided into topicwise sections. At the beginning of each subject, analysis of previous papers are given to improve the understanding of subject.

I have true desire to serve student community by way of providing good source of study and quality guidance. I hope this book will be proved an important tool to succeed in GATE examination. Any suggestions from the readers for the improvement of this book are most welcome.

**B. Singh (Ex. IES)**

Chairman and Managing Director

MADE EASY Group



# GATE-2026

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## Chemical Engineering

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# Process Calculations

UNIT

# I

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# Process Calculations

## *Syllabus*

Steady and unsteady state mass and energy balances including multiphase, multi-component, reacting and non-reacting systems. Use of tie components; recycle, bypass and purge calculations; Gibb's phase rule and degree of freedom analysis.

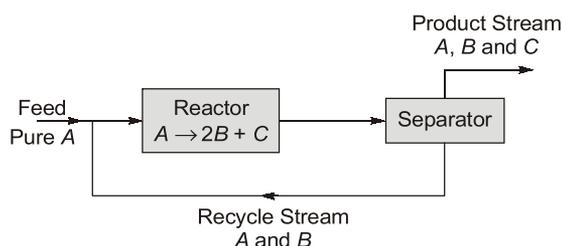
### Analysis of Previous GATE Papers

Exam Year	1 Mark Ques.	2 Marks Ques.	5 Marks Ques.	Total Marks
2000	1	–	–	1
2001	1	1	–	3
2002	1	3	–	7
2003	–	4	–	8
2004	–	4	–	8
2005	–	2	–	4
2006	–	2	–	4
2007	–	4	–	8
2008	–	7	–	14
2009	1	1	–	3
2010	–	2	–	4
2011	–	2	–	4
2012	–	2	–	4
2013	–	3	–	6
2014	–	3	–	6
2015	–	1	–	2
2016	1	1	–	3
2017	–	2	–	4
2018	2	–	–	2
2019	–	–	–	–
2020	–	2	–	4
2021	1	1	–	3
2022	–	1	–	2
2023	1	1	–	3
2024	2	2	–	6
2025	2	–	–	2

# 2

## Material Balance Calculations

- 2.1** The reaction  $A \rightarrow 2B + C$  takes place in a catalytic reactor (see diagram below). The reactor effluent is sent to a separator. The overall conversion of  $A$  is 95%. The product stream from the separator consists of  $B$ ,  $C$  and 0.5% of  $A$  entering the separator, while the recycle stream consists of the remainder of the unreacted  $A$  and 1% of  $B$  entering the separator. Calculate the
- single pass conversion of  $A$  in the reactor.
  - molar ratio of recycle to feed.



[2000 : 5 M]

- 2.2** A butane isomerization process produces 70 kmol/h of pure isobutane. A purge stream, removed continuously, contains 85%  $n$ -butane and 15% impurity (mole %). The feed stream is  $n$ -butane containing 1% impurity (mole %). The flow rate of the purge stream will be:
- 3 kmol/h
  - 4 kmol/h
  - 5 kmol/h
  - 6 kmol/h

[2001 : 2 M]

- 2.3** Fresh orange juice contains 12% (by weight) solids and the rest water. 90% of the fresh juice is sent to an evaporator to remove water and subsequently mixed with the remaining 10% of fresh juice. The resultant product contains 40% solids. The kg of water removed from 1 kg fresh juice is
- 0.4
  - 0.5
  - 0.6
  - 0.7

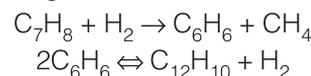
[2002 : 2 M]

- 2.4** 1 kg of a saturated aqueous solution of a highly soluble component  $A$  at  $60^\circ\text{C}$  is cooled to  $25^\circ\text{C}$ . The solubility limits of  $A$  are (0.6 kg  $A$ )/(kg water) at  $60^\circ\text{C}$  and (0.2 kg  $A$ )/(kg water) at  $25^\circ\text{C}$ . The amount, in kgs, of the crystals formed is

- 0.4
- 0.25
- 0.2
- 0.175

[2002 : 2 M]

- 2.5** In the hydrodealkylation of toluene to benzene, the following reactions occur



Toluene and hydrogen are fed to a reactor in a molar ratio 1 : 5. 80% of the toluene gets converted and the selectivity of benzene (defined as moles of benzene formed per moles of toluene converted) is 90%. The fractional conversion of hydrogen is

- 0.16
- 0.144
- 0.152
- 0.136

[2002 : 2 M]

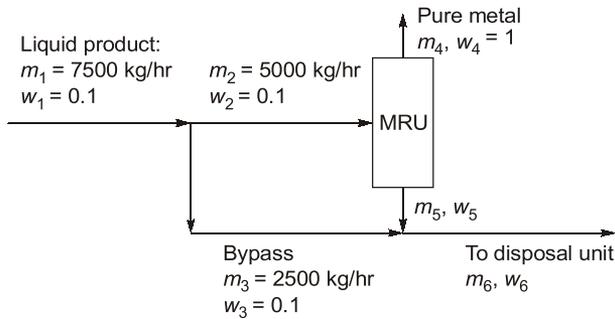
- 2.6**  $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$  crystals are formed by cooling 100 kg of 30% by weight aqueous solution of  $\text{Na}_2\text{SO}_4$ . The final concentration of the solute in the solution is 10%. The weight of crystals is
- 20
  - 32.2
  - 45.35
  - 58.65

[2003 : 2 M]

- 2.7** 80 kg of  $\text{Na}_2\text{SO}_4$  (molecular weight = 142) is present in 330 kg of an aqueous solution. The solution is cooled such that 80 kg of  $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$  crystals separate out. The weight fraction of  $\text{Na}_2\text{SO}_4$  in the remaining solution is
- 0.00
  - 0.18
  - 0.24
  - 1.00

[2004 : 2 M]

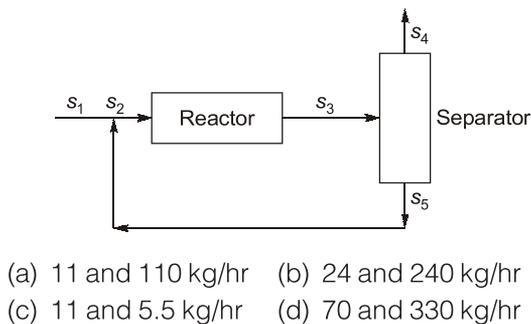
- 2.8** A metal recovery unit (MRU) of intake capacity 5000 kg/hr treats a liquid product from a plant and recovers 90% of the metal in the pure form. The unrecovered metal and associated liquid are sent to a disposal unit along with the untreated product from the plant (see figure below). Find the flow rate ( $m_6$ ) and the weight fraction of the metal ( $w_6$ ). The liquid product flow rate is 7500 kg/hr of composition 0.1 (wt. fraction). Assume steady state.



- (a)  $m_6 = 7500 \text{ kg/hr}$ ,  $w_6 = 0.0$   
 (b)  $m_6 = 7050 \text{ kg/hr}$ ,  $w_6 = 0.04255$   
 (c)  $m_6 = 4500 \text{ kg/hr}$ ,  $w_6 = 0.1712$   
 (d)  $m_6 = 5600 \text{ kg/hr}$ ,  $w_6 = 0.0314$

[2005 : 2 M]

- 2.9** A feed stream ( $S_1$ ) at 100 kg/hr and containing only A mixes with recycle stream  $S_5$  before entering the reactor (see figure below), where the reaction  $A \rightarrow B$  takes place. The operation is at steady state. The stream  $S_3$  leaving the reactor is separated, without either phase or composition change, into two streams  $S_4$  and  $S_5$ . If the mass fraction of B in  $S_4$  is 0.95 and total flow rate of  $S_5$  is 10 kg/hr, then the ratio of flow rates of streams ( $S_3/S_5$ ), and the flow rate of A in  $S_3$  are, respectively,

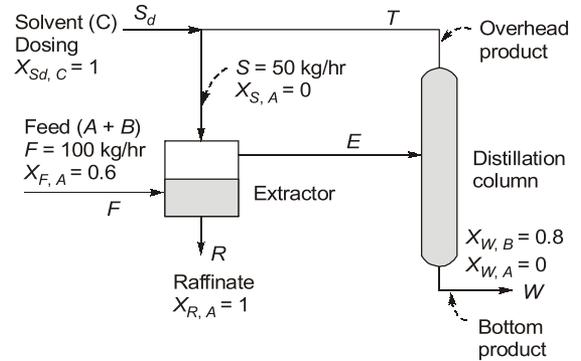


- (a) 11 and 110 kg/hr (b) 24 and 240 kg/hr  
 (c) 11 and 5.5 kg/hr (d) 70 and 330 kg/hr

[2005 : 2 M]

**Statement for Linked Answer Question (2.10 & 2.11)**

Solvent C is used to extract solute B selectively from 100 kg/hr feed mixture A + B in a steady state continuous process shown below. The solubility of C in the raffinate and the solubility of A in the extract are negligible. The extract is distilled to recover B in the bottom product. The overhead product is recycled to the extractor. The loss of solvent in the bottoms is compensated by make up solvent  $S_d$ . The total flow rate of the solvent stream S going to the extractor is 50 kg/hr. The mass fractions ( $X_i$ 's) of some selected streams are indicated in the figure below.



- 2.10** Distillation bottoms flow rate  $W$  and solvent dosing rate  $S_d$  in kg/hr are

- (a)  $W = 50$ ,  $S_d = 50$  (b)  $W = 100$ ,  $S_d = 20$   
 (c)  $W = 10$ ,  $S_d = 50$  (d)  $W = 50$ ,  $S_d = 10$

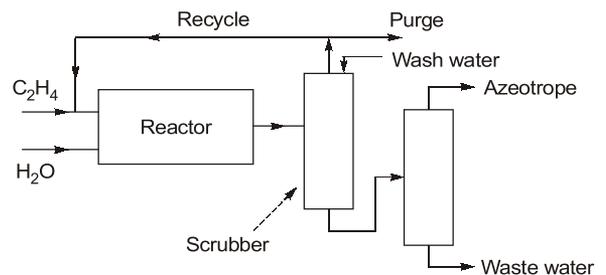
[2006 : 2 M]

- 2.11** Feed rate  $E$  to the distillation column and overhead product rate  $T$  in kg/hr are

- (a)  $E = 90$ ,  $T = 40$  (b)  $E = 80$ ,  $T = 40$   
 (c)  $E = 90$ ,  $T = 50$  (d)  $E = 45$ ,  $T = 20$

[2006 : 2 M]

- 2.12** A simplified flow sheet is shown in the figure for production of ethanol from ethylene. The conversion of ethylene in the reactor is 30% and the scrubber following the reactor completely separates ethylene (as top stream) and ethanol and water as bottoms. The last (distillation) column gives an ethanol-water azeotrope (90 mol% ethanol) as the final product and water as waste. The recycle to purge ratio is 34.



The reaction is:  $C_2H_4(g) + H_2O(g) \rightarrow C_2H_5OH(g)$   
 For an azeotrope product rate of 500 mols/hr, the recycle gas flowrate in mols/hr is

- (a) 30 (b) 420  
 (c) 1020 (d) 1500 [2007 : 2 M]

- 2.13** For the same process, if fresh  $H_2O$  feed to the reactor is 600 mol/hr and wash water for scrubbing is 20% of the condensables coming out of the reactor, the water flowrate in mols/hr from the distillation column as bottom is

- (a) 170 (b) 220  
(c) 270 (d) 480

[2007 : 2 M]

**2.14** A 35%  $\text{Na}_2\text{SO}_4$  solution in water, initially at  $50^\circ\text{C}$ , is fed to a crystallizer at  $20^\circ\text{C}$ . The product stream contains hydrated crystals  $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$  in equilibrium with a 20 wt%  $\text{Na}_2\text{SO}_4$  solution. The molecular weights of  $\text{Na}_2\text{SO}_4$  and  $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$  are 142 and 322, respectively. The feed rate of the 35% solution required to produce 500 kg/hr of hydrated crystals is

- (a) 403 kg/hr (b) 603 kg/hr  
(c) 803 kg/hr (d) 1103 kg/hr

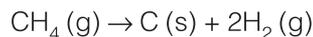
[2008 : 2 M]

**2.15** 600 kg/hr of saturated steam at 1 bar (enthalpy 2675.4 kJ/kg) is mixed adiabatically with superheated steam at  $450^\circ\text{C}$  and 1 bar (enthalpy 3382.4 kJ/kg). The product is superheated steam at  $350^\circ\text{C}$  and 1 bar (enthalpy 3175.6 kJ/kg). The flow rate of the product is

- (a) 711 kg/hr (b) 1111 kg/hr  
(c) 1451 kg/hr (d) 2051 kg/hr

[2008 : 2 M]

**2.16** Carbon black is produced by decomposition of methane:



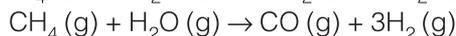
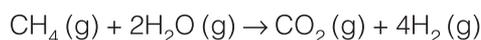
The single pass conversion of methane is 60%. If fresh feed is pure methane and 25% of the methane exiting the reactor is recycled, then the molar ratio of fresh feed stream to recycle stream is

- (a) 0.9 (b) 9  
(c) 10 (d) 90

[2008 : 2 M]

**Common Data for Questions (2.17 to 2.18):**

Methane and steam are fed to a reactor in molar ratio 1 : 2. The following reactions take place,



where  $\text{CO}_2$  is the desired product,  $\text{CO}$  is the undesired product and  $\text{H}_2$  is a byproduct. The exit stream has the following composition:

Species	$\text{CH}_4$	$\text{H}_2\text{O}$	$\text{CO}_2$	$\text{H}_2$	$\text{CO}$
Mole %	4.35	10.88	15.21	67.39	2.17

**2.17** The selectivity for desired product relative to undesired product is

- (a) 2.3 (b) 3.5  
(c) 7 (d) 8

[2008 : 2 M]

**2.18** The fractional yield of  $\text{CO}_2$  is \_\_\_\_ (where fractional yield is defined as the ratio of moles of the desired product formed to the moles that would have been formed if there were no side reactions and the limiting reactant had reacted completely)

- (a) 0.7 (b) 0.88  
(c) 1 (d) 3.5

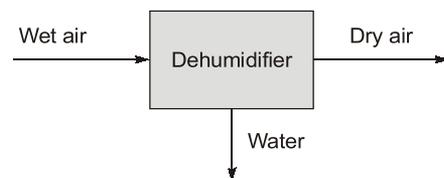
[2008 : 2 M]

**2.19** The fractional conversion of methane is

- (a) 0.4 (b) 0.5  
(c) 0.7 (d) 0.8

[2008 : 2 M]

**2.20** A dehumidifier (shown below) is used to completely remove water vapor from air.

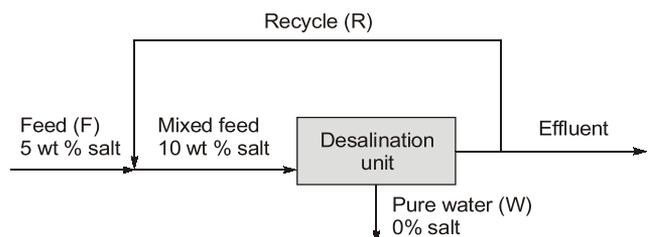


Which one of the following statements is true?

- (a) Water is the only tie component.  
(b) Air is the only tie component.  
(c) Both water and air are tie components.  
(d) There are no tie components.

[2009 : 1 M]

**2.21** Pure water (stream W) is to be obtained from a feed containing 5 wt % salt using a desalination unit as shown below.

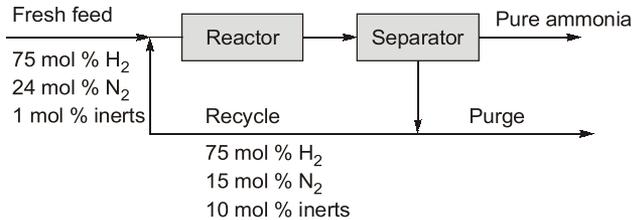


If the overall recovery of pure water (through stream W) is 0.75 kg/kg feed, then the recycle ratio (R/F) is

- (a) 0.25 (b) 0.5  
(c) 0.75 (d) 1.0

[2009 : 2 M]

- 2.22** Ammonia is synthesized at 200 bar and 773 K by the reaction  $N_2 + 3H_2 \rightleftharpoons 2NH_3$ . The yield of ammonia is 0.45 mol/mol of fresh feed. Flow sheet for the process (along with available compositions) is shown below.

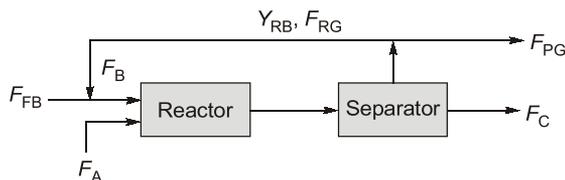


The single pass conversion for  $H_2$  in the reactor is 20%. The amount of  $H_2$  lost in the purge as a percentage of  $H_2$  in fresh feed is

- (a) 10 (b) 20  
(c) 45 (d) 55 [2011 : 2 M]

**Common Data for Questions 2.23 and 2.24:**

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



**Notation:**

Molar flow rate of fresh B is  $F_B$

Molar flow rate of A is  $F_A$

Molar flow rate of recycle gas is  $F_{RG}$

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

Molar flow rate of purge gas is  $F_{PG}$

Molar flow rate of C is  $F_C$

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

- 2.23** If  $Y_{RB} = 0.3$ , the ratio of recycle gas to purge gas ( $F_{RG}/F_{PG}$ ) is
- (a) 2 (b) 5  
(c) 7 (d) 10 [2012 : 2 M]

- 2.24** If the ratio of recycle gas to purge gas ( $F_{RG}/F_{PG}$ ) is 4 then  $Y_{RB}$  is

- (a)  $\frac{3}{8}$  (b)  $\frac{2}{5}$   
(c)  $\frac{1}{2}$  (d)  $\frac{3}{4}$

[2012 : 2 M]

**Common Data for Questions 2.25 and 2.26:**

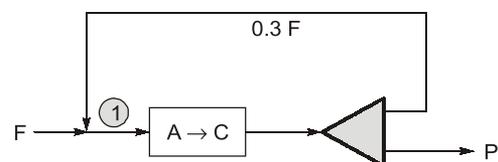
A reverse osmosis unit treats feed water (F) containing fluoride and its output consists of a permeate stream (P) and a reject stream (R). Let  $C_F$ ,  $C_P$ , and  $C_R$  denote the fluoride concentrations in the feed, permeate, and reject streams, respectively. Under steady state conditions, the volumetric flow rate of the reject is 60 % of the volumetric flow rate of the inlet stream, and  $C_F = 2$  mg/L and  $C_P = 0.1$  mg/L.

- 2.25** The value of  $C_R$  in mg/L, up to one digit after the decimal point, is \_\_\_\_\_. [2013 : 2 M]

- 2.26** A fraction  $f$  of the feed is bypassed and mixed with the permeate to obtain treated water having a fluoride concentration of 1 mg/L. Here also the flow rate of the reject stream is 60% of the flow rate entering the reverse osmosis unit (after the bypass). The value of  $f$ , up to 2 digits after the decimal point, is \_\_\_\_\_. [2013 : 2 M]

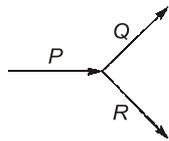
- 2.27** Two elemental gases (A and B) are reacting to form a liquid (C) in a steady state process as per the reaction  $A + B \rightarrow C$ . The single-pass conversion of the reaction is only 20% and hence recycle is used. The product is separated completely in pure form. The fresh feed has 49 mol% of A and B each along with 2 mol% impurities. The maximum allowable impurities in the recycle stream is 20 mol%. The amount of purge stream (in moles) per 100 moles of the fresh feed is \_\_\_\_\_. [2014 : 2 M]

- 2.28** The schematic diagram of a steady state process is shown below. The fresh feed (F) to the reactor consists of 96 mol% reactant A and 4 mol% inert-I. The stoichiometry of the reaction is  $A \rightarrow C$ . A part of the reactor effluent is recycled. The molar flow rate of the recycle stream is 0.3 F. The product stream P contains 50 mol% C. The percentage conversion of A in the reactor based on A entering the reactor at point 1 in the figure (up to one decimal place) is \_\_\_\_\_. [2015 : 2 M]



[2015 : 2 M]

**2.29** 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:

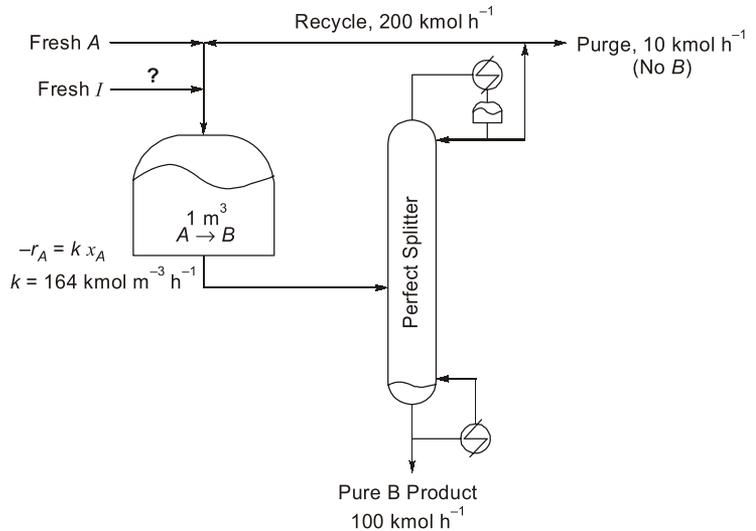


The flowrate of  $P$ , containing 30 mass% of ethanol, is 100 kg/h. What is the least number of additional specification(s) required to determine the mass flowrates and compositions (mass%) of the two exit streams?

- (a) 0 (b) 1  
(c) 2 (d) 3 [2016 : 1 M]

**2.30** All aqueous salt-solution enters a crystallizer operating at steady state at 25°C. The feed temperature is 90°C and the salt concentration in the feed is 40 weight %. The salt crystallizes as a pentahydrate. The crystals and the mother liquor leave the crystallizer. The molecular weight of the anhydrous salt is 135. The solubility of the salt at 25°C is 20 weight %.

**2.32** Consider the process flowsheet in the figure. An irreversible liquid-phase reaction  $A \rightarrow B$  (reaction rate  $-r_A = 164 x_A$  kmol m<sup>-3</sup> h<sup>-1</sup>) occurs in a 1 m<sup>3</sup> continuous stirred tank reactor (CSTR), where  $x_A$  is the mole fraction of  $A$ . A small amount of inert,  $I$ , is added to the reactor. The reactor effluent is separated in a perfect splitter to recover pure  $B$  product down the bottoms and a  $B$ -free distillate. A fraction of the distillate is purged and the rest is recycled back to the reactor. At a particular steady state, the product rate is 100 kmol h<sup>-1</sup>, the recycle rate is 200 kmol h<sup>-1</sup> and the purge rate is 10 kmol h<sup>-1</sup>. Given the above information, the inert feed rate into the process is \_\_\_\_\_ kmol h<sup>-1</sup> (rounded off to two decimal places).



[2022 : 2 M]

**2.33** 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<sub>2</sub>O in the stack gas is 0.07. The mole fraction of N<sub>2</sub> calculated on a wet basis is \_\_\_\_\_ (rounded off to two decimal places).

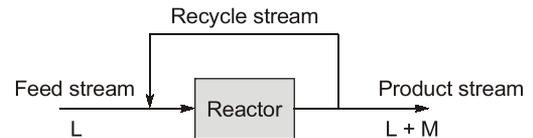
Species	N <sub>2</sub>	CO <sub>2</sub>	CO	O <sub>2</sub>
mol %	65	15	10	10

[2023 : 2 M]

The feed flowrate required for a production rate of 100 kg/s of the hydrated salt, rounded to the nearest integer, is \_\_\_\_\_ kg/s.

[2017 : 2 M]

**2.31** A feed stream containing pure species  $L$  flows into a reactor, where  $L$  is partly converted to  $M$  as shown in the figure.



The mass flow rate of the recycle stream is 20% of that of the product stream. The overall conversion of  $L$  (based on mass units) in the process is 30%. Assuming steady state operation, the one-pass conversion of  $L$  (based on mass units) through the reactor is

- (a) 34.2% (b) 30%  
(c) 26.3% (d) 23.8%

[2020 : 2 M]

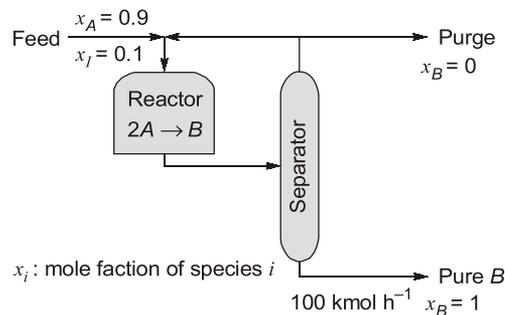
**2.34** Consider the reaction  $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$  in a continuous flow reactor under steady-state conditions. The component flow rates at the reactor inlet are  $F_{\text{N}_2}^0 = 100 \text{ mol s}^{-1}$ ,  $F_{\text{H}_2}^0 = 300 \text{ mol s}^{-1}$ ,  $F_{\text{inert}}^0 = 1 \text{ mol s}^{-1}$ . If the fractional conversion of  $\text{H}_2$  is 0.60, the outlet flow rate of  $\text{N}_2$ , in  $\text{mol s}^{-1}$ , rounded off to the nearest integer, is \_\_\_\_\_.

[2024 : 1 M]

**2.35** Consider the process in the figure for manufacturing  $B$ . The feed to the process is 90 mol%  $A$  and a close-boiling inert component  $I$ . At a particular steady-state:

- $B$  product rate is  $100 \text{ kmol h}^{-1}$ .
- Single-pass conversion of  $A$  in the reactor is 50%.
- Recycle-to-purge stream flow ratio is 10.

The flow rate of  $A$  in the purge stream in  $\text{kmol h}^{-1}$ , rounded off to 1 decimal place, is \_\_\_\_\_.



[2024 : 2 M]

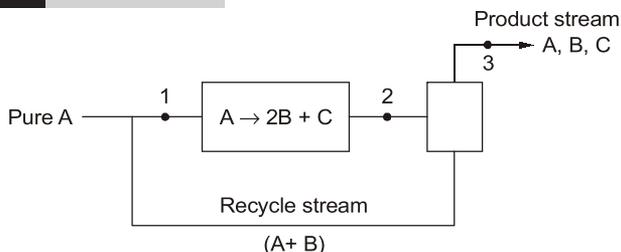
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### Answers Material Balance Calculations

<b>2.1</b>	(8.675%, 9.97)	<b>2.2</b>	(c)	<b>2.3</b>	(d)	<b>2.4</b>	(c)	<b>2.5</b>	(c)	<b>2.6</b>	(d)
<b>2.7</b>	(b)	<b>2.8</b>	(b)	<b>2.9</b>	(c)	<b>2.10</b>	(d)	<b>2.11</b>	(a)	<b>2.12</b>	(c)
<b>2.14</b>	(c)	<b>2.15</b>	(d)	<b>2.16</b>	(b)	<b>2.17</b>	(c)	<b>2.18</b>	(a)	<b>2.19</b>	(c)
<b>2.21</b>	(b)	<b>2.22</b>	(a)	<b>2.23</b>	(b)	<b>2.24</b>	(a)	<b>2.25</b>	(3.27)	<b>2.26</b>	(0.264)
<b>2.28</b>	(45.33)	<b>2.29</b>	(b)	<b>2.30</b>	(200)	<b>2.31</b>	(c)	<b>2.32</b>	(0.99)	<b>2.33</b>	(0.61)
<b>2.34</b>	(40)	<b>2.35</b>	(18.2)								

### Explanations Material Balance Calculations

**2.1** (8.675%, 9.97)



Basis 100 moles of  $A$  in pure feed

Overall conversion of  $A = 95\%$

So moles of  $A$  at point 3 ( $n_{A_3}$ ) =  $100 \times 0.05$

= 5 moles

Product stream from separator contains 0.5% of  $A$  entering the separator

$$n_{A_3} = 0.005 n_{A_2}$$

$$n_{A_2} = \frac{5}{0.005} = 1000 \text{ moles}$$

$A$  in recycle stream =  $n_{A_2} - n_{A_3}$

$$= 1000 - 5 = 995 \text{ moles}$$

At point 1  $n_{A_1} = 100 + 995 = 1095 \text{ moles}$

(a) So conversion per pass =  $\frac{1095 - 1000}{1095} \times 100$   
 = 8.675%

Total moles of A converted in the reactor  
 =  $n_{A_2} - n_{A_1}$   
 =  $1095 - 1000 = 95$  moles

Moles of B formed in reactor = Moles of B entering the separator  $n_{B_2} = 95 \times 2 = 190$  moles

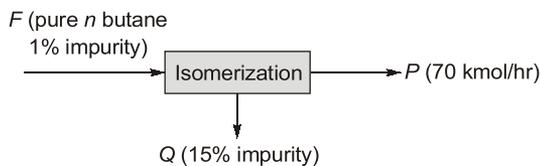
Recycle stream contains 1% of B entering the separator  $n_{B_4} = 0.01 n_{B_2} = 1.9$  moles

Total moles in recycle =  $995 + 1.9 = 996.9$  moles

(b) Molar ratio of recycle to feed  
 =  $\frac{996.9}{100} = 9.969 \approx 9.97$

**2.2 (c)**

Butane isomerization process produces 70 kmol/hr of pure butane as shown in figure below.



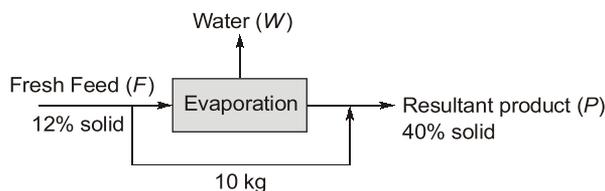
Overall balance :  
 $F = P + Q$   
 $F = 70 + Q$  ... (1)

From impurity balance:  
 $F \times 0.01 = Q \times 0.15$  ... (2)

From equation (1) and (2)  
 $Q = 5$  kmol/hr  
 $F = 75$  kmol/hr

**2.3 (d)**

Fresh orange juice contains 12% (by weight) solid and rest water.



Assuming 100 kg of fresh feed.  
 From overall solid balance:  
 $F \times 0.12 = P \times 0.4$   
 $P = \frac{100 \times 0.12}{0.4} = 30$  kg

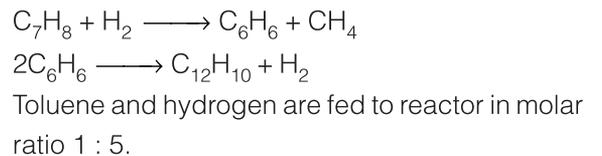
From overall balance;  
 $F = P + W$   
 $100 = 30 + W \Rightarrow W = 70$  kg  
 Amount of water removed from 1 kg of fresh feed  
 =  $\frac{70}{100} = 0.7$

**2.4 (c)**



Solubility at 60°C =  $\frac{0.6 \text{ kg A}}{\text{kg of water}}$   
 =  $\frac{0.6}{1+0.6} = 0.375$  kg of A/kg solution  
 Similarly solubility at 25°C = 0.2 kg A/kg water  
 =  $\frac{0.2}{1+0.2} = 0.167$  kg A/kg solution  
 So, crystal formed =  $0.375 - 0.167 = 0.2$  kg

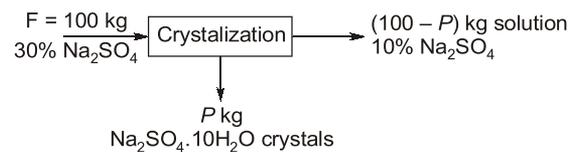
**2.5 (c)**



Toluene converted is 80%  
 Selectivity of benzene is 90%  
 Benzene formed =  $0.8 \times 0.9 = 0.72$  moles  
 So benzene reacted in 2<sup>nd</sup> reaction is  
 $0.8 - 0.72 = 0.08$  moles  
 So hydrogen formed in 2<sup>nd</sup> reaction is  
 $\frac{0.08}{2} = 0.04$  moles

Hydrogen reacted in first reactor is 0.8 moles.  
 So fractional conversion of H<sub>2</sub> is  
 =  $\frac{0.8 - 0.04}{5} = 0.152$

**2.6 (d)**



Na<sub>2</sub>SO<sub>4</sub>.10H<sub>2</sub>O crystals are formed by cooling 100 kg of 30% by weight aqueous solution of Na<sub>2</sub>SO<sub>4</sub>.

From overall balance

$$100 = P + (100 - p) \quad \dots(1)$$

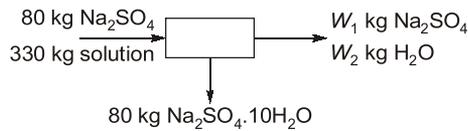
From  $\text{Na}_2\text{SO}_4$  balance

$$100 \times 0.3 = P \times \frac{142}{322} + (100 - P) \times 0.1$$

$$P = 58.65 \text{ kg}$$

**2.7 (b)**

80 kg of  $\text{Na}_2\text{SO}_4$  (M.W. = 142) is present in 330 kg of an aqueous solution.



$$80 = 80 \times \frac{142}{(142 + 10 \times 18)} + W_1$$

$$W_1 = 44.72 \text{ kg}$$

$$330 = 80 + W_2 + W_1$$

(Overall material balance)

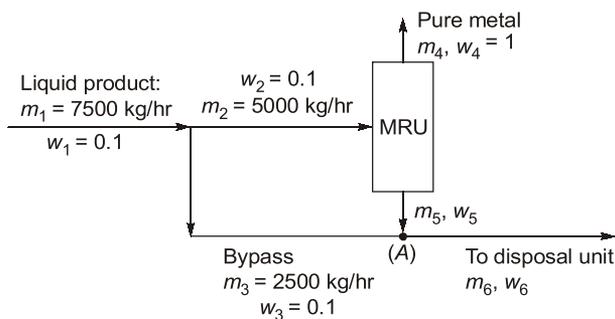
$$W_2 = 205.92 \text{ kg}$$

Weight fraction of  $\text{Na}_2\text{SO}_4$  in remaining solution

$$= \frac{44.72}{44.72 + 205.29} = 0.179 \approx 0.18$$

**2.8 (b)**

A metal recovery unit has intake capacity 5000 kg/hr and recovers 90% of metal in pure form.



From overall balance

$$m_2 = m_4 + m_5 = 5000 \quad \dots(1)$$

From metal material balance

$$m_2 w_2 = m_4 w_4 + m_5 w_5 \quad \dots(2)$$

(metal recovery is 90% given in question)

$$m_4 \times 1 = 0.9 \times 5000 \times 0.1$$

$$m_4 = 450 \text{ kg/hr}$$

$$m_5 = 5000 - m_4 \quad (\text{from equation 1})$$

$$m_5 = 4550 \text{ kg/hr}$$

From equation (2)

$$450 + 4550 \times w_5 = 500$$

$$w_5 = 0.01099$$

Applying material balance at point (A)

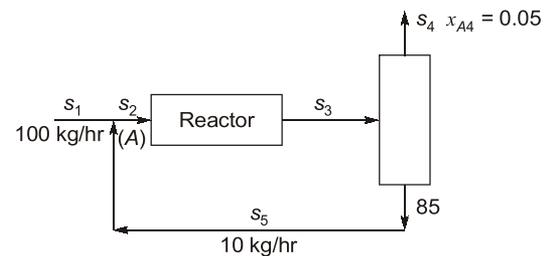
$$m_3 w_3 + m_5 w_5 = m_6 w_6$$

$$7050 \times w_6 = 2500 \times 0.1 + 4550 \times 0.01099$$

$$w_6 = 0.04255$$

**2.9 (c)**

The reaction given in question is  $A \rightarrow B$



Mass fraction  $B$  in  $s_4$  is 0.95.

From material balance at point A

$$s_2 = s_1 + s_5$$

$$s_2 = 100 + 10 = 110 \text{ kg/hr}$$

Separation does not change composition.

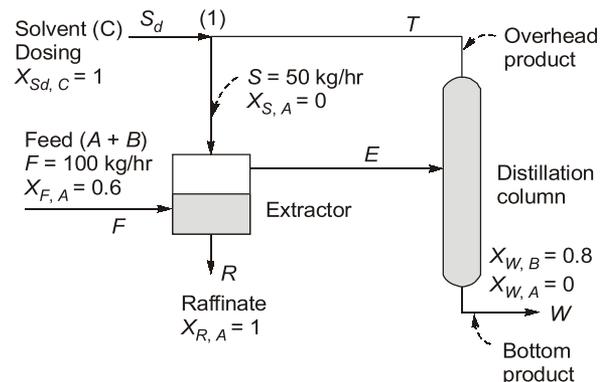
So,  $x_{A4} = x_{A3} = x_{A5} = 0.05$

$$x_{B4} = 0.95$$

Flow rate of  $A$  in  $s_3 = s_3 x_{A3}$

$$= 110 \times 0.05 = 5.5 \text{ kg/hr}$$

$$\frac{s_3}{s_5} = \frac{110}{10} = 11$$

**2.10 (d)**

From overall material balance

$$F + S_d = R + W \quad \dots(1)$$

Component  $B$  balance

$$S_d \times 0 + F \times 0.4 = R \times 0 + W \times 0.8$$

$$W = 100 \times \frac{0.4}{0.8} = 50 \text{ kg/hr}$$

From component C balance

$$F \times 0 + S_d \times 1 = R \times 0 + W \times 0.2$$

$$S_d = 50 \times 0.2 = 10 \text{ kg/hr}$$

**2.11 (a)**

Applying material balance at point 1

$$S = S_d + T$$

From previous question,

$$S = 50 \text{ kg/hr}$$

$$S_d = 10 \text{ kg/hr}$$

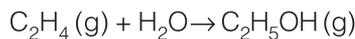
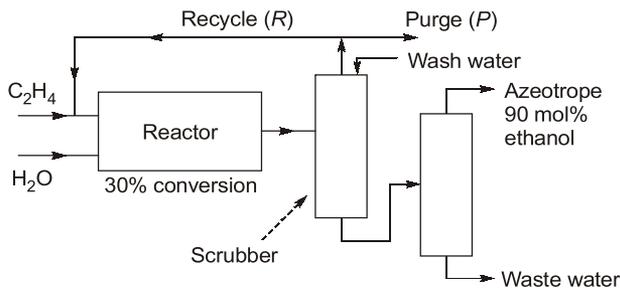
$$T = 50 - 10 = 40 \text{ kg/hr}$$

Applying material balance on distillation column,

$$E = T + W$$

$$= 50 + 40 = 90 \text{ kg/hr}$$

**2.12 (c)**



Azeotrope product rate is 500 mol/hr which contain 90 mol% ethanol. So, ethanol product rate is

$$= 500 \times 0.9 = 450 \text{ mol/hr}$$

Reactor conversion is 30%.

So, to produce 450 mol/hr ethanol,  $C_2H_4$  required

$$= \frac{450}{0.3} = 1500 \text{ mol/hr}$$

$$\text{Unreacted } C_2H_4 = 1500 - 450$$

$$= 1050 \text{ mol/hr}$$

Recycle to purge ratio = 34 (given)

$$\frac{R}{P} = 34 \Rightarrow R = 34P \quad \dots(1)$$

$$R + P = 1050 \quad \dots(2)$$

From eqn. (1) and (2),

$$P = 30 \text{ mol/hr}$$

$$R = 1020 \text{ mol/hr}$$

**2.13 (d)**

Fresh  $H_2O$  feed to reactor = 600 mol/hr

$H_2O$  reacted to produce ethanol (450 mol/hr)

$$= 450 \text{ mol/hr}$$

Water unreacted =  $600 - 450 = 150 \text{ mol/hr}$

Wash water flow rate is 20% of condensable coming out of reactor.

Condensable = 450 mol/hr ethanol + 150 mol/hr  $H_2O$  + 1050 mol/hr  $C_2H_4$  unreacted = 1650 mol/hr

Wash water flow rate =  $0.2 \times 1650 = 330 \text{ mol/hr}$

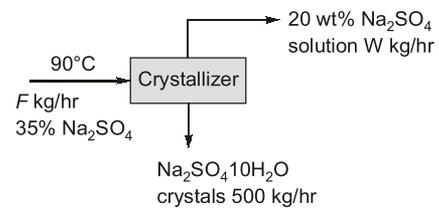
Waste water flow rate

$$= \text{Water unreacted} + \text{Wash water}$$

$$= 150 + 330 = 480 \text{ mol/hr}$$

**2.14 (c)**

A 35 wt%  $Na_2SO_4$  solution in water initially at  $50^\circ C$  is fed to crystallizer at  $20^\circ C$  as shown in figure below:



From overall balance

$$F = W + 500 \quad \dots(1)$$

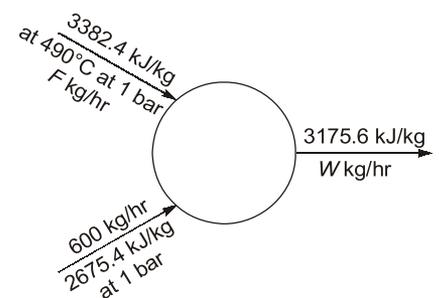
From  $Na_2SO_4$  balance

$$F \times 0.35 = W \times 0.2 + 500 \times \frac{142}{322} \quad \dots(2)$$

On solving equations (1) and (2)

$$F = 803.3 \text{ kg/hr}$$

**2.15 (d)**



Assuming product stream flow rate is  $W \text{ kg/hr}$ .

Now from overall balance :

$$F + 600 = W \quad \dots(1)$$

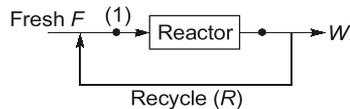
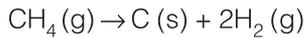
Now from energy balance

$$F \times 3382.4 + 600 \times 2675.4 = W \times 3175.6 \quad \dots(2)$$

On solving equation (1) and (2)

$$F = 1451.257 \text{ kg/hr}$$

$$W = 2051.257 \text{ kg/hr}$$

**2.16 (b)**

Assuming 1 mol of feed to the reactor at point 1.

∴ Single pass conversion is 0.6

Remaining  $\text{CH}_4 = 1 - 0.6 = 0.4$

25% of remaining  $\text{CH}_4$  is recycled.

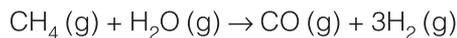
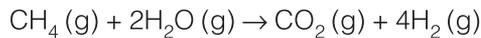
So,  $0.4 \times 0.25 = 0.1$  mol of  $\text{CH}_4$  is recycled

Now, Fresh feed =  $1 - 0.1 = 0.9$

$$\frac{\text{Fresh feed}}{\text{Recycle stream}} = \frac{0.9}{0.1} = 9$$

**2.17 (c)**

Methane and steam are fed to a reactor in molar ratio of 1 : 2 and following reaction take place:



$$\begin{aligned} \text{Selectivity} &= \frac{\text{Moles of desired product}}{\text{Moles of undesired product}} \\ &= \frac{15.21}{2.17} = 7.00 \end{aligned}$$

**2.18 (a)**

Basis 100 mole of exit stream.

Moles of desired product  $\text{CO}_2$  formed = 15.21 mol

$\text{CO}_2$  is formed when no side reaction is occur and limiting reactant had reacted completely means total  $\text{CH}_4$  in feed =  $\text{CH}_4$  reacted +  $\text{CH}_4$  unreacted  
 $= 15.21 + 2.17 + 4.35 = 21.73$

$$\text{Now, fractional yield} = \frac{15.21}{21.73} = 0.70$$

**2.19 (c)**

Fractional conversion of methane

$$\begin{aligned} &= \frac{\text{Moles of } \text{CH}_4 \text{ reacted to form } \text{CO}_2}{\text{CH}_4 \text{ in feed}} \\ &= \frac{15.21}{21.73} = 0.70 \end{aligned}$$

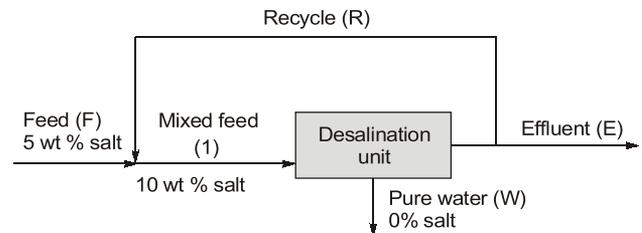
**2.20 (b)**

Tie component is defined as component which is used to relate a quantity of one process stream to

another process stream and in this question only air is tie component because its mass remains same in feed (wet air) and exit (dry air).

**2.21 (b)**

Pure water (stream W) is to be obtained from a feed containing 5% salt using a desalination unit as shown below:



Assuming,  $F = 100$  kg for basis

$$F = W + E$$

$$100 = W + E$$

Since overall recovery of pure water is 0.75 kg/kg of feed.

$$\text{So, } W = 100 \times 0.75 = 75 \text{ kg}$$

$$E = 100 - 75 = 25 \text{ kg}$$

From overall salt balance:

$$F \times 0.05 = W \times 0 + E \times x$$

$$x = 0.2$$

Now, overall balance on point 1

$$M = F + R = 100 + R$$

From salt balance at point 1

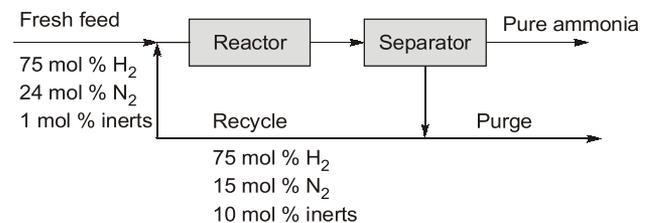
$$F \times 0.05 + R \times 0.2 = (R + F) \times 0.1$$

On solving,  $R = 50$

$$\therefore R/F = \frac{50}{100} = 0.5$$

**2.22 (a)**

Ammonia is synthesized at 200 bar and 773 K by the reaction  $\text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3$ .



Assuming 100 mol of feed basis

Yield of ammonia = 0.45 mol/mol of fresh feed

Moles of  $\text{NH}_3$  produced

$$= 100 \times 0.45 = 45 \text{ mol}$$

From stoichiometry moles of H<sub>2</sub> required

$$= 45 \times \frac{3}{2} = 67.5$$

Moles of H<sub>2</sub> in fresh feed = 75 mole

From inert balance

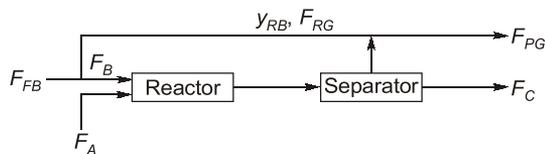
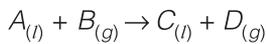
$$100 \times 0.01 = P \times 0.1$$

$$P = 10$$

H<sub>2</sub> lost in purge = 10 × 0.75 = 7.5

$$\frac{\text{Amount of H}_2 \text{ lost in purge}}{\text{H}_2 \text{ in fresh feed}} \times 100 = \frac{7.5}{75} \times 100 = 10\%$$

**2.23 (b)**



$$F_{FB} = 2 \text{ mols, } F_A = 1 \text{ mol/s}$$

$$\frac{F_B}{F_A} = 5$$

$$\therefore X_A = 1$$

Hence,  $F_C = 1 \text{ mol/s}$

$$y_{RB} = 0.3$$

From overall material balance

$$F_A + F_{FB} = F_C + F_{PG}$$

$$F_{PG} = 1 + 2 - 1 = 2 \text{ mol/s}$$

Now, from material balance of component B at point 1,

$$F_B = F_{FB} + y_{RB} \times F_{RG}$$

$$F_{RG} = \frac{5 - 2}{0.3} = 10 \text{ mol/s}$$

$$\frac{F_{RG}}{F_{PG}} = \frac{10}{2} = 5$$

**2.24 (a)**

Given:  $\frac{F_{RG}}{F_{PG}} = 4$

$$F_{PG} = 2 \text{ (from question 2.23)}$$

So,  $F_{RG} = 4 \times 2 = 8 \text{ mol/s}$

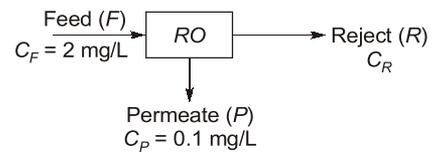
Now from material balance at point 1

$$F_B = F_{FB} + y_{RB} \times F_{RG}$$

$$y_{RB} = \frac{5 - 2}{8} = \frac{3}{8}$$

**2.25 (3.27)**

Reverse osmosis plant is treating feed water ( $F$ ) containing fluoride and its output consists of a permeate stream ( $P$ ) and a reject stream ( $R$ ) as shown in diagram below.



From mass balance:

$$F = P + R$$

Given:  $R = 0.6F$

$$F = P + 0.6F$$

$$P = 0.4F$$

From fluoride content balance

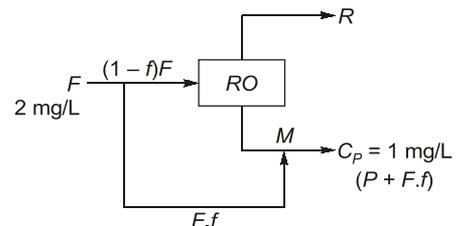
$$FC_F = PC_P + RC_R$$

$$F \times 2 = 0.4 \times F \times 0.1 + 0.6F C_R$$

$$C_R = \frac{2 - 0.04}{0.6} = 3.27 \text{ mg/L}$$

**2.26 (0.264)**

The fraction  $f$  of the feed is bypassed and mixed with the permeate to obtain treated water having a content of fluoride is 1 mg/L as shown in diagram below.



Now from component balance

$$2(f.F) + PC_P = (P + f.F) \times 1$$

$$2(f.F) + P \times 0.1 = P + f.F$$

$$\therefore P = 0.4(1 - f)F \text{ is given}$$

$$\therefore 2f.F + 0.4(1 - f)F \times 0.1 = 0.4(1 - f)F + f.F$$

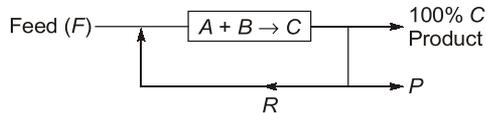
$$f = 0.264$$

**2.27 (10)**

Elemental gases ( $A$  and  $B$ ) are reacting to form a liquid ( $C$ ) in steady state as per the reaction  $A + B \rightarrow C$ .

Single pass conversion is 20%.

Fresh feed consists 49 mol%  $A$ , 49 mol %  $B$  and 2 mol % impurities. Maximum allowable impurity in recycle stream is 20% given.



Assuming,  $F = 100 \text{ mol}$

By inert balance

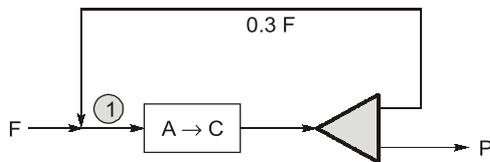
$$F \times 0.02 = P \times 0.2$$

( $\because$  purge and recycle stream contains same composition)

$$100 \times 0.02 = P \times 0.2 = 10 \text{ moles}$$

### 2.28 (45.33)

Fresh feed ( $F$ ) enters to reactor consisting 96 mol % A and 4 mol% inert and reacts as  $A \rightarrow C$  as shown in diagram below.



Basis 100 kmol of fresh feed.

From overall steady-state balance :

$$F = P = 100 \text{ kmol}$$

Product stream  $P$  contains 50 mol% C (given)

So,  $P$  contains 50 kmol of C.

From inert balance:

$$\begin{aligned} \text{Inert in feed} &= \text{Inert in } P \\ &= 100 \times 0.04 = 4 \text{ kmol} \end{aligned}$$

$$\begin{aligned} \text{A in } P &= 100 - 4 - 50 = 46\% \\ &= 46 \text{ kmol} \end{aligned}$$

Now A at point 1 =  $96 + 0.3 \times 46 = 109.8 \text{ kmol}$

A in outlet of reaction

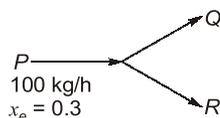
$$= 46 + 0.3 \times 46 = 59.8 \text{ kmol}$$

% conversion on the basis of point 1

$$= \frac{109.8 - 59.8}{109.8} \times 100 = 45.33\%$$

### 2.29 (b)

A liquid mixture of ethanol and water is flowing as inlet stream  $P$  into a stream splitter as shown in figure below.



Mass % of ethanol in  $P$  stream = 30.

From overall balance :

$$P = Q + R \quad \dots(1)$$

From ethanol balance

$$P \cdot x_P = Q \cdot x_Q + R \cdot x_R$$

where,  $x_Q$  = Ethanol mass fraction in stream  $Q$

$x_R$  = Ethanol mass fraction in stream  $R$

Since, it is a simple splitting process,

So,  $x_P = x_Q = x_R = 0.3$

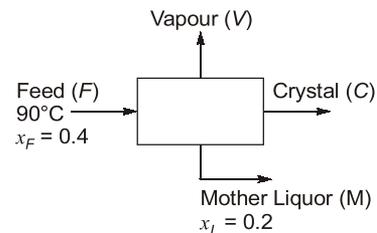
Now, from equation (1)

$$100 = Q + R$$

Now, there is two unknown and one independent equation is available. So, additional specification required to know all mass flow rates is  $2 - 1 = 1$ .

### 2.30 (200)

Aqueous salt-solution enters the crystallizer operating at  $25^\circ\text{C}$  as shown in figure below.



Salt crystallizes as pentahydrate and molecular weight of anhydrous salt is 135.

So, weight fraction of salt in crystal

$$x_c = \frac{135}{135 + 5 \times 18} = 0.6$$

Since, no water loss is given so  $V = 0$ .

So, from overall balance

$$F = C + M \quad \dots(1)$$

From salt balance

$$F \times 0.4 = C \times 0.6 + M \times 0.2$$

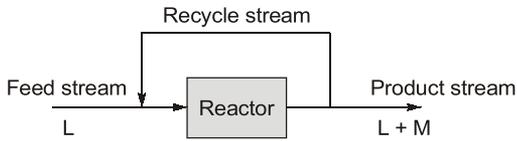
$$C = 100 \text{ kg/s (given)}$$

$$F \times 0.4 = 100 \times 0.6 + (F - 100) \times 0.2$$

$$F = \frac{100 \times 0.4}{0.2} = 200 \text{ kg/s}$$

**2.31 (c)**

Feed stream containing pure species *L* flows into the reactor and partially converted to *M* as shown in figure below.



$$R = 0.2P \text{ (given)}$$

So,

$$R = 0.2 \times 70 = 14 \text{ mol/s}$$

Overall conversion,  $X_0 = 0.3$

Assuming 100 mol/s feed rate of pure *L* stream.

$$M \text{ in product} = 100 \times 0.3 = 30 \text{ mol/s}$$

$$= 70 \text{ mol/s } (\because \text{steady state})$$

*L* in product stream.

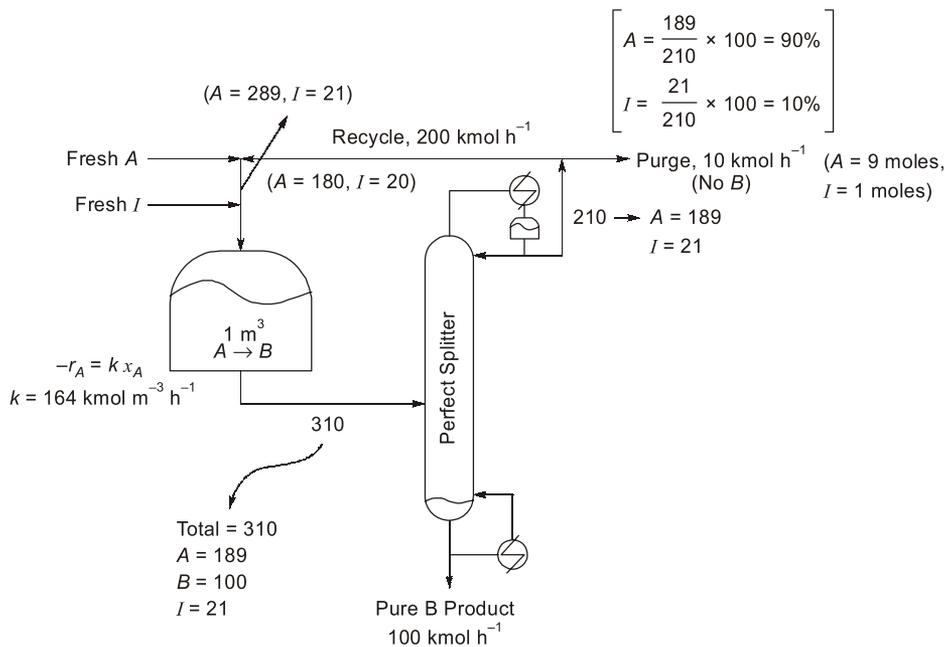
Now, assuming  $X_p$  is single pass conversion

Pure species '*L*' balance around reactor.

$$(100 + 70 \times 0.2)(1 - X_p) = 70 + 70 \times 0.2$$

$$X_p = 26.31\%$$

**2.32 (0.99)**



For CSTR

$$\frac{v}{F_{AO}} = \frac{X_A}{-r_A}$$

$$\frac{1}{F_{AO}} = \frac{X_A}{k x_A}$$

$$\frac{1}{F_{AO}} = \frac{X_A}{164 \times \frac{F_A}{310}}$$

$$\frac{1}{F_{AO}} = \frac{X_A}{164 \frac{F_{AO}(1-X_A)}{310}}$$

$A \rightarrow B,$

$$X_A = 0.3459$$

$$F_B = F_{B0} + F_{AO} X_A = F_{AO} X_A$$

$$100 = F_{AO} \times 0.346$$

$$F_{AO} = 289$$

$$F_A = F_{AO}(1 - X_A)$$

$$F_A = 289(1 - 0.346) = 189$$

$$\text{Inert} = 1$$

**2.33 (0.61)**

Let for basis: Moles = 100

$$N_2 = 65\%, \quad O_2 = 10\%$$

$$CO_2 = 15\%, \quad CO = 10\%$$

$$\text{Moles of } N_2 = 65$$

$$CO_2 = 15, \quad CO = 10$$

$$O_2 = 10$$

Let,  $m = \text{moles of } H_2O$

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

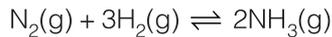
$$m = 7.527 \text{ moles}$$

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

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

**2.34 (40)**

Consider the following reaction in a continuous flow reactor under steady state condition



Consider the following inlet flow condition

$$F_{N_2}^0 = 100 \text{ mol/s}$$

$$F_{H_2}^0 = 300 \text{ mol/s}$$

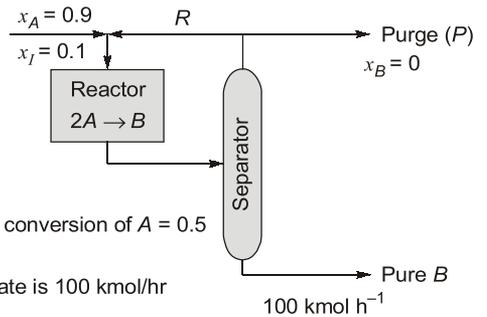
$$F_{\text{inert}}^0 = 1 \text{ mol/s}$$

Fractional conversion of  $H_2 = 0.6$

$$\text{Moles of } H_2 \text{ converted/sec} = 300 \times 0.6 = 180$$

$$\text{Moles of } N_2 \text{ converted/sec} = \frac{180}{3} = 60$$

$$\text{Outlet moles flow rate of } N_2 = 100 - 60 = 40 \text{ mol/s}$$

**2.35 (18.2)**

Reaction is given as  $2A \rightarrow B$  so to form 100 moles of  $B$  200 moles of  $A$  should be converted since single pass conversion of  $A$  is 50% so feed rate

of  $A$  to reactor is  $\frac{200}{0.5} = 400 \text{ mol/hr}$  unconverted

$A$  either will be in purge as in recycle so applying mass balance for component  $A$ .

$$400 \times 0.5 = (R + P)y_A$$

$$\text{Since, } R = 10P$$

$$\text{So, } 200 = 11P y_A$$

$$P y_n = \frac{200}{11} = 18.18 \approx 18.2 \text{ kmol/hr}$$

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