25 *Years*

Previous Solved Papers

GATE 2025

Chemical Engineering

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

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GATE - 2025

Chemical Engineering

Topicwise Previous GATE Solved Papers (2000-2024)

Edition

1st Edition : 2021
2nd Edition : 2022
3rd Edition : 2023

4th Edition : 2024

Preface


B. Singh (Ex. IES)

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.

The first edition of **GATE 2025 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-2025

Chemical Engineering

CONTENTS

Process Calculations

UNIT

I

CONTENTS

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**

1 Introduction and Basic Concepts

1.1 The molar composition of a gas is 10% H_2, 10% O_2, 30% CO_2 and balance H_2O. If 50% H_2O condenses, the final mole percent of H_2 in the gas on a dry basis will be

(a) 10% (b) 5%
(c) 18.18% (d) 20% **[2000 : 1 M]**

1.2 An aqueous solution of 2.45% by weight H_2SO_4 has a specific gravity of 1.011. The composition expressed in normality is

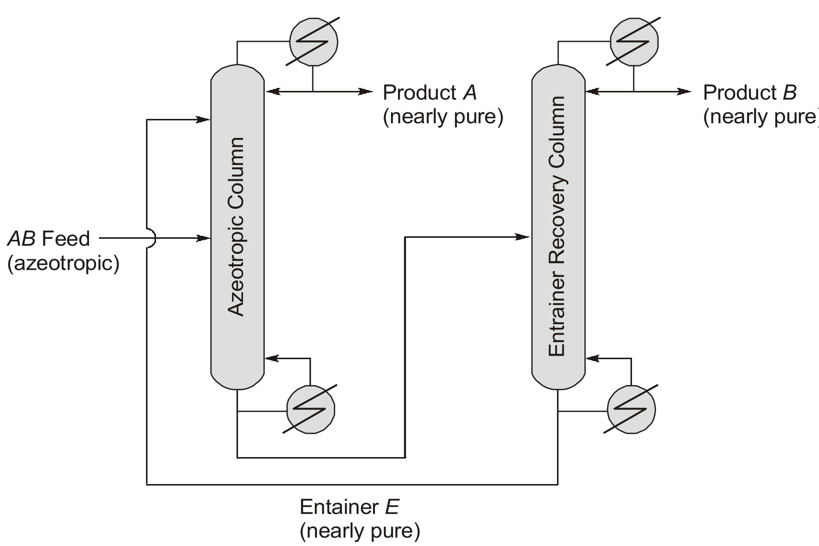
(a) 0.2500 (b) 0.2528
(c) 0.5000 (d) 0.5055 **[2003 : 2 M]**

1.3 A saturated solution at 30°C contains 5 moles of solute (M.W. = 50 kg/kmol) per kg of solvent (M.W. = 20 kg/kmol). The solubility at 100°C is 10 moles of the solute per kg of the solvent. If 10 kg of the original solution is heated to 100°C, then the weight of the additional solute that can be dissolved in it, is

(a) 0.25 kg (b) 1 kg
(c) 2 kg (d) 3.34 kg

[2010 : 2 M]

1.4 A homogeneous azeotropic distillation process separates an azeotropic *AB* binary feed using a heavy entrainer, *E*, as shown in the figure. The loss of *E* in the two product streams is negligible so that *E* circulates around the process in a closed-circuit. For a distillation column with fully specified feed(s), given operating pressure, a single distillate stream and a single bottoms stream, the steady-state degrees of freedom equals 2. For the process in the figure with a fully specified *AB* feed stream and given column operating pressures, the steady-state degrees of freedom equals



(a) 3 (b) 4
(c) 5 (d) 6 **[2024 : 1 M]**

■■■■

Answers Introduction and Basic Concepts

1.1 (d) **1.2** (d) **1.3** (c) **1.4** (c)

Explanations Introduction and Basic Concepts

1.1 (d)

Assuming 100 mol of wet gas, 50% water condenses.

Component	Wet basis (mol)	Dry basis (mol)
H_2	10	10
O_2	10	10
CO_2	30	30
H_2O	(100 – 50) = 50	
Total	100	

Mol % of H_2 on dry basis $= \frac{10}{50} \times 100 = 20\%$

1.2 (d)

Aqueous solution of 2.45% by weight H_2SO_4 has specific gravity of 1.011.

So, density of solution is 1.011×10^3 gram/L

2.45% by weight H_2SO_4

So, in 1 litre solution weight of H_2SO_4

$= 1011 \times 0.0245 = 24.769$ gram

$$\text{Normality} = \frac{\text{Weight of } H_2SO_4}{\text{Equivalent weight of } H_2SO_4}$$

$$= \frac{24.769}{\text{Mol. Wt./Basicity}} = \frac{24.769}{\frac{98}{2}} = 0.5055$$

1.3 (c)

Saturated solution at 30°C contains 5 moles of solute (M.W. 50 kg/kmol) per kg of solvent (M.W. 20 kg/kmol).

Solubility at 100°C is 10 moles of solute per kg of solvent.

$$\text{At } 30° \text{ solubility} = \frac{\text{5 mole of solute}}{\text{kg of solvent}}$$

$$= 5 \times \frac{50}{1000} = 0.25 \text{ kg solute/kg solvent}$$

$$\text{or } \frac{0.25 \text{ kg solute}}{(1+0.25) \text{ kg solution}} = 0.2 \text{ kg solvent/kg sol.}$$

10 kg solution means 10 × 0.2 = 2 kg solute and 8 kg solvent.

$$\text{Now at } 100°\text{C solubility} = \frac{\text{10 mole solute}}{\text{kg solvent}}$$

$$= 10 \times \frac{50}{1000} = 0.5 \text{ kg of solute/kg solvent}$$

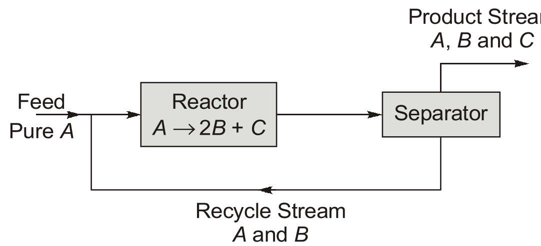
Now 8 kg of solvent will contain 8 × 0.5 = 4 kg solute.

Extra solute dissolved at 100°C = 4 – 2 = 2 kg.

■■■■

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
(a) single pass conversion of A in the reactor.
(b) 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:

(a) 3 kmol/h (b) 4 kmol/h
(c) 5 kmol/h (d) 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

(a) 0.4 (b) 0.5
(c) 0.6 (d) 0.7 [2002 : 2 M]

2.4 1 kg of a saturated aqueous solution of a highly soluble component A at 60°C is cooled to 25°C. The solubility limits of A are (0.6 kg A)/(kg water) at 60°C and (0.2 kg A)/(kg water) at 25°C. The amount, in kgs, of the crystals formed is

(a) 0.4 (b) 0.25
(c) 0.2 (d) 0.175

[2002 : 2 M]

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

$$C_7H_8 + H_2 \rightarrow C_6H_6 + CH_4$$
$$2C_6H_6 \Leftrightarrow C_{12}H_{10} + H_2$$

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

(a) 0.16 (b) 0.144
(c) 0.152 (d) 0.136

[2002 : 2 M]

2.6 $Na_2SO_4.10\ H_2O$ crystals are formed by cooling 100 kg of 30% by weight aqueous solution of Na_2SO_4. The final concentration of the solute in the solution is 10%. The weight of crystals is

(a) 20 (b) 32.2
(c) 45.35 (d) 58.65

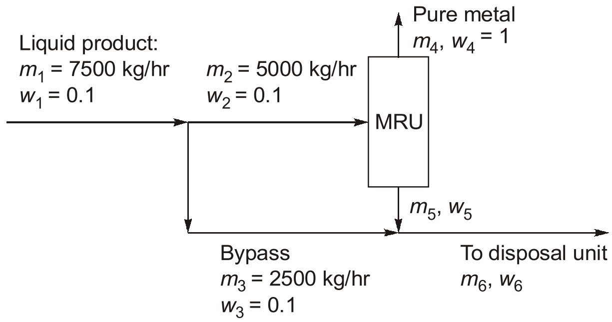
[2003 : 2 M]

2.7 80 kg of Na_2SO_4 (molecular weight = 142) is present in 330 kg of an aqueous solution. The solution is cooled such that 80 kg of $Na_2SO_4.10H_2O$ crystals separate out. The weight fraction of Na_2SO_4 in the remaining solution is

(a) 0.00 (b) 0.18
(c) 0.24 (d) 1.00

[2004 : 2 M]

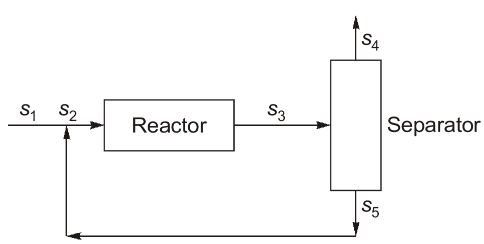
2.8 A metal recovery unit (MRU) of intake capacity 5000 kg/hr treats a liquid product from a plant and recovers 90% of the metal in the pure form. The unrecovered metal and associated liquid are sent to a disposal unit along with the untreated product from the plant (see figure below). Find the flow 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) $m_6 = 7500$ kg/hr, $w_6 = 0.0$
(b) $m_6 = 7050$ kg/hr, $w_6 = 0.04255$
(c) $m_6 = 4500$ kg/hr, $w_6 = 0.1712$
(d) $m_6 = 5600$ 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 S4 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,

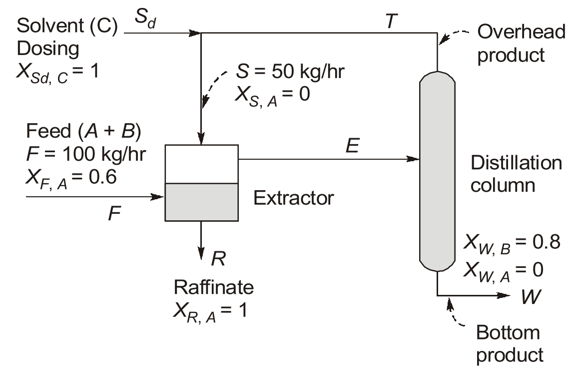


(a) 11 and 110 kg/hr
(b) 24 and 240 kg/hr
(c) 11 and 5.5 kg/hr
(d) 70 and 330 kg/hr

[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.



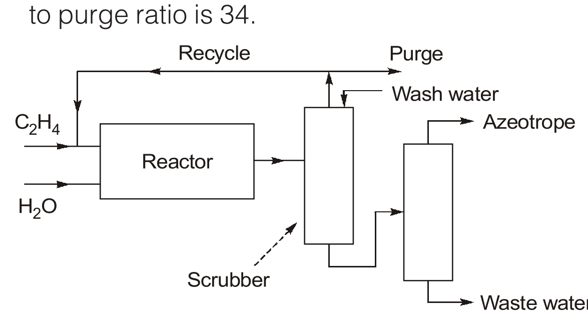
2.10 Distillation bottoms flow rate W and solvent dosing rate S_d in kg/hr are
(a) $W = 50$, $S_d = 50$
(b) $W = 100$, $S_d = 20$
(c) $W = 10$, $S_d = 50$
(d) $W = 50$, $S_d = 10$

[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% Na_2SO_4 solution in water, initially at 50°C, is fed to a crystallizer at 20°C. The product stream contains hydrated crystals $Na_2SO_4.10H_2O$ in equilibrium with a 20 wt% Na_2SO_4 solution. The molecular weights of Na_2SO_4 and $Na_2SO_4.10H_2O$ 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°C and 1 bar (enthalpy 3382.4 kJ/kg). The product is superheated steam at 350°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:

$$CH_4\,(g) \rightarrow C\,(s) + 2H_2\,(g)$$

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,

$$CH_4\,(g) + 2H_2O\,(g) \rightarrow CO_2\,(g) + 4H_2\,(g)$$
$$CH_4\,(g) + H_2O\,(g) \rightarrow CO\,(g) + 3H_2\,(g)$$

where CO_2 is the desired product, CO is the undesired product and H_2 is a byproduct. The exit stream has the following composition:

Species	CH_4	H_2O	CO_2	H_2	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 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

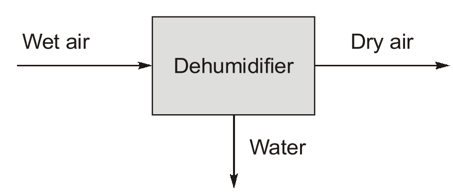
[2008 : 2 M]

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.

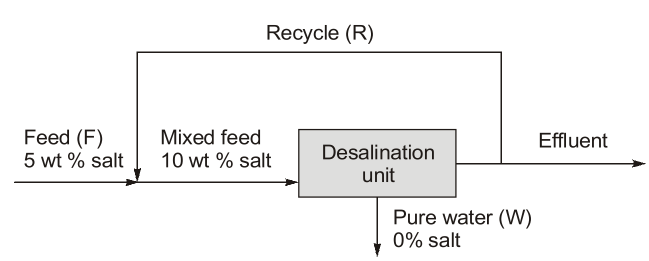


Which one of the following statements is true?

(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.

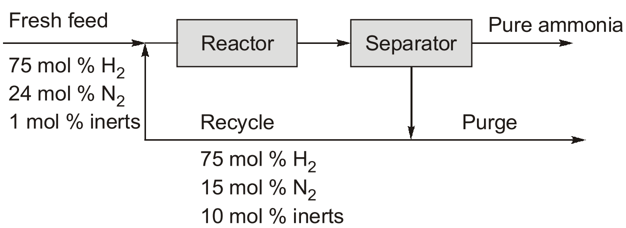


If the overall recovery of pure water (through steam W) is 0.75 kg/kg feed, then the recycle ratio (R/F) is

(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.

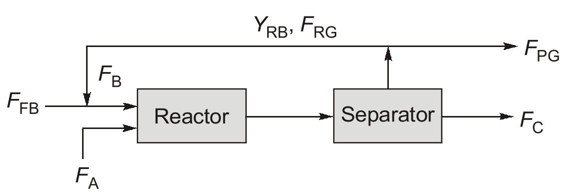


The single pass conversion for H_2 in the reactor is 20%. The amount of H_2 lost in the purge as a percentage of H_2 in fresh feed is

(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_{FB}
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.

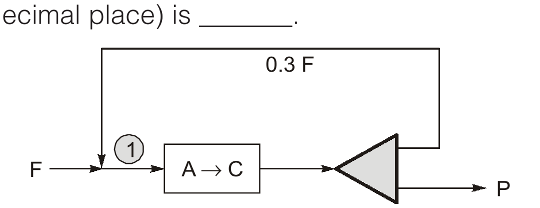
2.25 The value of C_R in mg/L, up to one digit after the decimal point, is ______.

[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]

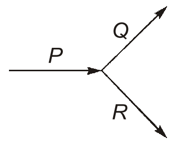
2.27 Two elemental gases (A and B) are reacting to form a liquid (C) in a steady state process as per the reaction $A + B \rightarrow C$. The single-pass conversion of the reaction is only 20% and hence recycle is used. The product is separated completely in pure form. The fresh feed has 49 mol% of A 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 → 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]

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?

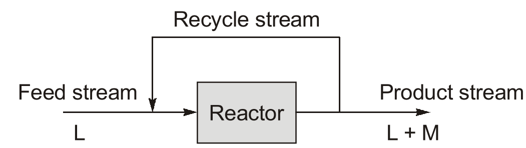
(a) 0 (b) 1
(c) 2 (d) 3 [2016 : 1 M]

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 %.

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.

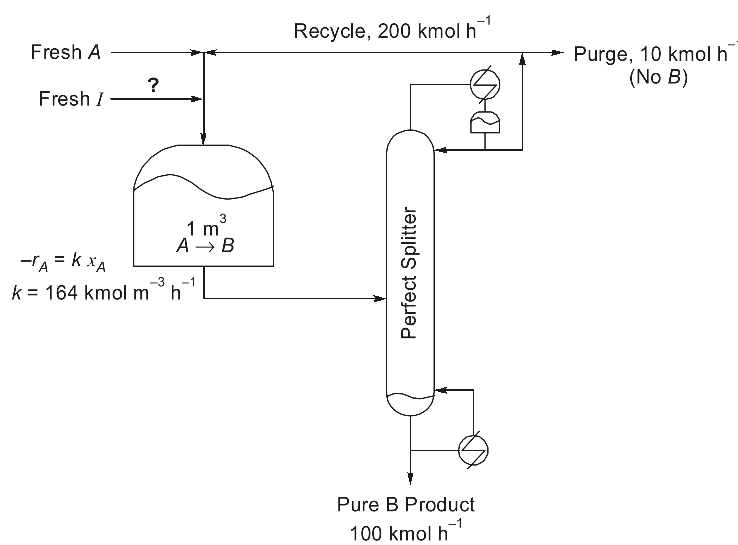


The mass flow rate of the recycle stream is 20% of that of the product stream. The overall conversion of *L* (based on mass units) in the process is 30%. Assuming steady state operation, the one-pass conversion of *L* (based on mass units) through the reactor is

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

[2020 : 2 M]

2.32 Consider the process flowsheet in the figure. An irreversible liquid-phase reaction $A \rightarrow B$ (reaction rate $-r_A = 164\, x_A$ kmol m^{-3} h^{-1}) occurs in a 1 m^3 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^{-1}, the recycle rate is 200 kmol h^{-1} and the purge rate is 10 kmol h^{-1}. Given the above information, the inert feed rate into the process is ____________ kmol h^{-1} (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_2O in the stack gas is 0.07. The mole fraction of N_2 calculated on a wet basis is _____ (rounded off to two decimal places).

Species	N_2	CO_2	CO	O_2
mol %	65	15	10	10

[2023 : 2 M]

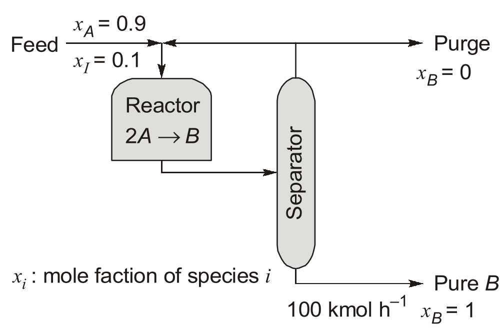
2.34 Consider the reaction $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ in a continuous flow reactor under steady-state conditions. The component flow rates at the reactor inlet are $F^0_{N_2} = 100 \text{ mol s}^{-1}$, $F^0_{H_2} = 300 \text{ mol s}^{-1}$, $F^0_{inert} = 1 \text{ mol s}^{-1}$. If the fractional conversion of H_2 is 0.60, the outlet flow rate of N_2, in 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 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 kmol h^{-1}, rounded off to 1 decimal place, is ________.



[2024 : 2 M]

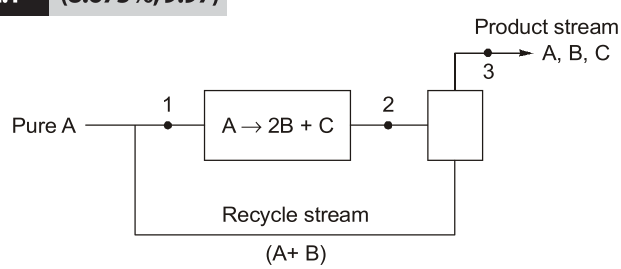
■■■■

Answers Material Balance Calculations

2.1	(8.675%, 9.97)			**2.2**	(c)	**2.3**	(d)	**2.4**	(c)	**2.5**	(c)
2.6	(d)	**2.7**	(b)	**2.8**	(b)	**2.9**	(c)	**2.10**	(d)	**2.11**	(a)
2.12	(c)	**2.13**	(d)	**2.14**	(c)	**2.15**	(d)	**2.16**	(b)	**2.17**	(c)
2.18	(a)	**2.19**	(c)	**2.20**	(b)	**2.21**	(b)	**2.22**	(a)	**2.23**	(b)
2.24	(a)	**2.25**	(3.27)	**2.26**	(0.264)	**2.27**	(10)	**2.28**	(45.33)	**2.29**	(b)
2.30	(200)	**2.31**	(c)	**2.32**	(0.99)	**2.33**	(0.61)	**2.34**	(40)	**2.35**	(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 $= n_{A_2} - n_{A_3}$

$= 1000 - 5 = 995$ moles

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

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

$= 8.675\%$

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

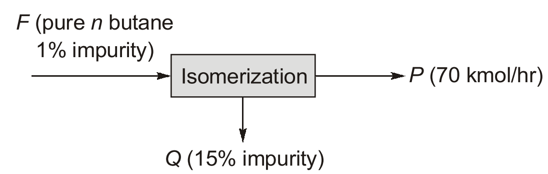
Total moles in recycle = 995 + 1.9 = 996.9 moles

(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 :

$$F = P + Q$$

$$F = 70 + Q \quad \text{...(1)}$$

From impurity balance:

$$F \times 0.01 = Q \times 0.15 \quad \text{...(2)}$$

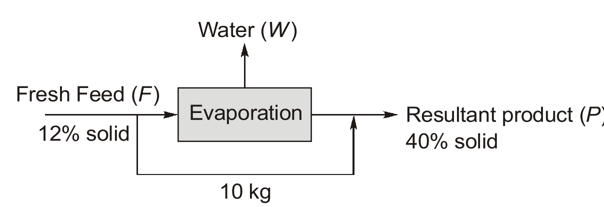
From equation (1) and (2)

$$Q = 5 \text{ kmol/hr}$$

$$F = 75 \text{ kmol/hr}$$

2.3 (d)

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



Assuming 100 kg of fresh feed.

From overall solid balance:

$$F \times 0.12 = P \times 0.4$$

$$P = \frac{100 \times 0.12}{0.4} = 30 \text{ kg}$$

From overall balance;

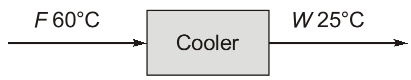
$$F = P + W$$

$$100 = 30 + W \Rightarrow W = 70 \text{ kg}$$

Amount of water removed from 1 kg of fresh feed

$$= \frac{70}{100} = 0.7$$

2.4 (c)



$$\text{Solubility at } 60°\text{C} = \frac{0.6 \text{ kg } A}{\text{kg of water}}$$

$$= \frac{0.6}{1+0.6} = 0.375 \text{ kg of } A/\text{kg solution}$$

Similarly solubility at 25°C = 0.2 kg A/kg water

$$= \frac{0.2}{1+0.2} = 0.167 \text{ kg } A/\text{kg solution}$$

So, crystal formed = 0.375 – 0.167 = 0.2 kg

2.5 (c)

$$C_7H_8 + H_2 \longrightarrow C_6H_6 + CH_4$$

$$2C_6H_6 \longrightarrow C_{12}H_{10} + H_2$$

Toluene and hydrogen are fed to reactor in molar ratio 1 : 5.

Toluene converted is 80%

Selectivity of benzene is 90%

Benzene formed = 0.8 × 0.9 = 0.72 moles

So benzene reacted in 2nd reaction is

$$0.8 - 0.72 = 0.08 \text{ moles}$$

So hydrogen formed in 2nd reaction is

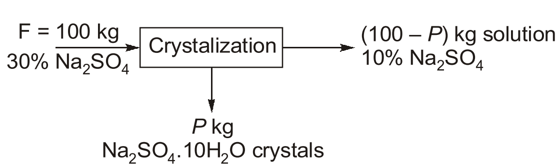
$$\frac{0.08}{2} = 0.04 \text{ moles}$$

Hydrogen reacted in first reactor is 0.8 moles.

So fractional conversion of H_2 is

$$= \frac{0.8 - 0.04}{5} = 0.152$$

2.6 (d)



$Na_2SO_4.10H_2O$ crystals are formed by cooling 100 kg of 30% by weight aqueous solution of Na_2SO_4.

From overall balance

$$100 = P + (100 - p) \quad \text{...(1)}$$

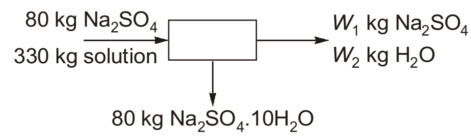
From Na_2SO_4 balance

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

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

2.7 (b)

80 kg of Na_2SO_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)

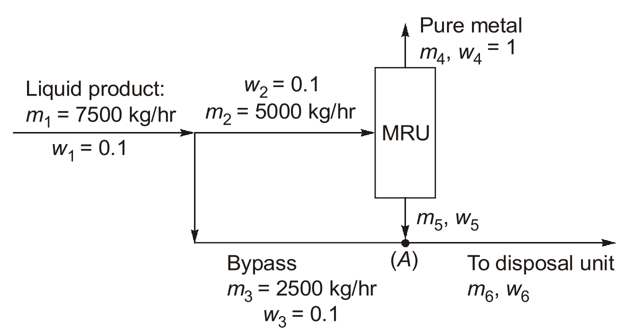
$$W_2 = 205.92 \text{ kg}$$

Weight fraction of Na_2SO_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

$$m_2 = m_4 + m_5 = 5000 \quad \text{...(1)}$$

From metal material balance

$$m_2 w_2 = m_4 w_4 + m_5 w_5 \quad \text{...(2)}$$

(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)

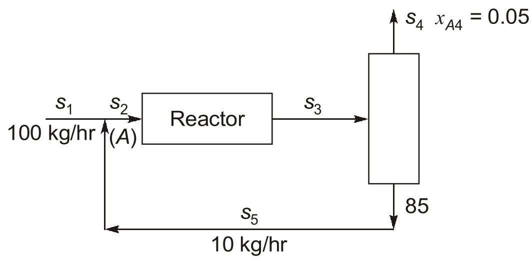
$$m_3 w_3 + m_5 w_5 = m_6 w_6$$

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

$$w_6 = 0.04255$$

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

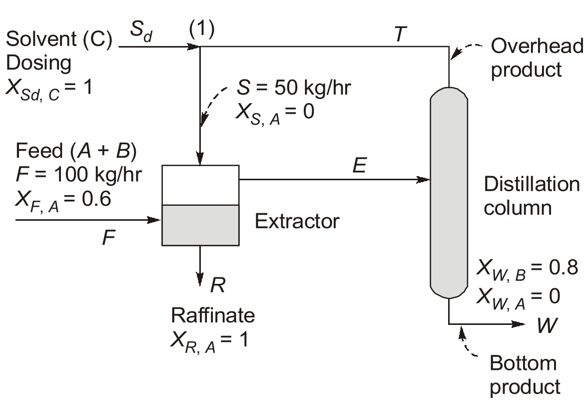
$$x_{B4} = 0.95$$

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

$$F + S_d = R + W \quad \text{...(1)}$$

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,

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

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

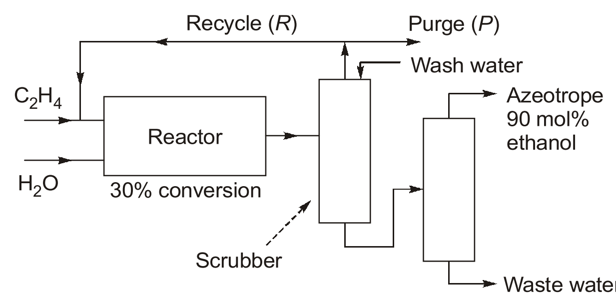
$$T = 50 - 10 = 40 \text{ kg/hr}$$

Applying material balance on distillation column,

$$E = T + W$$

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

2.12 (c)



$$C_2H_4\,(g) + H_2O \rightarrow C_2H_5OH\,(g)$$

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

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

Unreacted $C_2H_4 = 1500 - 450$

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

Recycle to purge ratio = 34 (given)

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

$$R + P = 1050 \quad \text{...(2)}$$

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 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 × 1650 = 330 mol/hr

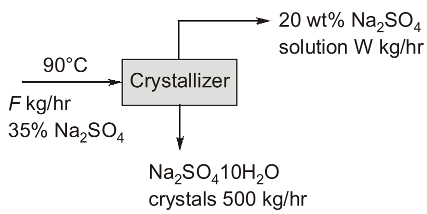
Waste water flow rate

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

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

2.14 (c)

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



From overall balance

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

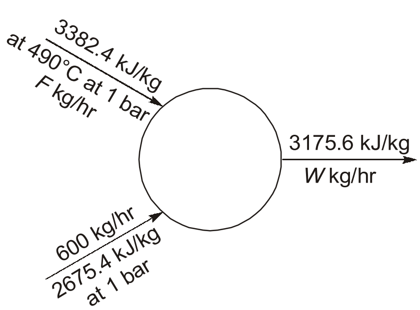
From Na_2SO_4 balance

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

On solving equations (1) and (2)

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

2.15 (d)



Assuming product stream flow rate is *W* kg/hr.

Now from overall balance :

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

Now from energy balance

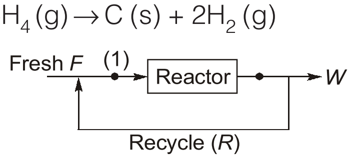
$$F \times 3382.4 + 600 \times 2675.4 = W \times 3175.6 \quad ...(2)$$

On solving equation (1) and (2)

$$F = 1451.257 \text{ kg/hr}$$
$$W = 2051.257 \text{ kg/hr}$$

2.16 (b)

$$CH_4\,(g) \rightarrow C\,(s) + 2H_2\,(g)$$



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

∵ Single pass conversion is 0.6

Remaining CH_4 = 1 – 0.6 = 0.4

25% of remaining CH_4 is recycled.

So, 0.4 × 0.25 = 0.1 mol of 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:

$$CH_4\,(g) + 2H_2O\,(g) \rightarrow CO_2\,(g) + 4H_2\,(g)$$
$$CH_4\,(g) + H_2O\,(g) \rightarrow CO\,(g) + 3H_2\,(g)$$

$$\text{Selectivity} = \frac{\text{Moles of desired product}}{\text{Moles of undesired product}}$$

$$= \frac{15.21}{2.17} = 7.00$$

2.18 (a)

Basis 100 mole of exit stream.

Moles of desired product CO_2 formed = 15.21 mol

CO_2 is formed when no side reaction is occur and limiting reactant had reacted completely means total CH_4 in feed = CH_4 reacted + 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

$$= \frac{\text{Moles of } CH_4 \text{ reacted to form } CO_2}{CH_4 \text{ in feed}}$$

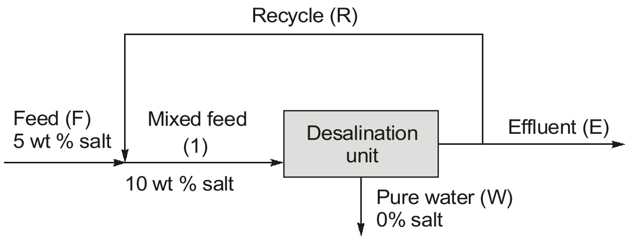
$$= \frac{15.21}{21.73} = 0.70$$

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.

So, $W = 100 \times 0.75 = 75$ 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

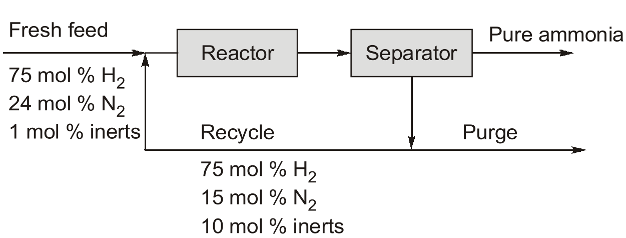
$$F \times 0.05 + R \times 0.2 = (R + F) \times 0.1$$

On solving, $R = 50$

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

2.22 (a)

Ammonia is synthesized at 200 bar and 773 K by the reaction $N_2 + 3H_2 \rightarrow 2NH_3$.



Assuming 100 mol of feed basis

Yield of ammonia = 0.45 mol/mol of fresh feed

Moles of NH_3 produced

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

From stoichiometry moles of H_2 required

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

Moles of H_2 in fresh feed = 75 mole

From inert balance

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

$$P = 10$$

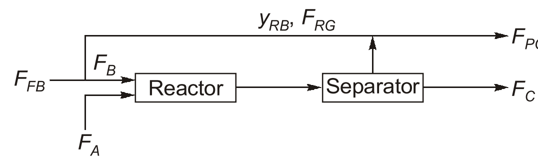
H_2 lost in purge = $10 \times 0.75 = 7.5$

$$\frac{\text{Amount of } H_2 \text{ lost in purge}}{H_2 \text{ in fresh feed}} \times 100 = \frac{7.5}{75} \times 100$$

$$= 10\%$$

2.23 (b)

$$A_{(l)} + B_{(g)} \rightarrow C_{(l)} + D_{(g)}$$



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

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

$\because \quad X_A = 1$

Hence, $F_C = 1$ 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: $\dfrac{F_{RG}}{F_{PG}} = 4$

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

So, $F_{RG} = 4 \times 2 = 8$ 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.