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POLITEKNIK MALAYSIA
KUCHING SARAWAK

E-Module
Mass & Energy Balance
Practice Exercises

JABATAN KEJURUTERAAN PETROKIMIA
POLITEKNIK KUCHING SARAWAK

AUTHOR BY
HAFIZAH BINTI NAIHI
DR. MUHAMAD NAZRI BIN ABU SHAH

Authors

HAFIZAH BINTI NAIHI
DR MUHAMAD NAZRI BIN ABU SHAH

POLITEKNIK KUCHING SARAWAK
MINISTRY OF HIGHER EDUCATION
KM22, JALAN MATANG,
93050 KUCHING, SARAWAK.

Phone No. : (082) 845596/7/8
Fax No. : (082) 845023
E-mail : poliku.info@poliku.edu.my
Website : http://www.poliku.edu.my/

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PREFACE

Mass & Energy Balance Practice Exercises is an e-module published in 2024 that references from the Department of Petrochemical Engineering's Mass and Energy Balance Course at Politeknik Kuching Sarawak. This module focused on the fundamentals of material balance from Chapter 2 of the Mass and Energy Balance Course.

This module intends to assist students improve their grasp of problem identification, identifying essential keywords from questions, formulas, and problem-solving methods.

In short, the editors are grateful to the Department of Petrochemical Engineering, Politeknik Kuching Sarawak for giving them this valuable opportunity.

Hafizah binti Naihi
Dr. Muhamad Nazri Bin Abu Shah
Department of Petrochemical Engineering
Politeknik Kuching Sarawak

ABSTRACT

MASS & ENERGY BALANCE PRACTICE EXERCISES

by

HAFIZAH BINTI NAIHI AND DR. MUHAMAD NAZRI BIN ABU SHAH

The Mass & Energy Balance Practice Exercises e-module provides students with examples of mass and energy balance issues and solutions. This e-module focuses on the "Fundamentals of Material Balances" topic, which is covered in Chapter 2 of the Mass and Energy Balance Course of the Diploma in Engineering Process (Petrochemical) at Politeknik Kuching Sarawak. This e-module is also meant to be a textbook for students studying chemical engineering and related topics.

This e-module provides practice questions and solutions. The detailed solution steps guide and teach students in a series of integrated calculations for problem-solving. This book serves as a teaching assistance for educators, particularly those in the Department of Petrochemical Engineering at Politeknik Kuching Sarawak, and can be used as a reference for students.

There is enough information supplied in the text of the problem for the students to carry out the calculation themselves before they can compare their answer version to the answer in the text of the solution. This is a fantastic exercise for students to assess their comprehension depending on the number of accurate responses they receive. It is also a challenge for students to accurately solve the issues highlighted in the solution text. The answer text describes each step of computation, and the student must determine when and why specific values are generated.

Keywords: Fundamental of material balance, Calculation, Mass and energy balance, Engineering, Problem-solving

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SOLVED PROBLEMS

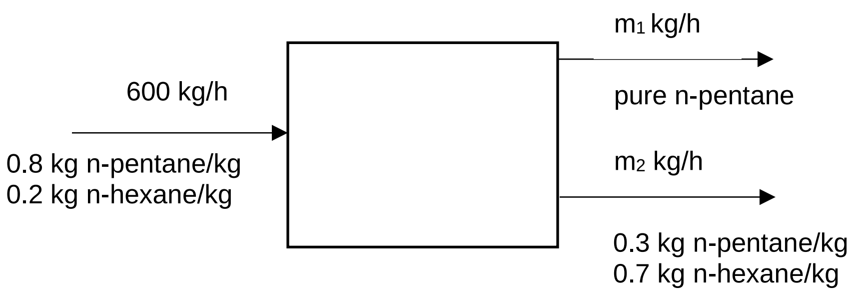
FUNDAMENTAL OF MATERIAL BALANCE

1. Material balances on a non-reactive system:
   a. Single unit separation

Example 1

A flash separator that operates at a steady state receives 600 kg/h of a mixture containing 80% n-pentane and 20% n-hexane. Only n-pentane is present in the top product stream, but 30% of the mass of the bottom streams contains n-pentane. Calculate the flow rate of both products leaving the separator.

Step 1: Draw the flow chart of the single-unit process.



Method I:

Overall balance:

$$\text{INPUT} = \text{OUTPUT}$$

$$m_1 + m_2 = 600$$

$$m_1 = 600 - m_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

**Strategy: Use the mass balance of the components involved*

Mass balance n-hexane:

$$\text{INPUT} = \text{OUTPUT}$$

$$600\ (0.2) = m_2\ (0.7)$$

$$m_2 = 171.429 \text{ kg/h}$$

From Equation 1:

$$m_1 = 600 – 171.429$$

$$m_1 = 428.57 \text{ kg/h}$$

Therefore, the flow rate of the top and bottom products is 428.57 kg/h and 171.429 kg/h, respectively.

Method II:

Overall balance:

$$\text{INPUT} = \text{OUTPUT}$$

$$m_1 + m_2 = 600$$

$$m_1 = 600 – m_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Mass balance n-pentane:

$$\text{INPUT} = \text{OUTPUT}$$

$$600\ (0.8) = 1\ (m_1 + 0.3m_2)$$

$$480 = 1\ (m_1 + 0.3m_2)$$

$$480 = 600 - m_2 + 0.3m_2$$

$$0.7m_2 = 120$$

$$m_2 = 171.429 \text{ kg/h}$$

From Equation 1:

$$m_1 = 600 – 171.429$$

$$m_1 = 428.57 \text{ kg/h}$$

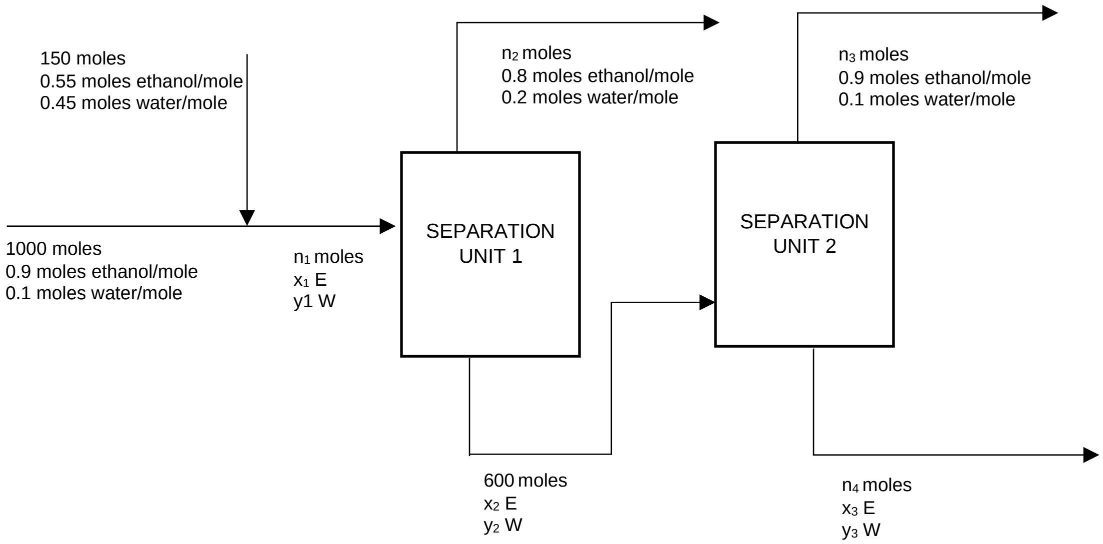
Therefore, the flow rate of the top and bottom products is 428.57 kg/h and 171.429 kg/h, respectively.

b. Multiple unit process

Example 2

150 moles of a 55 mol% aqueous ethanol stream are combined with 1000 moles of fresh feed with a 90% amount of ethanol; the rest is water. The mixture enters a separation unit, which divides it into two streams. A top stream exit comprises 80% ethanol and the remainder is water. The 600-mole stream enters a second separating unit. The second unit produces a top stream of 90% ethanol and 10% water, while the bottom stream is unknown. Determine the composition of the bottom stream leaving the second separation unit if the two top streams leaving the separation units have the same flow rate.

First step: Draw the flow chart of the multiple-unit process.



Total feed:

$$n_1 = 1000 \text{ moles} + 150 \text{ moles}$$
$$= 1150 \text{ moles}$$

**Strategy: Use the mass balance of the components involved*

Mass balance ethanol (feed):

$$\text{INPUT} = \text{OUTPUT}$$
$$1000\,(0.9) + 150\,(0.55) = 1150\,(x_1)$$
$$x_1 = 0.8543$$

Then,

$$y_1 = 1 - 0.8543$$
$$y_1 = 0.1457$$

Separation unit 1 balance:

$$\text{INPUT} = \text{OUTPUT}$$
$$n_1 = n_2 + n_3$$
$$1150 = n_2 + 600$$
$$n_2 = 550 \text{ moles}$$

Mass balance ethanol at separation unit 1:

$$\text{INPUT} = \text{OUTPUT}$$
$$1150\,(0.8543) = 550\,(0.8) + 600x_2$$
$$x_2 = 0.9041$$

Then,

$$y_2 = 1 - 0.9041$$
$$y_2 = 0.0959$$

Since

$$n_3 = n_2$$
$$n_3 = 550 \text{ moles}$$

Overall feed balance:

$$\begin{aligned} \text{INPUT} &= \text{OUTPUT} \\ n_1 &= n_2 + n_3 + n_4 \\ 1150 &= 550 + 550 + n_4 \\ n_4 &= 50 \text{ moles} \end{aligned}$$

Overall mass balance ethanol:

$$\begin{aligned} \text{INPUT} &= \text{OUTPUT} \\ 1000\,(0.9) + 150\,(0.55) &= 550\,(0.8) + 550\,(0.9) + 50x_3 \\ 982.5 &= 935 + 50x_3 \\ x_3 &= 0.95 \end{aligned}$$

Then,

$$\begin{aligned} y_3 &= 1 - 0.95 \\ y_3 &= 0.05 \end{aligned}$$

The composition of the bottom stream leaving the second separation unit is 50 moles output that contains a 0.95/0.05 ratio of ethanol/water.

2. Material balances on a reactive system:

Example 3

120 moles of aluminum are placed in a solution that contains 240 moles of sulphuric acid. Hydrogen gas and aluminum sulfate are produced in this reaction. The fractional conversion of Al is 0.7.

$$2Al + 3H_2SO_4 \rightarrow 3H_2 + Al_2(SO_4)_3$$

(a) Identify the limiting reactant.

(b) How many grams of excess reactant is consumed in this reaction?

(c) What is the mass of excess reactant remains after the reaction is complete?

The General Balance Equation:

Input – Output + Generation – Consumption = Accumulation

At steady state, accumulation = 0.
Therefore, the equation is simplified as below:

Input + Generation – Consumption = Output

$$\text{Consumption of Al} = 120\ (0.7) = 84 \text{ moles}$$

$$\text{Fractional conversion} = 0.7 = \frac{\text{120 moles of Al entering - moles of Al leaving}}{\text{120 moles of Al entering}}$$

$$(n_{Al})_{out} = 120 \text{ moles} - 84 \text{ moles} = 36 \text{ moles}$$

Method I:

The extent of reaction method:

Al:

$$(n_{Al})_{in} - (n_{Al})_{consumed} = (n_{Al})_{out}$$

$$120 \text{ moles Al} - 2\xi = 36 \text{ moles Al}$$

$$\xi = 42 \text{ moles}$$

H_2SO_4:

$$240 \text{ moles } H_2SO_4 - 3\xi = (n_{H_2SO_4})_{out}$$

$$(n_{H_2SO_4})_{out} = 240 - 3\,(42)$$

$$= 114 \text{ moles}$$

H_2:

$$(n_{H_2})_{out} = 3\xi$$

$$= 3\,(42)$$

$$= 126 \text{ moles}$$

$Al_2(SO_4)_3$:

$$\left(n_{Al_2(SO_4)_3}\right)_{out} = \xi$$

$$= 42 \text{ moles}$$

Method II:

The molecular species balance method:

H_2SO_4:

$$(n_{H_2SO_4})_{in} - \text{Consumption of } H_2SO_4 = (n_{H_2SO_4})_{out}$$

$$240 \text{ moles } H_2SO_4 - \left(\frac{3 \text{ moles } H_2SO_4 \text{ consumed}}{2 \text{ moles Al consumed}}\right)(84 \text{ moles Al}) = (n_{H_2SO_4})_{out}$$

$$(n_{H_2SO_4})_{out} = 114 \text{ moles}$$

$$\text{Consumption of } H_2SO_4 = 240 - 114$$

$$= 126 \text{ moles}$$

H_2:

$$(n_{H_2})_{out} = (84 \text{ moles Al consumed})\left(\frac{3 \text{ moles } H_2 \text{ generated}}{2 \text{ moles Al consumed}}\right) = 126 \text{ moles}$$

$$\text{Since Generation} = \text{Output}$$

$$\text{Generation of } H_2 = 126 \text{ moles}$$

$Al_2(SO_4)_3$:

$$(n_{Al_2(SO_4)_3})_{out} = (84 \text{ moles Al consumed})\left(\frac{1 \text{ moles } Al_2(SO_4)_3 \text{ generated}}{2 \text{ moles Al consumed}}\right) = 42 \text{ moles}$$

$$\text{Since Generation} = \text{Output}$$

$$\text{Generation of } Al_2(SO_4)_3 = 42 \text{ moles}$$

Method III:

The atomic species balance method:

Input + Generation – Consumption = Output

Generation = 0

* because atoms cannot be created in a chemical reaction

Consumption = 0

* because atoms cannot be destroyed in a chemical reaction

Therefore, balances on atomic species are written as:

Input = Output

Step 1:

Identify the element involved in the reaction.

Al H S O

Step 2:

Balance each element involved in the reaction.

Al:

$$(120 \text{ moles Al})\left(\frac{1 \text{ mole Al}}{1 \text{ mole Al}}\right) = (n_{Al})_{out}\left(\frac{1 \text{ mole Al}}{1 \text{ mole Al}}\right) + \left(n_{Al_2(SO_4)_3}\right)_{out}\left(\frac{2 \text{ mole Al}}{1 \text{ mole } Al_2(SO_4)_3}\right)$$

$$120 \text{ moles} = (n_{Al})_{out} + 2\left(n_{Al_2(SO_4)_3}\right)_{out}$$

$$120 \text{ moles} = 36 \text{ moles} + 2\left(n_{Al_2(SO_4)_3}\right)_{out}$$

$$\left(n_{Al_2(SO_4)_3}\right)_{out} = 42 \text{ moles}$$

S:

$$(240 \text{ mole } H_2SO_4)\left(\frac{1 \text{ mole S}}{1 \text{ mole } H_2SO_4}\right) = (n_{H_2SO_4})_{out}\left(\frac{1 \text{ moles S}}{1 \text{ mole } H_2SO_4}\right) + \left(n_{Al_2(SO_4)_3}\right)_{out}\left(\frac{3 \text{ mole S}}{1 \text{ mole } Al_2(SO_4)_3}\right)$$

$$240 \text{ moles} = (n_{H_2SO_4})_{out} + 3\left(n_{Al_2(SO_4)_3}\right)_{out}$$

$$(n_{H_2SO_4})_{out} = 240 - 3(42 \text{ moles})$$

$$(n_{H_2SO_4})_{out} = 114 \text{ moles}$$

H:

$$(240 \text{ moles } H_2SO_4)\left(\frac{2 \text{ moles H}}{1 \text{ mole } H_2SO_4}\right) = (n_{H_2SO_4})_{out}\left(\frac{2 \text{ moles H}}{1 \text{ mole } H_2SO_4}\right) + (n_{H_2})_{out}\left(\frac{2 \text{ moles H}}{1 \text{ mole } H_2}\right)$$

$$480 \text{ moles} = 2\,(114 \text{ moles}) + 2(n_{H_2})_{out}$$

$$(n_{H_2})_{out} = 126 \text{ moles}$$

3. Combustion reaction

Example 4

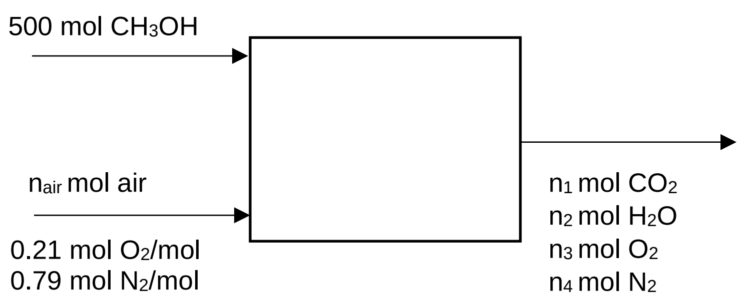
Methanol acts as an alternative fuel for internal combustion engines. The first reaction shows the complete combustion of methanol. A basis of 500 moles of methanol is fed to the reactor and the air is fed at 20% excess.

Complete combustion of methanol:

$$2CH_3OH + 3O_2 \rightarrow 2CO_2 + 4H_2O$$

Find moles of air fed to the reactor and moles of each component in the stack gas.

Step 1: Draw and label a flow chart.



$$\%\text{ Excess Air}=\frac{\text{moles of air fed-moles of air theoretical}}{\text{moles of air theoretical}}\times 100\%$$

$$\left(n_{O_2}\right)_{theoretical} = 500\text{ mol }CH_3OH \times \frac{3\text{ mol }O_2}{2\text{ mol }CH_3OH} = 750\text{ moles }O_2$$

$$\left(n_{air}\right)_{theoretical} = 750\text{ mol }O_2 \times \frac{1\text{ mol air}}{0.21\text{ mol }O_2} = 3571.429\text{ mol air}$$

$$20\% = \frac{n_{air} - 3571.429}{3571.429} \times 100\%$$

$$n_{air} = 4285.7148 \text{ mol}$$

Method I:

The extent of reaction method:

$$n_{out} = n_{in} + v_i \xi$$

CH_3OH:	$0 = 500 - 2\ \xi$ $\xi = 250$ moles
CO_2:	$n_1 = 0 + 2\ \xi$ $= 2\ (250)$ $= 500$ moles
H_2O:	$n_2 = 0 + 4\ \xi$ $= 4\ (250)$ $= 1000$ moles
O_2:	$n_3 = 0.21\ n_{air} - 3\ \xi$ $= 0.21\ (4285.7148) - 3\ (250)$ $= 150$ moles
N_2 balance:	In = Out $0.79\ n_{air} = n4$ $n_4 = 0.79\ (4285.7148)$ $n_4 = 3385.7147$ moles

Method II:

The molecular species balance method:

$$2CH_3OH + 3O_2 \rightarrow 2CO_2 + 4H_2O$$

Input – Output + Generation – Consumption = Accumulation

At steady state, accumulation = 0.

Therefore, the equation is simplified as below:

Input + Generation – Consumption = Output

CH_3OH:

$$(n_{CH_3OH})_{in} - \text{Consumption of } CH_3OH = (n_{CH_3OH})_{out}$$

$$500 \text{ moles } CH_3OH - \left(\frac{2 \text{ moles } CH_3OH \text{ consumed}}{3 \text{ moles } O_2 \text{ consumed}}\right)(n_{O_2 \text{ consumed}}) = (n_{CH_3OH})_{out}$$

$$500 - \left(\frac{2}{3}\right)(750) = (n_{CH_3OH})_{out}$$

$$(n_{CH_3OH})_{out} = 0 \text{ mole}$$

CO_2:

$$\text{Generation} = \text{Output}$$

$$\left((n_{CH_3OH})_{consumed}\right)\left(\frac{2 \text{ moles } CO_2 \text{ generated}}{2 \text{ moles } CH_3OH \text{ consumed}}\right) = (n_{CO_2})_{out}$$

$$(n_{CO_2})_{out} = 500\ (1)$$

$$(n_{CO_2})_{out} = 500 \text{ moles}$$

H_2O:

$$\text{Generation} = \text{Output}$$

$$\left((n_{CH_3OH})_{consumed}\right)\left(\frac{4 \text{ moles } Al_2(SO_4)_3 \text{ generated}}{2 \text{ moles } CH_3OH \text{ consumed}}\right) = (n_{H_2O})_{out}$$

$$(n_{H_2O})_{out} = 500\ (2)$$

$$(n_{H_2O})_{out} = 1000 \text{ moles}$$

O_2:

$$(n_{O_2})_{in} - \text{Consumption of } O_2 = (n_{O_2})_{out}$$

$$(0.21)(4285.7148) \text{ moles } O_2 - \left(\frac{3 \text{ moles } O_2 \text{ consumed}}{2 \text{ moles } CH_3OH \text{ consumed}}\right)\left(n_{CH_3OH \text{ consumed}}\right) = (n_{O_2})_{out}$$

$$900 - \left(\frac{3}{2}\right)(500) = (n_{O_2})_{out}$$

$$(n_{O_2})_{out} = 150 \text{ moles}$$

Method III:

The atomic species balance method:

Input + Generation – Consumption = Output

Generation = 0

* because atoms cannot be created in a chemical reaction

Consumption = 0

* because atoms cannot be destroyed in a chemical reaction

Therefore, balances on atomic species are written as:

Input = Output

Step 1:

Identify the element involved in the reaction.

C H O

Step 2:

Balance each element involved in the reaction.

C:

$$(500 \text{ moles } CH_3OH)\left(\frac{1 \text{ mole C}}{1 \text{ mole } CH_3OH}\right) = (n_{CH_3OH})_{out}\left(\frac{1 \text{ mole C}}{1 \text{ mole } CH_3OH}\right) + (n_{CO_2})_{out}\left(\frac{1 \text{ mole}}{1 \text{ mole C}}\right)$$

$$500 \text{ moles} = 0 + (n_{CO_2})_{out}$$

$$(n_{CO_2})_{out} = 500 \text{ moles}$$

H:

$$(500 \text{ moles } H_2SO_4)\left(\frac{4 \text{ moles H}}{1 \text{ mole } CH_3OH}\right) = (n_{CH_3OH})_{out}\left(\frac{4 \text{ mole H}}{1 \text{ mole } CH_3OH}\right) + (n_{H_2O})_{out}\left(\frac{2 \text{ mole H}}{1 \text{ mole } H_2O}\right)$$

$$2000 \text{ moles} = 4(n_{CH_3OH})_{out} + 2(n_{H_2O})_{out}$$

$$2(n_{H_2O})_{out} = 2000 \text{ moles} - 4\ (0)$$

$$(n_{H_2O})_{out} = 1000 \text{ moles}$$

O:

$$(500 \text{ moles } CH_3OH)\left(\frac{1 \text{ mole O}}{1 \text{ mole } CH_3OH}\right) + ((0.21)(4285.7148) \text{ moles } O_2)\left(\frac{2 \text{ mole O}}{1 \text{ mole } O_2}\right) = (n_{CH_3OH})_{out}\left(\frac{1 \text{ mole O}}{1 \text{ mole } CH_3OH}\right) + (n_{O_2})_{out}\left(\frac{2 \text{ mole O}}{1 \text{ mole } O_2}\right) + (n_{CO_2})_{out}\left(\frac{2 \text{ mole O}}{1 \text{ mole } CO_2}\right) + (n_{H_2O})_{out}\left(\frac{1 \text{ mole O}}{1 \text{ mole } H_2O}\right)$$

$$(500 + 1800) \text{ moles} = (n_{CH_3OH})_{out} + 2(n_{O_2})_{out} + 2(500\ moles) + (n_{H_2O})_{out}$$

$$2(n_{O_2})_{out} + (n_{H_2O})_{out} = 1300 \text{ moles}$$

$$2(n_{O_2})_{out} + 1000 \text{ moles} = 1300 \text{ moles}$$

$$(n_{O_2})_{out} = 150 \text{ moles}$$

Example 4

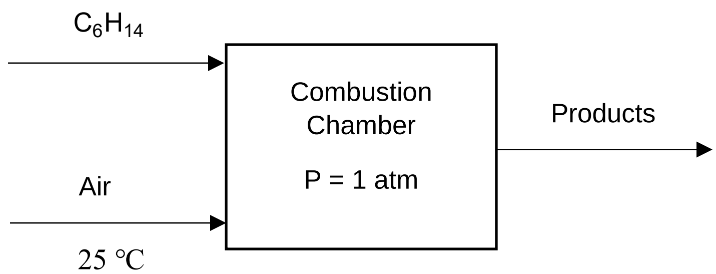
Hexane is burned with 65% excess air during the combustion process. Determine

i. the AF ratio on a mass and a mole basis
ii. the dew point temperature of the products

The combustion equation:

$$C_6H_{14} + xO_2 + 3.76xN_2 \rightarrow yCO_2 + zH_2O + 3.76xN_2$$

Fuel + Air → Products



Method I:

Mass basis:

C:	1 (6) = y (1) y = 6 kg mol
H:	1 (14) = z (2) z = 7 kg mol
O:	x (2) = 6 (2) + 7 (1) x = 9.5 kg mol
N:	3.76 (9.5) = 35.72 kg mol

Thus, the equation becomes as follows:

$$C_6H_{14} + 9.5O_2 + 35.72N_2 \rightarrow 6CO_2 + 7H_2O + 35.72N_2$$

↓ 65% excess air

$$C_6H_{14} + (1+0.65)(9.5O_2 + 35.72N_2) \rightarrow 6CO_2 + 7H_2O + (1+0.65)35.72N_2 + aO_2$$

O: (1.65)(9.5)(2) = 6(2) + 7(1) + a (2)

a = 6.175 kg mol

Hence, the balanced equation with excess air can be written as:

$$C_6H_{14} + 15.675O_2 + 58.938N_2 \rightarrow 6CO_2 + 7H_2O + 58.938N_2 + 6.175O_2$$

Fuel Air

Remember the atomic weight of these elements:

O = 16

N = 14

C = 12

H = 1

$$AF_{actual} = \frac{m_{air,actual}}{m_{fuel}} = \frac{kg\ air}{kg\ fuel} = \frac{15.675\ O_2 + 58.938N_2}{C_6H_{14}}$$

$$AF_{actual} = \frac{15.675\ (16 \times 2) + 58.938\ (14 \times 2)}{(12 \times 6) + (1 \times 14)}$$

$$AF_{actual} = 25.02\ \frac{kg\ air}{kg\ fuel}$$

$$C_6H_{14} + 9.5O_2 + 35.72N_2 \rightarrow 6CO_2 + 7H_2O + 35.72N_2$$

Fuel Air

$$AF_{theo.} = \frac{m_{air,\ theo.}}{m_{fuel}} = \frac{kg\ air}{kg\ fuel} = \frac{9.5\ O_2 + 35.72N_2}{C_6H_{14}}$$

$$AF_{theo.} = \frac{9.5\,(16 \times 2) + 35.72\,(14 \times 2)}{(12 \times 6) + (1 \times 14)}$$

$$AF_{theo.} = 15.16\ \frac{\text{kg air}}{\text{kg fuel}}$$

Method II:

Assume

$$Air_{theo.}, a_{th.} = x$$

Combustion equation:

How? Ratio 79/21=3.76

$$C_6H_{14} + 1.65x\,[O_2+3.76N_2] \rightarrow 6CO_2 + 7H_2O + 0.65xO_2 + (1.65x3.76)xN_2$$

O_2 balance: $1.65x = 6 + 3.5 + 0.65x$

$$x = 9.5$$

Substituting:

$$C_6H_{14} + 15.675[O_2 + 3.76N_2] \rightarrow 6CO_2 + 7H_2O + 6.175O_2 + 58.938N_2$$

$$AF_{actual} = \frac{m_{air,actual}}{m_{fuel}} = \frac{\text{kg air}}{\text{kg fuel}} = \frac{(15.675 \times 4.76\ \text{kmol})(\frac{29\text{kg}}{\text{kmol}})}{(6\text{kmol})\left(\frac{12\text{kg}}{\text{kmol}}\right) + (7\text{kmol})(\frac{2\text{kg}}{\text{kmol}})} = 25.16\ \frac{\text{kg air}}{\text{kg fuel}}$$

$$AF_{theo.} = \frac{m_{air,\ theo.}}{m_{fuel}} = \frac{\text{kg air}}{\text{kg fuel}} = \frac{9.5(4.76)(29)}{86} = 15.25\ \frac{\text{kg air}}{\text{kg fuel}}$$

Mole basis:

$$AF_{actual} = \frac{n_{air,actual}}{n_{fuel}} = \frac{(15.675 \times 4.76 \text{ kmol})}{1 \text{ kmol fuel}} = 74.613 \frac{\text{kmol air}}{\text{kmol fuel}}$$

$$AF_{theo.} = \frac{n_{air,\ theo.}}{n_{fuel}} = \frac{9.5\ (4.76 \text{ kmol})}{1 \text{ kmol fuel}} = 45.22 \frac{\text{kmol air}}{\text{kmol fuel}}$$

Solution for Question (ii)

$n_{products}$ = 6 + 7 + 6.175 + 58.938 = 78.113 kmol

$$\text{Partial pressure water vapour, } P_v = \left(\frac{n_v}{n_{total.}}\right) P_{total}$$

$$P_v = \left(\frac{7 \text{ kmol}}{78.113 \text{ kmol}}\right)(101.325 \text{ kPa}) = 9.0801 \text{ kPa}$$

From the saturated water-temperature table,

Temperature/℃	Pressure/kPa
40	7.3851
x	9.0801
45	9.5953

Using interpolation,

$$\frac{x - 40}{9.0801 - 7.3851} = \frac{45 - 40}{9.5953 - 7.3851}$$

$$x = 43.83℃$$

$$T_{dp} = T_{sat@9.0801kPa} = 43.83℃$$

Info: T_{dp} of gas-vapor mixture is the saturation temperature of water vapor in the product gases corresponding to its partial pressure.

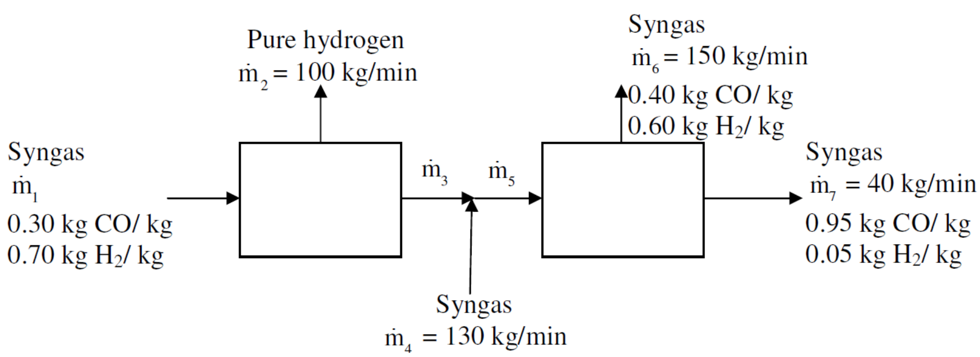
EXERCISES

Exercise

1. A liquid mixture containing 30mol% benzene (B), 25mol% toluene (T), and the balance xylene (X) is fed to a distillation column. The bottom product contains 98 mol% X and no B, and 96% of the X in the feed is recovered in this stream. The overhead product is fed to a second column. The overhead product from the second column contains 97% of the B in the feed to this column. The composition of this stream is 94mol% B and the balance T.
   a) Draw a process flowchart with labelling variables
   b) Calculate all unknown variables in the process flow chart

Answer :

2. Hydrogen can be produced by the processes of coal gasification and methane steam reforming. Both processes generate syngas as a by-product, which contains CO and H_2. The syngas obtained by the coal gasification process will be fed to a water gas shift reactor to produce pure hydrogen for use in Proton Exchange Membrane Fuel Cells (PEMFC). The unreacted syngas combine with a stream of syngas exiting a steam methane reforming reactor and entering a purification unit. The product stream from the purification process will be stored for use in Solid Oxide Fuel Cells (SOFC). A diagram of this process is shown below:



a) Calculate the mass flow rate of streams m_3 and m_5

b) Calculate the composition of syngas in-stream m_4

Answer :

3. The chlorination reaction of methane (CH_4) is as follows:

$$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$$

If the feed comprises CH_4 30 mol%, Cl_2 60 mol%, and N_2 10 mol% and the percentage conversion of the limiting reactant is 90%.

a) Draw a process flowchart with labelling variables
b) Identify the reactant is limiting
c) Calculate the percentage excess of reactant
d) Calculate the molar products of each species using:-
   i. The extent of reaction method
   ii. The molecular species balance method
   iii. The atomic species balance method

Answer :

i. The extent of reaction method

ii. The molecular species balance method

iii. The atomic species balance method

4. Acrylonitrile is produced by the reaction of propylene, ammonia, and oxygen.

$$C_3H_6 + NH_3 + \frac{3}{2}O_2 \rightarrow C_3H_3N + 3H_2O$$

The feed contains 8 mol% propylene, 12 mol% ammonia, and 80 mol% air (21% Oxygen dan 79% Nitrogen) by assuming 100 mol/s as the basic calculation.

a) Identify the reactant is limiting

e) Calculate the molar product of each species using :-

i. The extent of reaction method

ii. The molecular species balance method

iii. The atomic species balance method

Answer :

i. The extent of reaction method

ii. The molecular species balance method

iii. The atomic species balance method

5. Octane is fed into a burner with 20% excess air. Assuming complete combustion occurs.
    a) the AF ratio on a mass and a mole basis
    b) the dew point temperature of the products

Answer :

6. One hundred mol/h of Nonane and 8000 mol/h of air are fed into a combustion reactor.

   a) Calculate the percent excess Air

   b) Calculate the air-fuel ratio for theoretical and excess conditions.

Answer :

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REFERENCES

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