The University of Jordan
Faculty of Engineering & Technology
Chemical Engineering Department

(0905211) Chemical Engineering Principles — **Second Semester – 2015/2016**

Second Midterm Exam

Name: عبدالله الشنواب — ID # 0147452

Dear students:

Answer all questions to the best of your ability and knowledge.

Start with the easiest question to you. Use only the available space.

Don't waste your time on the questions that you are not confident about.

You know that cheating is not accepted and you would not need it anyway!

Good Luck!

Question #	Gained points	Full points
1	15	15
2	26	35
Total	41	50

Question 1: [15 points] 15

Ammonia (NH_3) is burned with oxygen to form nitric oxide (NO) and water as follows:

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$$

1- Calculate the stoichiometric ratio (lb-moles O_2 reacts / lb-moles NO formed).

2- If 3.0 kmol of ammonia and 3.0 kmol of oxygen are fed to a batch reactor, determine:

a. the limiting reactant,

b. the percentage by which the other reactant in excess,

c. the extent of reaction if 2.0 kmol of NO is formed, ~~and~~

d. the extent of reaction if the reaction proceeds to completion.

(1) $\frac{\text{lb-moles } O_2}{\text{lb-moles NO}} = \frac{5}{4}$ 3

(2)

(a) $\frac{3}{4} = 0.75$ $\frac{3}{5} = 0.6$

O_2 L.R 3

(b) % excess $= \frac{3-2.4}{2.4} = 25\%$ 3

$n_{stoich} = \frac{3 \text{ kmol } O_2 \mid 4 \text{ kmol } NH_3}{\mid 5 \text{ kmol } O_2}$

$= 2.4$ kmol NH_3

(c) $2 = 0 + 4\xi$

$\xi = \frac{1}{2}$ kmol NO 3

(d) $0 = 3 - 5\xi$

$\xi = 0.6$ kmol O_2 3

$0.25\,\dot{n}_3 = \dot{n}_6 \longrightarrow C_4H_{10}$ balance

$\dot{n}_5 = z_4\,\dot{n}_4 \longrightarrow C_3H_6$ balance

$\dot{n}_6 = y_4\,\dot{n}_4 \longrightarrow C_4H_{10}$ balance

$\dot{n}_7 = x_4\,\dot{n}_4 \longrightarrow C_6H_6$ balance

$\dot{n}_5 = 0.15\,\dot{n}_3 \longrightarrow$ Conversion 80% 2

$6\dot{n}_2 + 3.25\dot{n}_3 = 6\dot{n}_7 + \dot{n}_3 + 0.45\dot{n}_3 + 45000$

$7.98\dot{n}_7 + 1.8\dot{n}_3 =$

$1.98\dot{n}_7 + 1.8\dot{n}_3 = 45000 \longrightarrow (1)$

H balance $6\dot{n}_2 + 7\dot{n}_3 = 6\dot{n}_7 + 10\dot{n}_6 + 6\dot{n}_5 + 60000$

$7.98\dot{n}_7 + 7\dot{n}_3 = 6\dot{n}_7 + 2.5\dot{n}_3 + 0.9\dot{n}_3 + 60000$

$1.98\dot{n}_7 + 3.6\dot{n}_3 = 60000 \rightarrow (2)$

$-1.98\dot{n}_7 - 1.8\dot{n}_3 = -45000$

$1.8\dot{n}_3 = 15000$

$\boxed{\dot{n}_3 = 8333.3 \text{ mol/h}}$ → جواب: فرع (c)

(d)

$\boxed{\dot{n}_5 = 1249.9 \text{ mol } C_3H_6/h}$

$\boxed{\dot{n}_6 = 2083.3 \text{ mol } C_4H_{10}/h}$

→ جواب (d) → $x = 0.37$ mol C_3H_6/mol

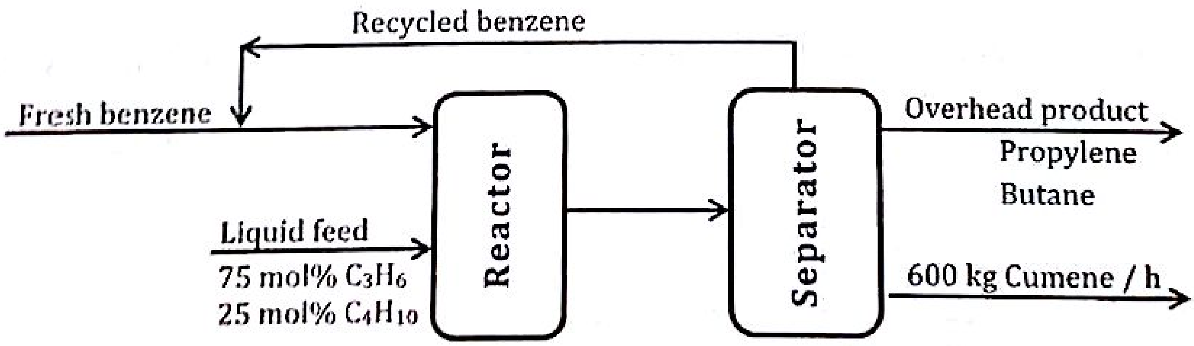
$1 - x = 0.63$ mol C_4H_{10}/mol

Question 2: [35 points]

Cumene (C_9H_{12}) is produced by reacting benzene (C_6H_6) with propylene (C_3H_6).

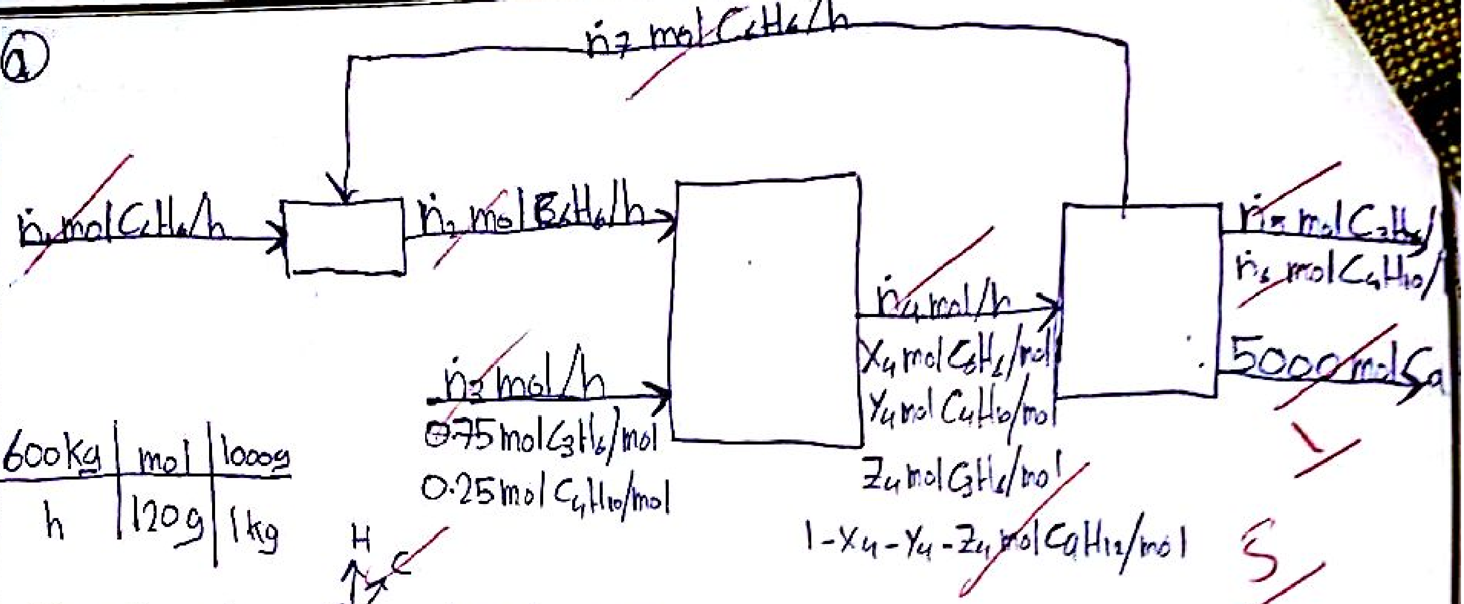
$$C_6H_6 + C_3H_6 \rightarrow C_9H_{12}$$

A liquid feed containing 75 mol% propylene and 25% n-butane (C_4H_{10}, inert) and a second stream containing **pure benzene are fed** to the reactor. **Fresh benzene** and **recycled benzene** are mixed in a 1:3 ratio (1 mole fresh feed/3 moles recycle). The reactor effluent is fed to a separator consisting of two distillation columns. All the butane and unreacted propylene are removed as **overhead product**. The unreacted benzene is also separated and recycled to be mixed with the fresh benzene feed. The overall conversion of propylene is 80%. The production rate of cumene (MW = 120 g/mol) is 600 kg/h. A simplified sketch of the process is shown below.



a) Draw a completely labeled flowchart, and do an ***overall DOF*** analysis.
b) Why was n-butane considered as an inert?
c) Calculate the molar flow rates of the ***two streams*** ***fed to the reactor***.
d) Find the composition of the overhead product.
e) Calculate the single-pass conversion of benzene.

(a)



$$\frac{600\,kg}{h}\left|\frac{mol}{120\,g}\right|\frac{1000\,g}{1\,kg}$$

1 5

$$DOF = 4 - 2 - 1 \mp 1 = 0$$

($4 \to \dot{n}_1, \dot{n}_7, \dot{n}_5, \dot{n}_6$; $2 \to$ H, C; $1 \to C_4H_{10}$; $1 \to 600$ kg/h)

4

(b) To prevent buildup of C_4H_{10}

2

(c) $\frac{\dot{n}_1}{\dot{n}_7} = \frac{1}{3}$ → Recyclye Ratio

1

$\dot{n}_7 = 3\dot{n}_1$ $\dot{n}_1 = \frac{\dot{n}_7}{3}$

C balance

$$6\dot{n}_2 + 2.25\dot{n}_3 + \dot{n}_3 = (6x_4 + 4y_4 + 3z_4 + 9(1-x_4-y_4-z_4))\dot{n}_4$$

$$6\dot{n}_2 + 3.25\dot{n}_3 = 6\dot{n}_7 + 4\dot{n}_6 + 3\dot{n}_5 + 45000$$ 1

C_6H_6 balance $\dot{n}_1 + \dot{n}_7 = \dot{n}_2$

$\boxed{\dot{n}_2 = 4\dot{n}_1}$ $\boxed{\dot{n}_2 = 1.33\dot{n}_7}$

$$\boxed{\dot{n}_4 = \dot{n}_5 + \dot{n}_6 + \dot{n}_7 + 5000}$$

3/

(e) Single pass $= \dfrac{\dot{n}_2 - X_4\dot{n}_4}{X_4 \dot{n}_4} \; \dot{n}_2 = \dfrac{38055.25 - 28541.45}{28541.45}$

$= 33.3\%$

$\boxed{\dot{n}_4 = 36874.65 \text{ mol/h}}$

C balance $6\dot{n}_1 = 57082.9$?

$\dot{n}_1 = 9513.8 \text{ mol } C_6H_6/h$

$\boxed{\dot{n}_7 = 28541.45 \text{ mol } C_6H_6/h}$

$\dot{n}_1 = 9513.8 \text{ mol/h}$

Overall $\dot{n}_1 + \dot{n}_7 = \dot{n}_2$

$\boxed{\dot{n}_2 = 38055.25 \text{ mol B/h}}$

(c)

(c) $\dot{n}_3 = 8333.3 \text{ mol/h}$ $\dot{n}_2 = 38055.25 \text{ mol B/h}$

(d) $0.37 \text{ mol } C_3H_6/\text{mol}$ $0.63 \text{ mol } C_4H_6/\text{mol}$

(e) 33.3%