UNIVERSITY OF
KWAZULU-NATAL
INYUVESI
YAKWAZULU-NATALI

SCHOOL OF ENGINEERING

MAIN EXAMINATIONS: JUNE 2019

COURSE AND CODE: MASS AND ENERGY BALANCES ENCH2MB

DURATION: 2 HOURS

TOTAL MARKS: 80

INTERNAL EXAMINER: DR K OSMAN

INTERNAL MODERATOR: MR MG NTUNKA

EXTERNAL MODERATOR: DR M LASICH

INSTRUCTIONS:

1. **ALL** questions should be attempted.
2. Any programmable or non-programmable calculator may be used provided it has been cleared of any information that would subvert the purpose of the examination.
3. Calculations must be shown in sufficient detail to illustrate your understanding of the procedure.
4. A data and equation sheet is provided on page 5.
5. A Degree of Freedom Table is provided on page 6 for Question 2. **Please detach and submit with your Answer Book.**

QUESTION 1

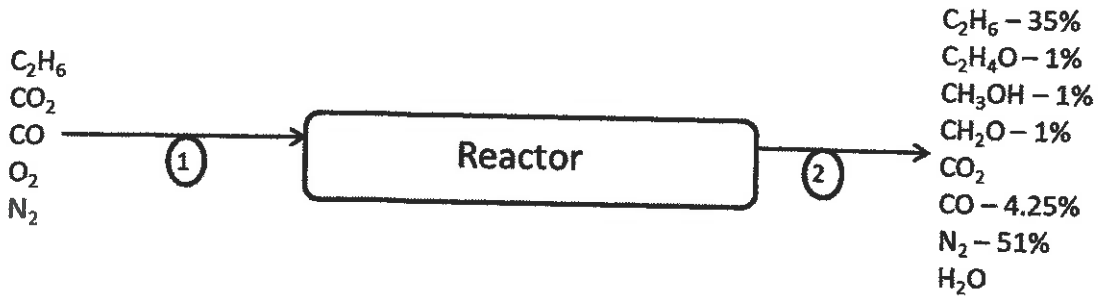

Figure 1 – Ethane Oxidation Reactor

The important chemical intermediate acetaldehyde (C_2H_4O) can be catalytically produced from partial oxidation of ethane. The primary reaction is

$$C_2H_6 + O_2 \rightarrow C_2H_4O + H_2O \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

There are a number of side reactions which also occur to a significant degree:

$$C_2H_6 + 7/2O_2 \rightarrow 2CO_2 + 3H_2O \ldots\ldots\ldots\ldots\ldots (2)$$

$$C_2H_6 + 3/2O_2 \rightarrow CH_3OH + CO + H_2O \ldots\ldots (3)$$

$$CH_3OH + 1/2O_2 \leftrightarrow CH_2O + H_2O \ldots\ldots\ldots\ldots (4)$$

$$2CO + 3H_2O \leftrightarrow C_2H_6 + 5/2O_2 \ldots\ldots\ldots\ldots\ldots (5)$$

Under a given set of operating conditions with the reactor inlet stream 1 consisting of 10 mol C_2H_6 per 1 mol CO, the reactor outlet stream is found to contain 35% C_2H_6, 1% C_2H_4O, 1% CH_3OH, 1% CH_2O, 4.25 % CO, and 51% N_2 (by mole), along with some CO_2 and H_2O. The total molar flow rate of the reactor outlet (stream 2) is 400 mol/hr.

NB. All reactions are **independent**. You are **not required** to draw up a degree of freedom table for this question.

If the overall reaction rate for reaction (2) is (r_2 = 2 mol/hr), calculate the molar flow rate of each species in stream 1.

TOTAL /20/

QUESTION 2

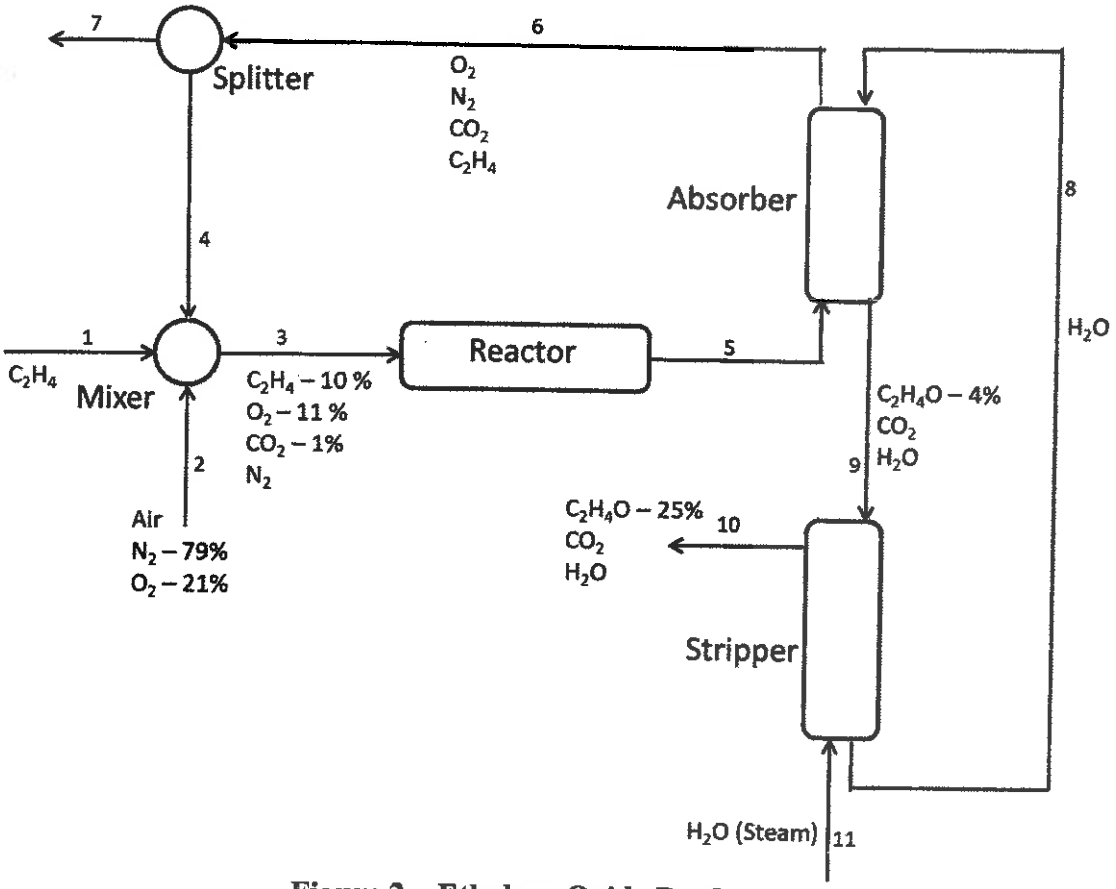

Figure 2 – Ethylene Oxide Production

Ethylene is mixed with air to produce ethylene oxide using a silver catalyst in a reactor. The reaction is a partial oxidation:

$$2C_2H_4 + O_2 \rightarrow 2C_2H_4O \quad \text{.....(1)}$$

An undesirable side reaction also occurs:

$$C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O \quad \text{.....(2)}$$

The process flow sheet is shown below. The reactor inlet molar composition contains 10% C_2H_4, 11% O_2, 1% CO_2 and the rest nitrogen and the reactor outlet stream contains 2 moles of CO_2 per mole of H_2O. Air supplied to the mixer contains an oxygen to nitrogen mole ratio of 21:79.

Ethylene oxide produced in the reactor is separated from ethylene using an absorber. Due to a low conversion of 25% of ethylene in the reactor per pass, the absorber overhead gases are recycled to be remixed with the fresh ethylene feed to the reactor. However, in order to prevent the accumulation of nitrogen in the process, the recycled gas stream is split and a portion is purged from the process.

QUESTION 2 continued ...

The liquid stream from the absorber (stream 9) contains 4 mole % C_2H_4O and is fed to a stripper which uses steam to strip all of the ethylene oxide and the CO_2 so that the gaseous product (stream 10) contains 25 mole% C_2H_4O. The stripped liquid (stream 8) contains only water which is then used as the absorbent in the absorber.

a) Explain whether the reactions in the reaction system shown in Figure 2 are independent or not.

(2)

b) Prepare a degree of freedom table provided for species balances. Is the problem correctly specified? Where should the solution begin? Explain your initial strategy.

(15)

TOTAL /17/

QUESTION 3

Calculate the work in [J/mol] of mechanical reversible isothermal compression of 1 mole of Dimethyl Sulphide from 1 bar to 40 bar at 398 K using the Virial equation of state:

$$z = \frac{PV}{RT} = 1 + B'P + C'P^2$$

The virial coefficients of Dimethyl Sulphide are:

B = -207.5 cm^3/mol C = 18200 cm^6/mol

N.B. $$B' = \frac{B}{RT} \quad ; \quad C' = \frac{C - B^2}{(RT)^2}$$

Some useful equations are provided in the data sheet on page 5.

TOTAL /15/

QUESTION 4

A catalytic reactor is charged with 600 moles/hr of feed at 400°C and at 5 bar, consisting of H_2 and CO_2.

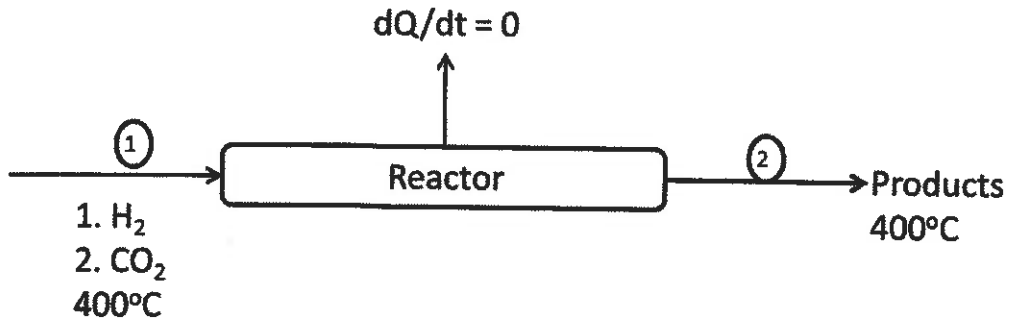

Figure 3 – Methane Production

The molar ratio of H_2 to CO_2 in the feed is 5 mol H_2 to 1 mol CO_2. The following reactions occur in the reactor:

1. $CO_2\ (g) + H_2\ (g) \rightarrow CO\ (g) + H_2O\ (g)$
2. $CO\ (g) + 3H_2\ (g) \rightarrow CH_4\ (g) + H_2O\ (g)$

90% conversion of CO_2 is observed. If the reactor operates adiabatically and the product temperature is 400°C, write down species material balances and energy balances and use them to find the molar flow rate of each component in the product stream.

NB: Pressure effects may be assumed to be negligible and the enthalpy of vapourisation of H_2O is 40.65 kJ/mol at 151.8 °C and 5 bar.

Data is provided in the data sheet on page 5.

TOTAL /28/

SUPPLEMENTARY MATERIAL AND DATA SHEET

Universal gas constant:

8.314	$J\ K^{-1}mol^{-1}$
83.14	$cm^3\ bar\ K^{-1}\ mol^{-1}$
8.314	$m^3\ Pa\ K^{-1}\ mol^{-1}$
8.314×10^{-5}	$m^3\ bar\ K^{-1}\ mol^{-1}$
8314	$cm^3\ kPa\ mol^{-1}\ K^{-1}$

Important equations:

$Q = {}_{T1}\int^{T2} C_V dT$ $\qquad$ $W = -RT\ln(P_1/P_2)$

$Q = {}_{T1}\int^{T2} C_P dT$ $\qquad$ $W = [(RT_1)/(\gamma - 1)][(P_2/P_1)^{(\gamma-1)/\gamma} - 1]$

$W = {}_{V1}\int^{V2} -PdV$ $\qquad$ $P_1V_1^{\gamma} = P_2V_2^{\gamma} = \text{constant}$

Data for Question 4:

	Average Cp coefficients (kJ/mol.K)	ΔH_f^0 (kJ/mol)
CO_2 (g)	0.0190	-393.8
H_2 (g)	0.0176	0
CO (g)	0.0290	-110.6
CH_4 (g)	0.0384	-74.9
H_2O (ℓ)	0.0183	-242.0
H_2O (g)	0.0340	-

STUDENT NUMBER: _____

DETACH THIS PAGE AND SUBMIT WITH YOUR ANSWER BOOK.

TABLE 1: DOF ANALYSIS FOR QUESTION 2

	Mixer	Reactor	Absorber	Stripper	Splitter	Process	Overall
No. Indep. Variables							
No. Indep. Balances							
Indep. Specified: **Compositions** **Flows**							
Subsidiary relations:							
DOF							