SCHOOL OF ENGINEERING

EXAMINATIONS: NOVEMBER 2017

COURSE AND CODE: CHEMICAL ENGINEERING PRINCIPLES 2 ENCH11EB

DURATION: 2 HOURS

TOTAL MARKS: 100

INTERNAL EXAMINERS: MRS N MASEKO
ASSOCIATE PROF P NAIDOO

INTERNAL MODERATOR: DR S MOODLEY

EXTERNAL MODERATOR: DR SL KIAMBI

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. Two answer books are provided. Label them Book A and Book B.
   Answer Section A in Book A and Section B in Book B.
SECTION A

QUESTION 1

A catalytic reactor is used to produce formaldehyde from methanol according to the reaction

\[ CH_3OH \rightarrow HCHO + H_2 \]

Fresh methanol and the recycled gas are mixed to form a mixture with a composition of 71 mol% methanol and the remainder hydrogen. This stream is then fed into the catalytic reactor to form formaldehyde. A single pass conversion of 90% is achieved in the reactor. The reactor effluent is then scrubbed with water in the absorber to remove all of the formaldehyde product as a 67 wt% aqueous solution. A portion of the product gas leaving the top of the absorber is recycled while the remainder is incinerated. The process is described by the below flowchart.

*Use a basis of 100 mol/h for the reactor feed.

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a) Perform a degree of freedom analysis around the reactor.

b) Calculate the flow rate of the recycle stream and its composition.

c) Determine the flow rates of hydrogen and methanol found in the purge stream.

d) Calculate the molar flow rate of methanol in the fresh feed.

e) What is the overall conversion of methanol.

f) Describe in your own words the need for a purge and a recycle stream.

TOTAL /25/
QUESTION 2

Methane is burned with air in a continuous steady-state combustion reactor to yield a mixture of carbon dioxide, carbon monoxide, and water. The reactions taking place are:

\[
CH_4 + \frac{3}{2}O_2 \rightarrow CO + 2H_2O
\]

\[
CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O
\]

The feed to the reactor contains 7.8 mole% CH₄, 19.4 mole% O₂, and 72.8 mole% N₂. The percentage conversion of methane is 90.0% and the gas leaving the reactor contains 0.78 mol of CO.

a) Draw and fully label a flow chart and do a degree of freedom analysis.

b) Taking basis of 100 mol/s of the reactor feed, determine the molar flow rate of CH₄, CO₂, H₂O, O₂ and N₂ coming out of the reactor.

c) Determine the composition of this stack gas on a dry basis.

d) What is the percentage yield of CO₂?

e) What is the selectivity of CO₂ production relative to CO production?

TOTAL /25/
SECTION B

QUESTION 3

Steam is initially contained in a rigid container at \( P = 25 \) MPa and \( \mathcal{V} = 10^{2.507} \text{ cm}^3/\text{mol} \). The cylinder is allowed to cool to 295 °C.

What is the pressure, quality and overall internal energy of the final mixture?

DATA

Steam tables are provided on PAGES 6 - 8.

TOTAL /15/
QUESTION 4

Ethanol is produced by the hydration of ethylene as shown in reaction 1. The reaction is carried out with an excess of high pressure steam at 320 °C. Some of the product is converted to diethyl ether in the side reaction (2).

\[
C_2H_4 (g) + H_2O (g) \rightarrow C_2H_5OH (g) \quad \text{Reaction 1}
\]
\[
2 C_2H_5OH (g) \rightarrow (C_2H_5)_2O (l) + H_2O (g) \quad \text{Reaction 2}
\]

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<tr>
<th>54 mol% (C_2H_4)</th>
<th>52.7 mol% (C_2H_4)</th>
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<td>10 mol% (\text{Inert (N}_2)</td>
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The fractional conversion of ethylene is 5 %, and the selectivity of ethanol production relative to the ether production is 18 mol/mol.

a) Calculate the standard heats of reactions \(\Delta H^0_{r_1}\) and \(\Delta H^0_{r_2}\) (kJ/mol).

b) Calculate the heat of reaction, \(\Delta H_{r_1}\), at 320 °C.

c) Calculate the heat of reaction, \(\Delta H_{r_2}\), at 320 °C.

d) Calculate the enthalpy of reactions (in kJ) at 320 °C.

e) The percentage conversion of the ethylene is very low. Why do you think the reactor would be designed to consume so little of the reactant?

f) What additional processing steps are likely to take place downstream from the reactor?

TOTAL 135/
QUESTION 4 continued ...

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<th>Constant ( \text{Cp (liquid)} ) (J/mol-K)</th>
<th>Constant ( \text{Cp (gas)} ) (J/mol-K)</th>
<th>( \Delta H_{\text{vap}}(T_b) ) kJ/mol</th>
<th>( \Delta H_f^\circ ) (^c) kJ/mol</th>
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\(^a\) Boiling point at 1 atm.

\(^b\) In the \( \text{Cp} \) equation, \( T \) is in °C.

\(^c\) At 1 atm and 25 °C.
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