UNIVERSITY OF TORONTO

FACULTY OF APPLIED SCIENCE AND ENGINEERING

FINAL EXAMINATION, APRIL 23, 2001: 9:30 – 12:00

JTC102S - PROCESS ENGINEERING

EXAMINER: T.A. UTIGARD

ANSWER ALL FOUR(4) QUESTIONS
Total of 4 pages

This exam is marked out of 100

NOTE: the memory of all calculators must be clear at the start of the exam

No aid sheet or any other written material

Data:

- Gas Constant: R = 0.082 l·atm/mol·K = 8.314 J/mol·K = 1.987 cal/mol·K
- 1 cal = 4.187 J; 1 W = 1 J/s
- 1 atm = 760 mmHg = 1.0132 bar = $1.0132 \cdot 10^5$ N/m^2 = $1.0132 \cdot 10^5$ Pa
- T(K) = T(°C) + 273
- Dry air: 79 mol% N_2 and 21 mol% O_2
- 1 m^3 = 1000 liters
- For Water – Vapour: $\text{Log}_{10}p^*(\text{mm Hg}) = A - B/[T(^\circ C) + C]$;
  where A = 8.10765; B = 1750.286; C = 235.00

Problem One [25 marks out of 100]:

Methane(CH_4) and oxygen react in the presence of a catalyst to form formaldehyde(HCHO). In an unwanted parallel side reaction, some of the methane is instead oxidized to carbon dioxide and water.

$$CH_4 + O_2 \rightarrow HCHO + H_2O$$
$$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O$$

The fresh feed to the process contains 100 mol/h of CH_4 and 50% excess air. The once-through (single pass) conversion of CH_4 in the reactor is 80%. The selectivity of HCHO over CO_2 is 15.0. The stream leaving the reactor enters a separator where all the CH_4 is separated from the rest of the stream. The separated CH_4 is recycled back and mixed with the fresh feed to the reactor. The other stream from the separator, the product stream containing HCHO, O_2, CO_2 and H_2O, leaves the process as a gas mixture.

a) (5 marks) draw a schematic process outline and label all streams based on the information given
b) (8 marks) calculate the production rate of HCHO in mol/h
c) (8 marks) determine the feed rate(mol/h) of CH_4 to the reactor
d) (4 marks) determine the composition(mol %) of the product gas mixture on a dry basis

Problem Two [25 marks out of 100]:

A chemical laboratory with the following dimensions(L = 10 m, W = 8 m, h = 3.5 m) is continuously ventilated with clean air at a rate of 1,500 m^3/hr at 20 °C and 1.0 atm. At some point there is an accidental leak of sulphur dioxide(SO_2) from a gas cylinder leading to the instantaneous release of 1.5 kg of SO_2 into the laboratory. From a safety and health point of view, the safety limit is 10^{-5} mol% SO_2. The molecular mass of SO_2 is 64 g/mol.

a) (5 marks) Assuming that the leaked SO_2 gas mixes uniformly in the laboratory, determine the SO_2 concentration(in mol%) in the laboratory immediately after the accidental release.

b) (8 marks) How many minutes will it take before it is acceptable to enter the laboratory safely after the leak occurred.

For parts c) and d) assume that instead of a sudden release of 1.5 kg SO_2, SO_2 accidentally starts to leak into the laboratory at a constant rate of 0.10 mol/hr.

c) (7 marks) How long will it take(in minutes) after the leak started, before the SO_2 concentration reaches the safety limit of 10^{-5} mol% SO_2 in the room air.

d) (5 marks) If the leak continues undetected for a very long time, what will the steady state concentration(mol%) of SO_2 be in the laboratory.

Problem Three [25 marks out of 100]:

In the recycling of copper scrap, the copper scrap which initially is at 25 °C is heated and melted in a furnace. The furnace containing the copper scrap is heated by the combustion of natural gas(100 mol% CH_4) with 50% excess air. The natural gas is fed to the furnace at 25 °C and 1.0 atm at a volumetric flowrate of 21 m^3/min while the air enters the furnace at 450 °C. The natural gas is completely combusted and the molten copper as well as the off-gases leave the furnace at 1150 °C and 1.0 atm. The furnace treats 350 kg/min of copper.

a) (3 marks); Draw a schematic diagram of the process.
b) (5 marks); Determine the molar flowrate(mol/hr) of air to the furnace.
c) (5 marks); Determine the molar flowrate(mol/hr) of all gas components leaving the furnace.
d) (5 marks); Determine the energy(kJ/mol) required to heat up and melt copper
e) (7 marks); Determine the heat loss(in kW) from the furnace.

Table of Data

	Molecular Mass g/mole	Standard Enthalpy of Formation (kJ/mole)	Mean Heat Capacity (J/mole·°C)
$CH_4(g)$	16	-75	38
$H_2O(g)$	18	-242	39
$CO_2(g)$	44	-394	51
$O_2(g)$	32	0	34
$N_2(g)$	28	0	32

Note: Standard enthalpy of formation refers to 25 °C.

Copper:

Molecular mass of copper: M_{Cu} = 63.5 g/mol; $\Delta H^\circ_f(Cu) = 0$
Melting point: 1085 °C, $\Delta H_{melting}$ = 13.1 kJ/mol
Solid copper: C_p(J/mol·°C) = 22.76 + 0.0061×T(°C)
Liquid copper: C_p(J/mol·°C) = 32.8

Problem Four [25 marks out of 100]:

An adult takes 12 breaths of air each minute, inhaling 0.50 liters with each breath. The outside air at 1.0 atm and 22 °C has a relative humidity of 60%. The exhaled air which is saturated with water vapour at 36 °C(nearly body temperature), contains 75 mol% N_2. In the lungs, there is exchange of oxygen, carbon dioxide and water vapor. However, there is no transfer of nitrogen between the air and the lungs.

a) (5 marks) What is the water content of the outside air in mol/m^3.
b) (5 marks) What is the dew-point temperature of the outside air.
c) (15 marks) What is the rate of water loss(grams/day) due to breathing