CHE 211 BASIC PRINCIPLES IN CHEMICAL ENGINEERING
2021 - 2022 Fall Semester

Problem Set6

1. Sulfur dioxide is oxidized to sulfur trioxide in a reactor: $SO_2 + ½ O_2 \rightarrow SO_3$. SO_2 and 100% excess air are fed to the reactor at 400° C. Conversion of sulfur dioxide is 65% and products leave the reactor at 500° C. The production rate of SO_3 is 1250 mol/h.

(a) Calculate the feed rate of the SO_2 and air streams and the extent of reaction.

(b) Calculate the heat in kW that must be transferred from the reactor.

(c) The reactor is surrounded with a water jacket. Into this jacket water is fed at 25° C and heat is transferred to this water. Exit temperature of the water is 40° C. If the heat transferred from the reactor is 0.50 kW, What is the flow rate of this cooling water? Use the heat capacity data given below and the additional tabulated enthalpy data for oxygene, nitrogene and water.

SO_2: C_p (kJ/ mol. ° C) = $38.91x\ 10^{-3} + 3.9x10^{-5}$ T (T is in ° C)

SO_3 C_p (kJ/ mol. ° C) = $48.5x\ 10^{-3}$

2. Liquid hydrazine (N_2H_4) is injected in a combustion chamber at 400 K and burned with 100% excess air at 298 K. The combustion chamber is jacketed with water. The combustion products leave at 900 K. In the test; 50.0 gmol of N_2H_4 are burned per hour and water at 25°C enters the water jacket for cooling at the rate of 1.00 kg/min. The reaction is:

$N_2H_4\,(l) + O_2\,(g) \rightarrow N_2\,(g) + 2H_2O(g)$ Calculate: (a)The heat that is added or removed from the reactor to the water jacket, b)Exit temperature of water from the water jacket, (c) Volumetric flow rate of the water at exit.

Data:

Heat capacity is in the form; C_p(kJ/gmol. °C) = a + bT (T is in °C)

Component	T	a∗10^3	b∗10^5	ΔH°_f(kJ/gmol)
N_2H_4 (l)	(°C)	139		44.77
H_2O(l)	(°C)	75.4		-285.84
H_2O(g)	(°C)	33.5	0.7	-241.83
N_2 (g)	(°C)	29.0	0.22	
O_2 (g)	(°C)	29.1	1.2	

3. Superheated steam at 40 bar absolute and 500 $^{\circ}$C flows at a rate of 250 kg/min to an adiabatic turbine. Exit pressure from turbine is 5 bar. The turbine develops a work of 1500 kJ/s. From the turbine the steam flows to a heater, where it is reheated at constant pressure to 500 ^{0}C . Neglect kinetic and potential energy changes.

(a) Write an energy balance on the turbine and use it to determine the outlet stream temperature.

(b) Write an energy balance on the heater and use it to determine the required heat input (kJ/s) to the steam in the heater.

(c) Assuming ideal gas behavior, find the volumetric flow rate of feed to turbine.

4. Carbon monoxide at 25 ^{0}C and steam at 150 ^{0}C are fed to a continuous water-gas shift reactor. The product gas which contains 40 mole% H_2, 40 mole% CO_2, and the balance H_2O(v) .Its temperature is 500 ^{0}C and flow rate is 112 mol/h . Product gas enters a condenser and some part of H_2O vapor is condensed. Condensed liquid water is pure water. Temperature of gas and liquid stream from condenser is 15^{0}C . Mole fraction of water vapor is 0.017 in the gas stream leaving the condenser. Pressure is 1 atm throughout the process.

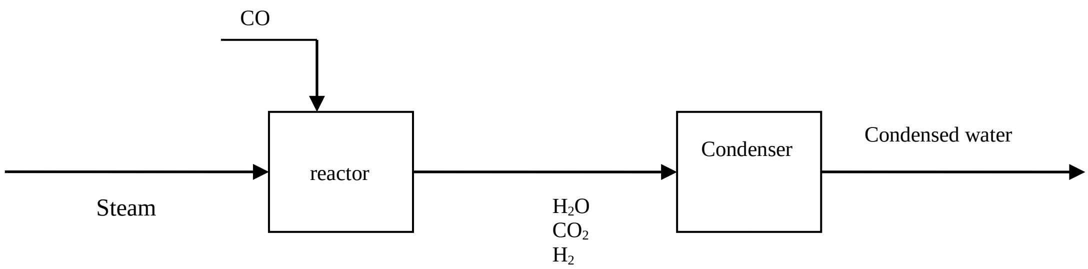
(a) Calculate the percent excess steam fed to the reactor and the rate of condensation of water (kg/h).

(b) Calculate the rate (kW) at which heat must be transferred from the over-all system.

The reaction is: $CO(g) + H_2O\,(v) \rightarrow CO_2(g) + H_2(g)$

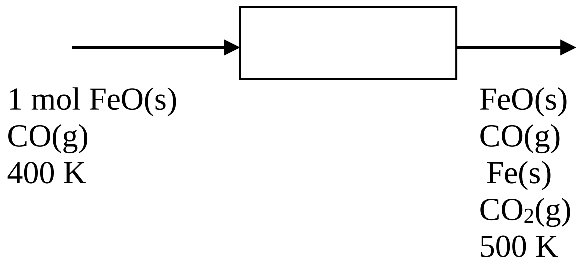
Data : $C_{p,H2O(l)} = 75.4\text{x}10^{-3}$ kj/mol. ^{0}C

Component	$\Delta\hat{H}^{0}_{f}$, kj/mol
CO(g)	-110.52
H_2O (g)	-241.83
CO_2 (g)	-393.5
H_2O (l)	-285.84



5) Metalic iron is produced in the reaction between ferrous oxide and carbon monoxide The flow chart shown below depicts this process for a basis of 1 mol FeO fed.

$FeO(s) + CO\,(g) \rightarrow Fe(s) + CO_2(g) \quad \Delta\hat{H}^0_r = -16.480$ kJ/mol



If the mole ratio of FeO(s) to CO(g) in feed is 1/0.8, calculate the heat duty Q(kJ) when fractional conversion of FeO (s) is 0.5. C_p (kJ/mol.K) in terms of T(K) adapted from Perry's Chemical Engineeers' Handbook

FeO(s): $C_p = 0.0528 + 6.243\times10^{-6}\,T$

Fe(s) : $C_p = 0.01728 + 2.67\times10^{-5}T$

CO(g): $C_p = 0.02761 + 5.02\times10^{-6}T$

CO_2(g): $C_p = 0.04326 + 1.146\times10^{-5}T$

6.Coke can be converted into CO according to following reaction

$CO_{2(g)} + C_{(s)} \rightarrow 2\,CO_{(g)} \qquad \Delta H_r^{\circ} = 74210$ Btu /lb-mole

A coke that contains 84 % carbon by mass and the balance noncombustible ash is fed to a reactor with a stoichiometric amount of CO_2. The coke is fed at 77°F, and the CO_2 enters at 400°F. The percentage conversion of the carbon in the coke is 80%. The gaseous products and the solid reactor effluent (the ash and unburned carbon) leave the reactor at 1830°F. The heat capacity of both solid carbon and ash is 0.24 Btu/(lb_m.°F). Calculate the heat transferred to the reactor in Btu / lb_m of coke fed .

7. Acetic acid (CH_3COOH) is cracked to produce the intermediate ketene ($CH_2CO(g)$) in a furnace.

$CH_3COOH(g) \rightarrow CH_2CO(g) + H_2O\,(g) \qquad \varepsilon_1 \qquad \Delta H^o_R(298K) = 132$ kJ/mol

The following side reaction also occurs to an appreciable extent.

$CH_3COOH(g) \rightarrow CH_4(g) + CO_2\,(g) \qquad \varepsilon_2 \qquad \Delta H^o_R(298K) = -33.53$ kJ/mol

A conversion of acetic acid is 80 % and a fractional yield of ketene is 0.0722. Yield is defined as the mole of ketene formed / the maximum ketene would be obtained when all reactant completely consumed without side reaction.

a. Complete mass balance calculation.

b. Calculate required furnace heating rate for a furnace feed of 100 mol/h acetic acid by using **Heat of Reaction Method** . The temperature of the feed is 300ºC and the temperature of the products is 700ºC.

C_p Data in J/K, T in K

Acetic acid ($CH_3COOH(g)$) C_p= 6.899 +0.257 T

Ketene ($CH_2CO(g)$) C_p= 17.2 +0.123 T

Metan $CH_4(g)$ C_p= 38.38 - 0.00736 T

Water H_2O (g) C_p= 34 - 0.00965 T

Carbondioxide CO_2 (g) C_p= 19 +0.0796 T