Introduction to Chemical Engineering

Problem Sheet Week 10

Problem 1

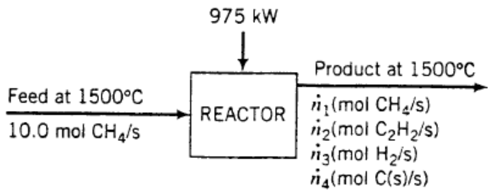
9.36. You are checking the performance of a reactor in which acetylene is produced from methane in the reaction

$$2\ CH_4(g) \rightarrow C_2H_2(g) + 3\ H_2(g)$$

An undesired side reaction is the decomposition of acetylene:

$$C_2H_2(g) \rightarrow 2\ C(s) + H_2(g)$$

Methane is fed to the reactor at 1500°C at a rate of 10.0 mol CH_4/s. Heat is transferred to the reactor at a rate of 975 kW. The product temperature is 1500°C and the fractional conversion of methane is 0.600. A flowchart of the process and an enthalpy table are shown below.



References: C(s), H_2(g), at 25°C, 1 atm

Substance	$\dot{n}_{in}$ (mol/s)	$\hat{H}_{in}$ (kJ/mol)	$\dot{n}_{out}$ (mol/s)	$\hat{H}_{out}$ (kJ/mol)
CH_4	10.0	41.65	$\dot{n}_1$	$\hat{H}_1$
C_2H_2	—	—	$\dot{n}_2$	$\hat{H}_2$
H_2	—	—	$\dot{n}_3$	$\hat{H}_3$
C	—	—	$\dot{n}_4$	$\hat{H}_4$

(a) Using the heat capacities given below for enthalpy calculations, write and solve material balances and an energy balance to determine the product component flow rates and the yield of acetylene (mol C_2H_2 produced/mol CH_4 consumed).

$$CH_4(g):\quad C_p \approx 0.079\ \text{kJ/(mol·°C)}$$
$$C_2H_2(g):\quad C_p \approx 0.052\ \text{kJ/(mol·°C)}$$
$$H_2(g):\quad C_p \approx 0.031\ \text{kJ/(mol·°C)}$$
$$C(s):\quad C_p \approx 0.022\ \text{kJ/(mol·°C)}$$

For example, the specific enthalpy of methane at 1500°C relative to methane at 25°C is [0.079 kJ/(mol·°C)](1500°C −25°C) = 116.5 kJ/mol.

(b) The reactor efficiency may be defined as the ratio (actual acetylene yield/acetylene yield with no side reaction). What is the reactor efficiency for this process?

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Problem 2

9.55. Methane at 25°C is burned in a boiler furnace with 10.0% excess air preheated to 100°C. Ninety percent of the methane fed is consumed, the product gas contains 10.0 mol CO_2/mol CO, and the combustion products leave the furnace at 400°C.

(a) Calculate the heat transferred from the furnace, $-\dot{Q}$(kW), for a basis of 1000 mol CH_4 fed/s. (The greater the value of $-\dot{Q}$, the more steam is produced in the boiler.)

(b) Would the following changes increase or decrease the rate of steam production? (Assume the fuel feed rate and fractional conversion of methane remain constant.) Briefly explain your answers. (i) Increasing the temperature of the inlet air; (ii) increasing the percent excess air for a given stack gas temperature; (iii) increasing the selectivity of CO_2 to CO formation in the furnace; and (iv) increasing the stack gas temperature.

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Additional problem

9.16. Sulfur dioxide is oxidized to sulfur trioxide in a small pilot-plant reactor. SO_2 and 100% excess air are fed to the reactor at 450°C. The reaction proceeds to a 65% SO_2 conversion, and the products emerge from the reactor at 550°C. The production rate of SO_3 is 1.00×10^2 kg/min. The reactor is surrounded by a water jacket into which water at 25°C is fed.

(a) Calculate the feed rates (standard cubic meters per second) of the SO_2 and air feed streams and the extent of reaction, $\dot{\xi}$(kmol/s).

(b) Calculate the standard heat of the SO_2 oxidation reaction, $\Delta\hat{H}_r^\circ$(kJ/mol). Then, taking molecular species at 25°C as references, prepare and fill in an inlet–outlet enthalpy table and write an energy balance to calculate the heat (kW) that must be transferred from the reactor to the cooling water.

(c) Calculate the minimum flow rate of the cooling water if its temperature rise is to be kept below 15°C.

(d) Briefly state what would have been different in your calculations and results if you had taken elemental species as references in part (b).