Chemical Engineering 1h

Mass and Energy Balances

Tutorial 2

Data for questions (2) and (3) appears at the end

1) 100kmol/h of reactant A, mixed with 900kmol/h of an inert substance D, are fed into a reactor at 200°C where all of the A reacts to form B and C according to the following equation:

$$A \rightarrow B + C \qquad \Delta h_R^{\circ} = -36kJ/mol$$

- If the reaction is carried out isothermally, at what rate must heat be removed?
- If the reaction is carried out adiabatically (ie with no heat removal or work done), at what temperature will the products leave the reactor?
- In the latter case, what would happen if the reactant were fed into the reactor as a pure substance (ie if no D is present)?

The average specific heat capacities are 40kJ/kmol.K for A and D and 20kJ/kmol.K for B and C.

2) 25000 te/yr of HCN is to be produced from methane and ammonia.

$$CH_{4(g)} + NH_{3(g)} \rightarrow HCN_{(g)} + 3H_{2(g)} \qquad \Delta h_R^{\circ} = 251.2MJ/kmol$$

The reaction takes place in ceramic tubes coated with catalyst.

If the reactor is designed to operate isothermally at 1250°C with the temperature on the outside of the tubes being maintained at 1400°C, estimate the heat transfer area, A (surface area of the tubes), required for an estimated overall heat transfer coefficient, U, (assuming turbulent flow in the tubes) of 300$\mathrm{Wm^{-2}K^{-1}}$. You may assume an 8000 hour working year. The rate of heat transfer, Q, across the tubes is given in this case by $Q = UA\Delta T$.

3) In a reactor designed for the production of HCN in the presence of air, the reaction occurs on a catalyst gauze. The only heat exchange from the gauze is by radiation, the rest of the heat remains in the fluid. 50% of the heat of reaction is radiated from the gauze.

$$CH_{4(g)} + NH_{3(g)} + 1.5O_{2(g)} \rightarrow HCN_{(g)} + 3H_2O_{(g)} \qquad \Delta h_R^{\circ} = -606.2MJ/kmol$$

- If the catalyst gauze is to be maintained at 1100°C, estimate the temperature at which the gaseous reactants should be introduced into the reactor. You may assume that the conversion of methane and oxygen are 100%, that ammonia is provided in 10% excess and that no other reactions occur (Air may be assumed to be 79% N_2, 21% O_2).

4) The gaseous feed to a reactor, in which ammonia reacts with air to produce nitrogen monoxide, comprises 340.9kmol/h NH_3, 2379.2kmol/h N_2, 632.4kmol/h O_2 and 68.5kmol/h H_2O.

97% of the ammonia reacts to give NO:

$$NH_{3(g)} + 1.25O_{2(g)} \rightarrow NO_{(g)} + 1.5H_2O_{(g)} \qquad \Delta h_R^{\ominus} = -227MJ/kmol$$

and 3% reacts to give N_2:

$$NH_{3(g)} + 0.75O_{2(g)} \rightarrow 0.5N_{2(g)} + 1.5H_2O_{(g)} \qquad \Delta h_R^{\ominus} = -409MJ/kmol$$

- If the temperature of the reaction at the Platinum Gauze, and thus of the products leaving the reactor, is to be maintained at 870°C determine the temperature at which the reactants should be introduced to the reactor. The reactor is adiabatic (i.e. no heat is added or removed, and no work is done).

Data
The specific heats of the gaseous components are approximately

Component	average specific heat (kJ/kmol.K)
H_2	30
N_2	30
O_2	30
H_2O	45
NH_3	60
CH_4	75
HCN	45
NO	30