Department of Energy and Process Engineering, NTNU
TEP4150 Energy management and technology (Energiforvaltning- og teknologi)
Thermodynamics-part

ise,mar03/feb09

Exercise 5

1)
Natural gas can be simplified to a mixture of 91% (by volume, mole) methane CH4, 4% ethane C2H6, 3 % CO2 and 2 % N2. The stoichiometric (theoretical) amount of air for this mixture is 15,3 kg/kg (kg air per kg fuel). Both fuel and air have temperature 25 °C and pressure 1 bar. We assume that air, natural gas, and combustion products (i.e. the exhaust mixture) have constant specific heat capacity Cp =1,1 kJ/(kgK) and specidic heat ratio *k*=1,4. (Thus, for consitency, the gas constant $R = C_p(1-1/k)$).
We also assume that the combustion chamber is adiabatic and with no pressure loss. The amount of air is 45 kg per kg fuel and combustion is complete. Air and fuel is compressed to 15 bar prior to the combustion chamber. The isentropic efficiencies for the compressors are 0,85.

a) Determine the lower heating value and the chemical exergy for this fuel mixture (kJ/kg).
b) Determine the temperature of the exhaust gas of the combustion chamber.
c) Determine the chemical exergy of the flue gas (kJ/kg).
d) Determine the irreversibility of the combustion chamber (per kg of fuel)

e) In exercise 4, we neglected the chemical exergy in the flue gas. What is the effect of neglecting this quantity in the analysis; that is, what would have been changed in the table made in item h) of Exercise 4 if the chemical exergy of the flue gas had been included?

Molar mass: $\tilde{m} = \sum_i x_i \tilde{m}_i$ (cf. Kotas p.4), enthalpy: $\tilde{h} = \sum_i x_i \tilde{h}_i$, $h = \tilde{h} / \tilde{m}$. Heating values and molar masses can be found in, e.g., Kotas Table A.3-A.4 or Moran and Shapiro, 5th ed (2004/06) Table A-25.

2)
Hydrogen can be produced by a reaction between methane and water vapour at approximately 700—900 ºC. This process is called reforming.

We assume complete reaction of methane according to the reaction balance $CH_4 + H_2O \rightarrow CO + 3\,H_2$

The process requires heat, and in this case the heat is obtained by heat exchange with a flow of hot air. We neglect heat losses. The surroundings have temperature 298 K and pressure 1 atm.

Determine the irreversibility due to reforming of 1 kmol CH_4,
a) if the mixture of methane and water vapour is stoichiometric (i.e. just sufficient vapour)
b) if the amount of water vapour is 2 times the stoichiometric amount

(You also have to find the amounts of reactants, products, and of hot air and heat transferred from it.)

Data:
Reactants (mixture) inflow: 1 MPa, 500 K. Product out 1 MPa, 1100 K
Air, inflow: 1 atm, 1300 K, outflow 1 atm, 900 K.

Data for enthalpy and entropy is found in tables in Moran & Shapiro (or some other book), or as specific heats in Kotas, Appendix D (use a mean value for the temperature range). In Appendix A, ”enthalpy of devaluation” is equivalent to lower heating value.