EXAM

'EXERGY ROUTE TO SUSTAINABLE CHEMICAL ENGINEERING'
6KM21

October 1st 2008, 9.00 – 12.00

Grading:
Problem 1: 20 points
Problem 2: 10 points
Problem 3: 30 points
Problem 4: 40 points

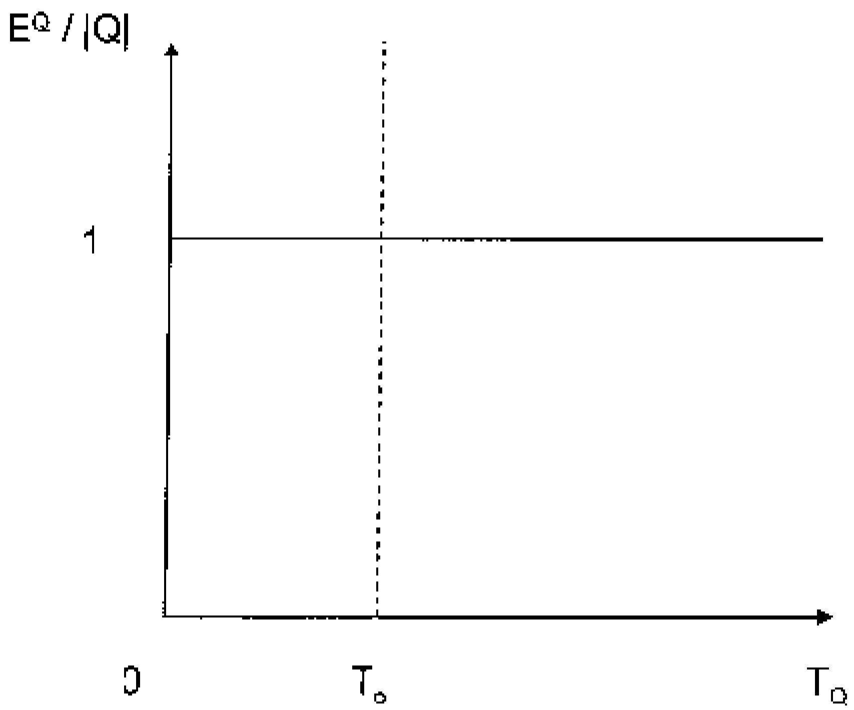
Problem 1

The exergy associated with heat transfer Q is called thermal exergy E^Q. Thermal exergy represents also the quality of heat.
Heat is available either at temperatures higher than the environmental temperature $T_Q > T_0$ or at temperatures lower than the environmental temperature $T_Q < T_0$.

Discuss the ratio $E^Q / |Q|$ between the thermal exergy flux and corresponding heat transfer rate Q (take the absolute value |Q|) for various temperatures of heat T_Q.

a. make a graph of the ratio $E^Q / |Q|$ for the temperature range starting from low temperatures $T_Q < T_o$ through $T_Q = T_o$ up to temperatures higher than the environmental $T_Q > T_o$.

b. explain your graph.



Problem 2

Recently published information on a process to convert coal to methanol (Chem. Eng. Progr., April 1982) is given here.

Inputs		Outputs	
Coal	1880 T/day	Methanol	1487 T/day
Pure oxygen	864 T/day	Ammonia	3 T/day
Electricity	$9.62 \cdot 10^8$ kJ/day	Sulfur	28 T/day

The heat of combustion of the coal is 29,014 kJ/kg. Take the following values of the chemical exergy for:

- oxygen (g):	3,970 kJ/kmol
- methanol (l):	718,000 kJ/kmol
- ammonia (g):	341,250 kJ/kmol
- sulfur (s):	598,850 kJ/kmol

The chemical exergy of the coal is 1.08 times the heat of combustion of the coal.

For the above-mentioned process:

a. calculate the exergy values for all input and output streams [kW]

b. calculate the exergy loss [kW]

c. make the Grassmann diagram

d. determine the rational efficiency.

Problem 3

Water stream (pressure 5 bar) is heated in a heat exchanger from t_1 = 20 °C to t_2 = 120 °C. Saturated steam (pressure 6.18 bar and t_S = 160 °C) is used as the heating medium. Steam leaves the heat exchanger as condensate at the boiling point. The mass flow rate of steam is S = 0.2 kg/s. The condensation enthalpy of steam at the pressure 6.18 bar is ΔH_S = 2081 kJ/kg.

The environmental conditions are: T_o = 25 °C and P_o = 1 bar.

Data water stream:

- temperature 20 °C, pressure 5 bar: enthalpy h_1 = 84 kJ/kg
  entropy s_1 = 0.296 kJ/kg K

- temperature 120 °C, pressure 5 bar: enthalpy h_2 = 504 kJ/kg
  entropy s_2 = 1.528 kJ/kg K

Calculate:

a. the mass flow rate of water [kg/s]

b. the exergy increase of water stream [kW]

c. the exergy decrease of steam [kW]

d. the exergy loss in the heat exchanger [kW]

e. the rational efficiency of this heat exchanger.

Problem 4

An engineer claims to have invented a steady flow device that will take air (stream 1) at 4 bar and 20 °C and separate it into two streams of equal mass, one at 1 bar and -20 °C (stream 2) and the second at 1 bar and 60 °C (stream 3). Furthermore, the inventor states that his device operates adiabatically and does not require (or produce) work.

a. calculate exergy values for all air streams 1, 2, 3 [kW]

b. calculate the exergy loss in this process [kW]

c. calculate the entropy production in this process [W/K]

d. is such device possible? Why? Design such device.

Data:

- air can be assumed to be an ideal gas with a constant heat capacity of $c_P = 1$ kJ/kg K
- for your calculation use the mass flow of inlet air (stream 1) equal to 1 kg/s
- environmental temperature $T_0 = 25$ °C and environmental pressure $P_0 = 1$ bar
- ideal gas constant R = 8.314 J/ mol K
- molecular mass air $M_{air} = 28.8$ kg/ kmol
- specific physical exergy $\varepsilon_{ph} = \Delta h - To\ \Delta s$ [kJ/kg]
- enthalpy change ideal gas $dh = c_P\ dT$ [kJ/kg]
- entropy change ideal gas $ds = (c_P/T)\ dT - (R/M)\ d\ lnP$ [kJ/kg K]