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

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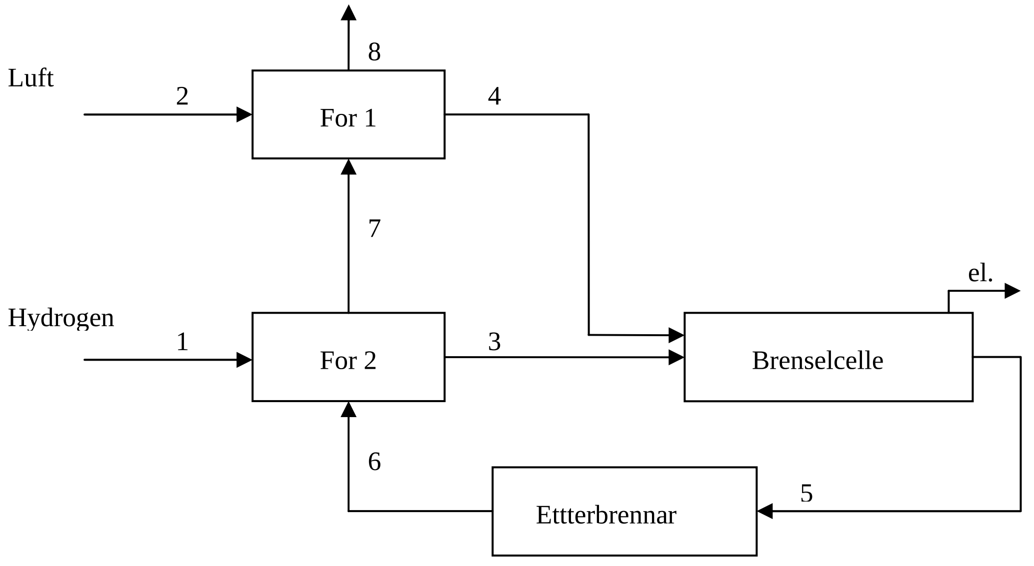
Exercise 6

The sketch (flow sheet) shows a (simplified) fuel cell process. Air (“luft”) and hydrogen (H_2) are each preheated in a preheater, For1 and For2, respectively. Heated air and hydrogen are brought to a fuel cell (“brenselcelle”) where 90 % of the hydrogen reacts with air and form H_2O (vapour). The product and surplus hydrogen and air are ducted to an afterburner (”etterbrennar”). There, the remaining fuel is burned. The hot flue gas is ducted through and cooled in the two preheaters before emitted to open air.



We assume the preheaters to be adiabatic. The fuel cell produce electric energy, and has a heat loss of 5 MJ per kg of the fuel that reacts. We assume that the air, surplus fuel and reaction products leave the fuel cell as a mixture. (In practice, the mixing may take place in the afterburner.)

The mass flow rate of fuel is 1 kg/s. The mass flow rate of air is 205 times the mass flow of hydrogen, or 6 times the stoichiometric (theoretical) amount of air.

Temperatures: Surroundings (air) and hydrogen (inflow): T_1=T_2=T_0=298 K, air and hydrogen entering the cell: T_3=T_4=1100 K; gas exiting the cell (entering the afterburner): T_5=1200K; exiting the afterburner (entering For2): T_6=1210 K. The pressure can be assumed constant and equal to 1 bar throughout the process.

For air and flue gas, the specific heat can be assumed constant, C_p =1,0 kJ/(kgK), gas constant R=0,29 kJ/(kgK). Air can be assumed to contain 21 % O_2 and 79 % N_2. For pure hydrogen gas, C_p =14,2 kJ/(kgK) and R=4,1 kJ/(kgK).

Enthalpy: $h=h_{br} + C_p(T-T°)$;where h_{br} is the lower heating value (for hydrogen: 120 MJ/kg) and $T°$ is the reference temperature (298 K) at which the heating value is determined.
Entropy difference: $s_a-s_b = C_p \ln(T_a/T_b)- R \ln(p_a/p_b)$

a) Determine the temperatures in the remaining flows.
b) Determine the thermomechanical (physical) exergy and the chemical exergy in each of the flows.
c) Determine the transferred heat and the irreversibility of the two heat exchangers. Compare the ratios of irreversibility to transferred heat in the two heat exchangers and explain the difference.
d) Determine the electric energy and the heat loss from the fuel cell, and the heat loss from the afterburner.
e) Determine the irreversibility in the fuel cell and the afterburner.