Department of Energy and Process Engineering, NTNU
TEP4150 Energy management and technology (Energiforvaltning- og teknologi)
EP8110 Exergy analysis

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Hints and answers to Exercise 7

Problem 1, melted aluminium

-define the relevant states. Calculate the thermomechanical (physical) exergy and the change of exergy and energy.
a) thermomech: 778 kJ/kg; chem: 32539 kJ/kg
b) heat: 1030 kJ/kg; exergy: 700 kJ/kg

Problem 2, liquefied nitrogen

Pure N2 from atmosphere to {flowing | stored} saturated liquid.
Define the relevant states (including intermediate states useful when calculating differences; the task is simpler when only one variable changes from one intermediate state to the next)
First, do the modeling/analysis. Then, put in values for physical quantities for each case.

Determine the heat transfer and exergy change between each pair of states that you have defined.

Specialfor product stored in a tank: In normal operation, tanks for liquefied gas are maintained at the specified pressure and (saturation) temperature, always with some liquid left. Thus filling the tank means increasing the liquid volume while the gas is displaced and brought back into the liquefaction process at the corresponding state, that is, saturated gas. (When tapping the tank, the reverse process has to be conducted. That is, some liquid has to be evaporated to fill the volume left by the tapped liquid.)
How do you determine the the ratio of the discharged gas mass to the filled liquid mass (same volume)?

a) (Using $X_{N_2}^{e} = 0,776$, i.e. 70% RH): $\varepsilon_{\mathrm{N_2}}^{\mathrm{ch}} = 20{,}9\ \mathrm{kJ/kg}$; thermomech: 675 kJ/kg; heat: 408 kJ/kg
b) thermomech: 635 kJ/kg; heat: 390 kJ/kg
c) thermomech: 675 kJ/kg; heat: 408 kJ/kg; mass of discharged gas to mass of filled liquid: 0,0054
d) thermomech: 635 kJ/kg; heat: 390 kJ/kg; mass of discharged gas to mass of filled liquid: 0,012
e1) like a) with $\varepsilon_{\mathrm{N_2}}^{\mathrm{ch}} = 23{,}1\ \mathrm{kJ/kg}$ (at 70% rel.hum.); thermomech: 738 kJ/kg; heat: 425 kJ/kg
e2) like a) with $\varepsilon_{\mathrm{N_2}}^{\mathrm{ch}} = 25{,}5\ \mathrm{kJ/kg}$ (at 70% rel.hum.);
f1) like c) thermomech: 738 kJ/kg; heat: 425 kJ/kg
f2) like c), thermomech: 770 kJ/kg; heat: 443 kJ/kg,

Briefly on humid air (Problems 2 and 3):
Dry air has an oxygen and nitrgen mole fractions $X_{O_2}^{\mathrm{dry}} = 0,2095$ and $X_{N_2}^{\mathrm{dry}} = 0,7808$
The relative humidity (RH) is defined as the ratio of the actual partial pressure of water vapor to the saturation pressure at the same temperature; for the environmental state ("e" and T_0), this is written as

$\varphi^e = p^e_{\mathrm{H_2O}} / p^{\mathrm{sat}}_{\mathrm{H_2O}}(T_0)$, and I have used the value 0,70. The environmental mole fraction of water vapor is then expressed as $X^e_{\mathrm{H_2O}} = p^e_{\mathrm{H_2O}} / p_0 = \varphi^e \cdot p^{\mathrm{sat}}_{\mathrm{H_2O}}(T_0) / p_0$. For oxygen, $X^e_{O_2} = X^{\mathrm{dry}}_{O_2} \cdot (1 - X^e_{H_2O})$

Problem 3, heating values and chemical exergy of H_2 at different ambient temperatures

The main challenge here is that the temperature of the definition T_0 is different from the temperature T_{tab} for which our tabulated data are obtained. (In the literature the latter is often denoted T_{ref} or T^0).

Heating values

Put up a sketch of the definition of heating value and the definition mathematically. Consider the table data available. What in your sketch do you have to modify to obtain the wanted quantity from the quantities available?

You need enthalpies of formation and specific heats for the involved species. For the temperature intervals that are relevant here, you can assume the specific heat to be a constant for each species.

Chemical exergy

Again, put up a sketch of the definition of chemical exergy and the definition mathematically. Consider the table data available. What in your sketch do you have to modify to obtain the wanted quantity from the quantities available?

You need enthalpies of formation, Gibbs energies of formation (or alternatively, the absolute entropies) and specific heats for the involved species. You also have to define the composition of the atmosphere; which is dry air + water vapor. The dry-air composition is a constant, while the water vapor varies with temperature and relative humidity (although you should keep the relative humidity constant).

The results can, e.g., be presented as a relative deviation from the value at $T_0 = T_{\mathrm{tab}}$:
$\mathrm{R.D.} = (\varepsilon_i^{\mathrm{ch}} / \varepsilon_i^{\mathrm{ch,tab}}) - 1$. A spreadsheet can be used for the model and the results become:

T_0	0 °C (273,15 K)	15 °C (288,15 K)	25 °C (298,15 K)	35 °C (308,15 K)
LHV(kJ/kmol)	241413	241657	241820	241983
R.D. (%) LHV	-0,17	-0,07	0,00	0,07
HHV(kJ/kmol)	286572	286127	285830	285533
R.D. (%) HHV	0,26	0,10	0,00	-0,10
$\varepsilon^{\mathrm{ch}}_{\mathrm{H_2}}$ (kJ/kmol=	240319	237785	236098	234410
R.D. (%) ch.e.	1,79	0,71	0,00	-0,72