Department of Energy and Process Engineering, NTNU
EP8110 Exergy analysis

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Exercise 1

Problem 1

The purpose of the exercise is to repeat thermodynamic analysis with the usage of the 1st and 2nd laws of thermodynamics. (You are supposed to know this from before.)
In many cases, we put up the equations as mathematical expressions in spreadsheets or other computer programs, and then let the various quantities vary. The variations – and their effects – we will investigate later. Here, we just put up the equations - precise and correct.

Start with the general forms of the mass balance, 1st and 2nd laws. For each of the following cases, sketch the system and put up the special version of the mass balance, 1^{st} and 2^{nd} laws:

All cases have diffuse heat losses to the surroundings, which should be included in the relevant equations. (For adiabatic, i.e. well isolated, cases, this becomes equal to zero.)

1. turbine
2. compressor
3. mixing chamber, 2 inlets and 1 outlet (if a reaction takes place, this is a combustion chamber)
4. heat exchanger (simple ”recuperator”, i.e. with two flows that are separated by a solid plate that transfers the heat)
5. condenser (as in a steam cycle, Rankine process; i.s. the ”warm” side of a heat exchanger)
6. throttle valve

7. heating of a gas in a closed, rigid chamber (i.e. with constant volume), from one state to another.
8. heating of a gas in a closed chamber that expands from one state to another.

9. A storage tank for cooled, liquified gas is partly filled by the substance (e.g., nitrogen, ammonia, methane) as a saturated liquid, and the remaining volume filled by saturated vapour of the same substance. More of the substance is supplied; first cooled in a heat exchanger (HX1) to saturated vapour, then cooled in another heat exchanger (HX2) to saturated liquid, and then filled into the tank. The liquid will displace vapour from the tank. This displaced vapour is led through HX2 and liquified together with the supplied substance. The pressure equals the atmospheric pressure, and the substance has a saturation temperature below the ambient temperature. The units are well insulated.

You may assume that you know or can determine the mass/mass flow rate, specific enthalpy, specific internal energy, specific entropy, heat/heat rate*, work/work rate which are required in the equations. You are not supposed to introduce numerical quantities.

*) ”–rate” (from latin) means that something is accounted per unit of time.

Problem 2:
The following is (should be) "piece of cake" for mechanical engineers. For the others, it will be taste of the "tribal language" of mechanical engineering. You may need an engineering thermodynamics textbook; a fellow student from mechanical engineering can also be helpful.

A gas turbine is fuelled by natural gas (here: methane). For a (somewhat simplified) analysis the following data are given: net power production 80 MW; pressure ratio of 20; turbine inlet temperature 1600 K; isentropic efficiencies of compressor and turbine (both one stage) 80%; fuel (methane) lower heating value 50 MJ/kg; specific heats for air and flue gas assumed constant c_p=1.1 kJ/(kgK); air (ambient) temperature of 15 °C and pressure 1 bar; fuel (methane) lower heating value 50 MJ/kg; fuel supplied at 60 bar and ambient temperature. Pressure losses, leakages and heat losses can be neglected.

--Sketch the flowsheet for the system.
--Sketch the process in a *T-s* (temperature-entropy) diagram.
--Analyse the process and determine the mass flows, temperatures and pressures.

Problem 3:
The flue gas (exhaust) from the gas turbine in the previous problem is used in a boiler to heat/evaporate water to steam. The steam is used for a two-stage steam turbine with reheat. The low pressure is maintained by a condenser cooled by seawater. The condensed steam is returned to the boiler.

--Sketch the flowsheet for the system.
--Sketch the process in a *T-s* (temperature-entropy) diagram.

Problem 4:
Describe the process of an air-to-air heat pump for heating (and cooling):
-Sketch the flowsheet and the *T-s* (temperature-entropy) diagram
-Sketch the arrangement of outdoor and indoor units and identify the corresponding units/sub-processes in the three sketches (flowsheet, *T-s* diagram, arrangement)

Problem 5:
Air composition varies with moisture, while the relative composition of dry air (gases other than H_2O) can be assumed constant.

-Make a model for the mole fraction of any species of air with varying temperature, total pressure and relative humidity.

Problem 6:
Natural gas (say methane, for simplicity) at ambient temperature and a pressure of 50 bar is liquefied by compression, cooling and throttling. The final product (LNG) should be liquid at the ambient pressure.

-Make a sketch of the flowsheet of the process, including necessary recycling. Indicate flows of heat and work (power).
-Sketch the process in a *T-s* (temperature-entropy) diagram and in a *h-s* (enthalpy-entropy) diagram