Thermodynamics and energetics I: Exercise 8

The exercise deals with the 2nd law of thermodynamics. You get to apply some basic concepts about the 2nd law and use the Carnot cycle.

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1. A Carnot power cycle is operated with steam/water as the working fluid. During the isothermal expansion, the water is heated from an initial state 1, with pressure p_1, temperature T_1 and the quality 15 %, to saturated vapor state 2. The vapor then expands isentropically to a state 3 with temperature T_3 and pressure $p_3 < p_1$. Isothermal compression then bring state 3 to state 4, and then back to state 1 with an isentropic compression.

   Note the specific entropies at the saturate states satisfies $s_g(p_3) > s_g(p_1) > s_f(p_1) > s_f(p_3)$

   (a) Sketch the states and the processes in the pv diagram. (Don't be concerned about the specific shape of the isentropic curve)

   (b) Describe how you would obtain the specific internal energy and specific entropy for each of the 4 states in the Carnot cycle. Provide an analytical expression, not a numerical solution.

   (c) Determine the expressions for heat and work transfer for each process, assuming you know the specific internal energy and specific entropy for each of the 4 states in the Carnot cycle. Provide an analytical expression, not a numerical solution.

   (d) Provide an expression for the thermal efficiency.

2. 1 kg of air, which is assumed to behave like a perfect gas, undergoes a Carnot cycle with an efficiency of 60 %. The heat transfer during the isothermal expansion is 40 kJ. At the beginning of the isothermal expansion the pressure is 7 bar and the volume is 0.24 m^3 ($c_p/c_v = 1.4$, $M_{air} = 29$ g/mol).
   Determine:

   (a) the maximum and minimum temperature during the process.

   (b) the volume at the end of the isothermal expansion.

   (c) pressures and temperatures for each of the 4 states in the Carnot cycle.

   (d) the heat and work transfer during the four processes.

   (e) draw the process in the pv diagram

3. In a closed system, 0.5 kg air, which is assumed a perfect gas, undergoes the following processes between two reservoirs at 500 K and 400 K ($c_\mathrm{p}/c_\mathrm{v} = 1.4$, $M_\mathrm{air} = 29$ g/mol):

   - 1-2: Reversible isothermal expansion from 50 bar to 10 bar at 500 K.
   - 2-3: Reversible adiabatic expansion to 400 K.
   - 3-4: Reversible isothermal compression.
   - 4-1: Reversible adiabatic compression.

   (a) Draw the Ts diagram.

   (b) Determine the pressure and volume of the air in each state.

   (c) Determine the heat and work transfer in each processes.

   (d) Determine the net work and the net heat of the cycle.

   (e) Determine the thermal efficiency.

   (f) Determine the change of the entropy of the system in each process and in the cycle.