SCHOOL OF ENGINEERING
MECHANICAL ENGINEERING

Thermodynamics and energetics I: Exercise 11

In this exercise you use the theory on energy conservation, entropy and exergy balances to analyse the performance of complete cycles and devices, namely a Rankine cycle, a Diesel cycle, and a solar heat exchanger.

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1. Consider a Rankine cycle with reheat as illustrated below. The working medium is steam (water). The steam enters the high pressure turbine at point **1** at a pressure of $p_1 = 10$ MPa and a temperature of $T_1 = 480°\text{C}$. The isentropic efficiency of the high pressure turbine is 80%. Steam leaves the high pressure turbine at a pressure of $p_2 = 0.7$ MPa. The steam is then reheated until it reaches a temperature of $T_3 = 480°\text{C}$. After expansion in the low pressure turbine, that operates with an isentropic efficiency of 80 %, the steam pressure is $p_4 = 6$ kPa. Saturated liquid water exits the condenser at point **5** before entering the pump, that operates with an isentropic efficiency of 80%. At the pump exit, the pressure is $p_6 = 10$ MPa.

   Answer the following questions, using the CoolProp database to find the properties that you need.

   (a) Label the 6 states in the h-s diagram on the next page. Indicate the isobars and connect the states according to the processes.

   (b) Compute the specific enthalpy at each point **1** - **6**.

   (c) Compute the thermal efficiency.

   (d) Compute the specific heat extracted during the condensation.

   Hints:

   – Assume that heating and condensation processes are isobaric.

   – Assume no heat losses in the turbine and pump, and no work in the heating and condensing processes.

   – Assume that between point **5** and **6** the water is liquid and incompressible.

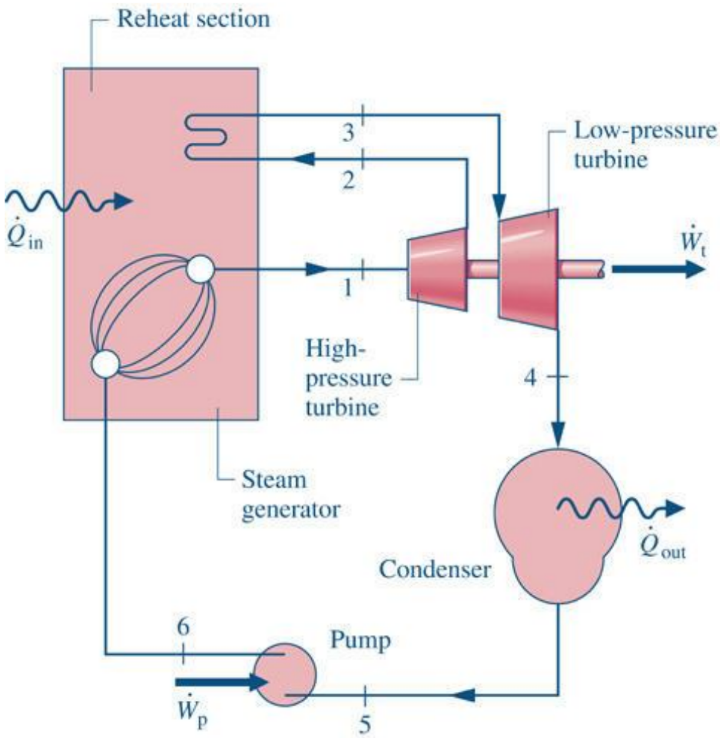

Figure 1: Schematic of the Rankine cycle with reheat.

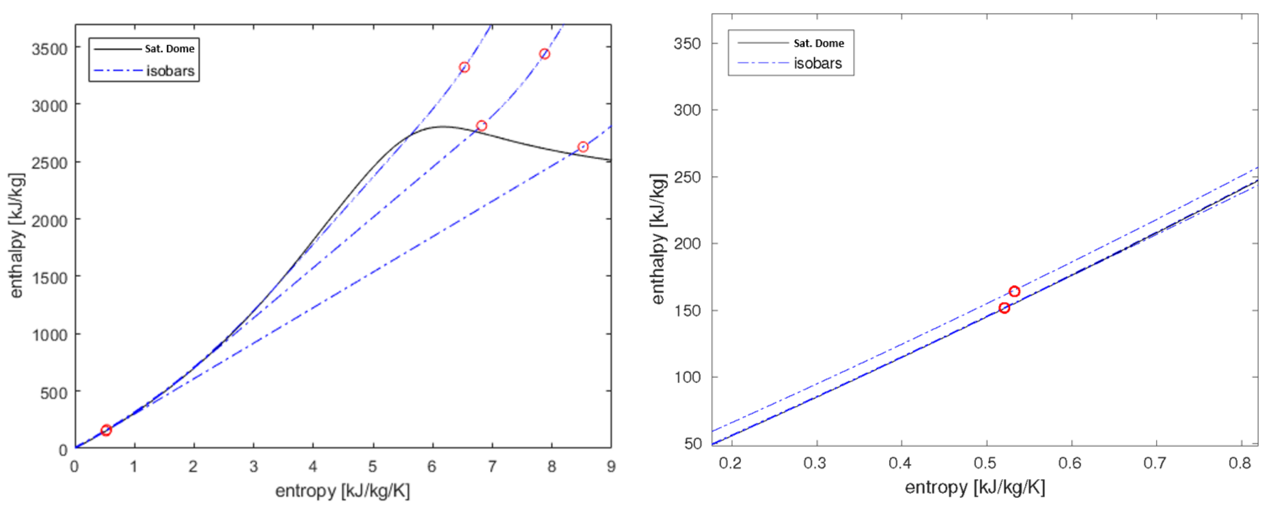

Figure 2: h-s diagram (left) with zoom into the liquid region (right).

2. Consider air, assuming to behave as an ideal gas, undergoing a Diesel cycle. The pressure before the compression phase is 95 kPa and the temperature 300 K. After heat addition, the pressure is 7.2 MPa and the temperature is 2150 K. Assuming a cold air-standard analysis with $c_v = 2.5R$

   (a) Draw the Diesel cycle in the p-v and T-s diagrams and label the processes either isochoric, isobaric, or isentropic.

   (b) Determine the compression factor.

   (c) Determine the cutoff ratio.

   (d) Determine the thermal efficiency of the cycle.

   – The compression ratio is defined as $r = V_1/V_2$.
   – The cutoff ratio is defined as $r_c = V_3/V_2$.

3. A heat exchanger is used to heat a working fluid using solar energy. The geometrical configuration is illustrated below. Assume incoming solar power of $\dot{Q}_{\text{solar}}/\text{A} = 1\ \text{kW/m}^2$. Due to heat losses ($= \dot{Q}_{\text{lost}}$) 50% of the incoming solar power is lost. Assume further that the heat is transferred to the fluid and lost to the environment at the temperature that the fluid reaches at the outlet. The environment temperature is $T_0 = 7°\text{C}$. The working fluid is air. The incoming velocity is 1 m/s, the inlet temperature is $T_{\text{in}} = 7°\text{C}$, and the inlet pressure $p_{\text{in}} = 1\text{bar}$. Assume that air behaves as a perfect gas with $c_v = 2.5R$ and neglect pressure losses in the heat exchanger. $M_{air} = 29g/mol$

   (a) Calculate the efficiency of the heat exchanger.
   Hint: The efficiency of the heat exchanger is defined as:

$$\eta_{\text{HX}} = \frac{\dot{Q}}{\dot{Q}_{\text{ideal}}} \tag{1}$$

   Where $\dot{Q}$ is the heat transfer rate exchanged and $\dot{Q}_{\text{ideal}}$ the one exchanged in ideal conditions.

   (b) Calculate the change in flow exergy between inlet and outlet.

   (c) Calculate the exergy destruction on the heat exchanger.

   (d) Calculate the exergetic efficiency of the heat exchanger.

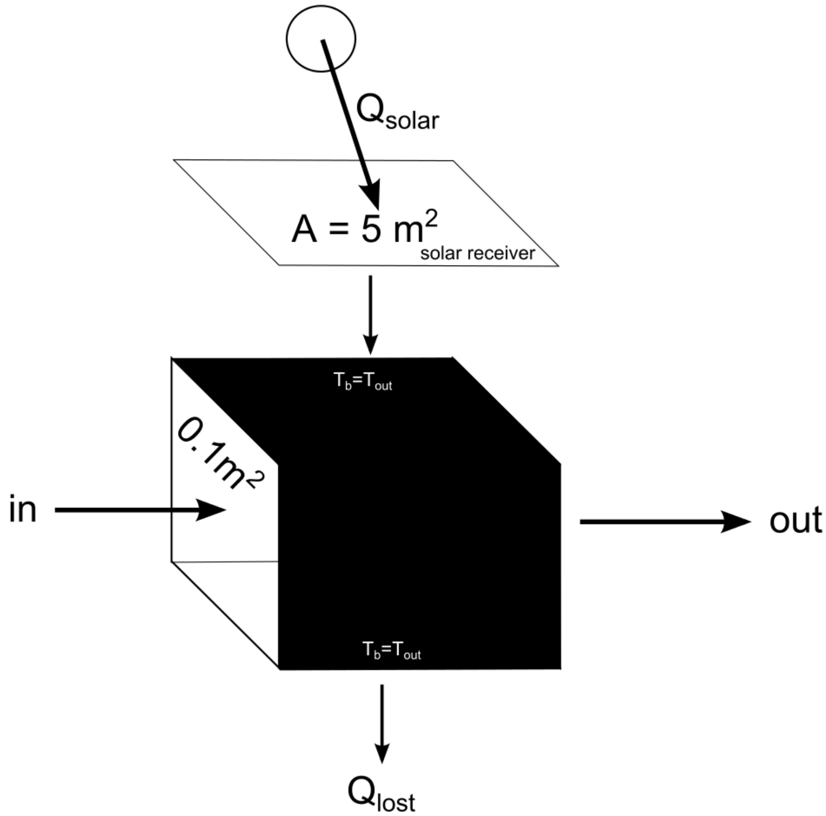

Figure 3: Illustration of the solar absorber.