Question 1: Heat Pump

1. Discuss the differences and the similarities of a compressor heat pump and an absorbtion heat pump, using a schematic. As shown in Figure 1 the refrigerant cycle (cyan) is the

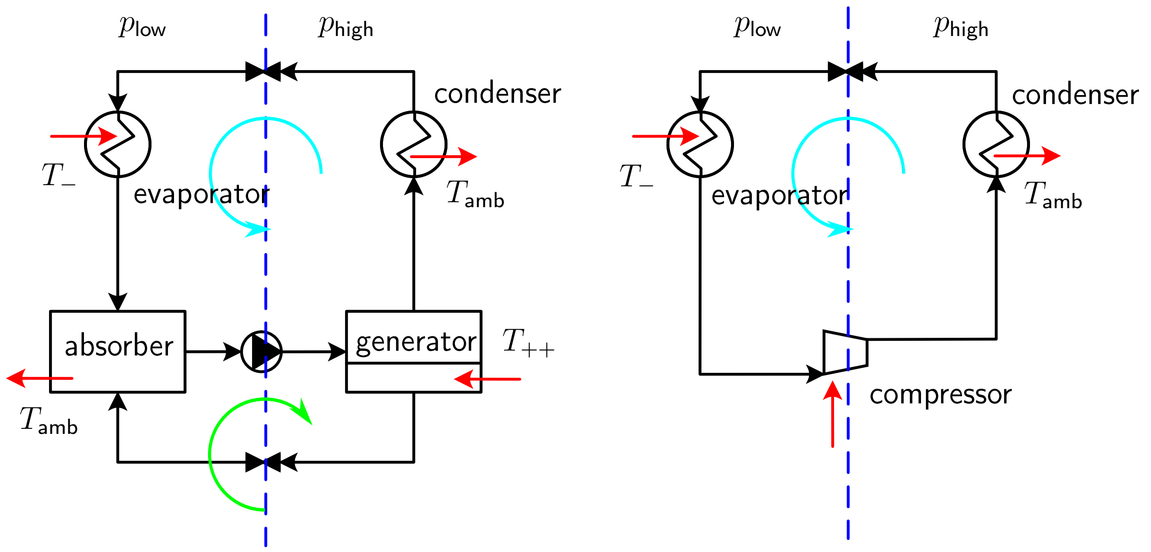


Figure 1: Comparsion of an absorbtion heat pump (leftside) and compressor heat pump (rightside).

   same for absorption as well as for a compressor heat pump. The difference lies in the make-up after the evaporator. In a compressor heat pump, a electrical (or mechanical) driven compressor is used to pressurize the refrigerant. Whereas in an absorption heat pump, a second liquid is employed (light green). This working fluid, absorbs the refrigerant vapor in the absorber. The mixture is afterwards heated up in the generator and the refrigerant is thereby seperated from the working fluid by means of distillation.

2. Explain why the full fuel chain is decisive for the ecological usefulness of a heat pump. The overall CO_2 emissions vary strongly depending on how the electricity is generated. Using electricity produced from fossil fuels, it depends on the efficiency of the plant, the COP of the heat pump and whether the power plant is connected to a district heating grid, whether it makes sense to run a heat pump or not. An alternative would be to run a small CHP plant instead and use its electricity to power a heat pump. On the other hand big power plants tend to have higher efficiencies than small engines, but the useage of waste heat needs a district heating grid.

3. Someone leaves the door of the fridge open. How does that influence the temperature in the room, in which the fridge is situated? Justify your answer using the first law of thermodynamics. Is there a time dependency to your answer? On the long run the room will get warmer. Initially, depending on the size of the fridge and the room and their temperatures it is possible, that the temperature of the room is lowered. This is due to

the mixing of the cold air inside the fridge and the warm air within the room. However as time passes the heat pump of the fridge transfers heat from the inside of the fridge to the outside, which in this case is the same. As constantly power is supplied to the compressor of the heat pump, the room has to get warmer. No heat is transported outside or into the room, therefore the change in internal energy of the air inside our room may be described according to the first law of thermodynamics for closed systems, as follows:

$$\Delta U = c_V \Delta T = W$$

Question 2: Geothermal

A double flash geothermal power plant is build to provide electricity and district heating. A schematic of the plant is shown in Figure 2. During summer the plant is operated to maximize the electric power output ($\dot{m}_i = 0$). In winter however the main purpose is to provide enough heat to the district heating grid.
The plant is run under the following conditions: Water is extracted at the well with a temperature of $T_1 = 195\,°C$ at a massflow rate of $\dot{m}_{well} = 130\,kg/s$. The two separators are run at $T_{sA} = 150\,°C$ and $T_{sB} = 105\,°C$. The water is reinjected with a temperature of $T_{10} = 60\,°C$. The efficiencies of the generators can be assumed to be 98 %. The low pressure turbine has an efficiency of 68 %. The properties of water at the different temperatures are listed in Table 1. Furthermore it is assumed that the two expansion ($1 \rightarrow 2$, $3 \rightarrow 5$) are isenthalpic.

Table 1: Properties of water at different temperatures

Temperature [°C]	Pressure [bar]	Enthalpy [kJ/kg] sat. Liquid h_{liquid}	Enthalpy [kJ/kg] sat. Vapor h_{vapor}
40	0.074	167.57	2406.7
60	0.199	251.13	2609.6
105	1.224	440.17	2683.8
150	4.758	632.20	2746.5
195	14.04	830.04	2789.8

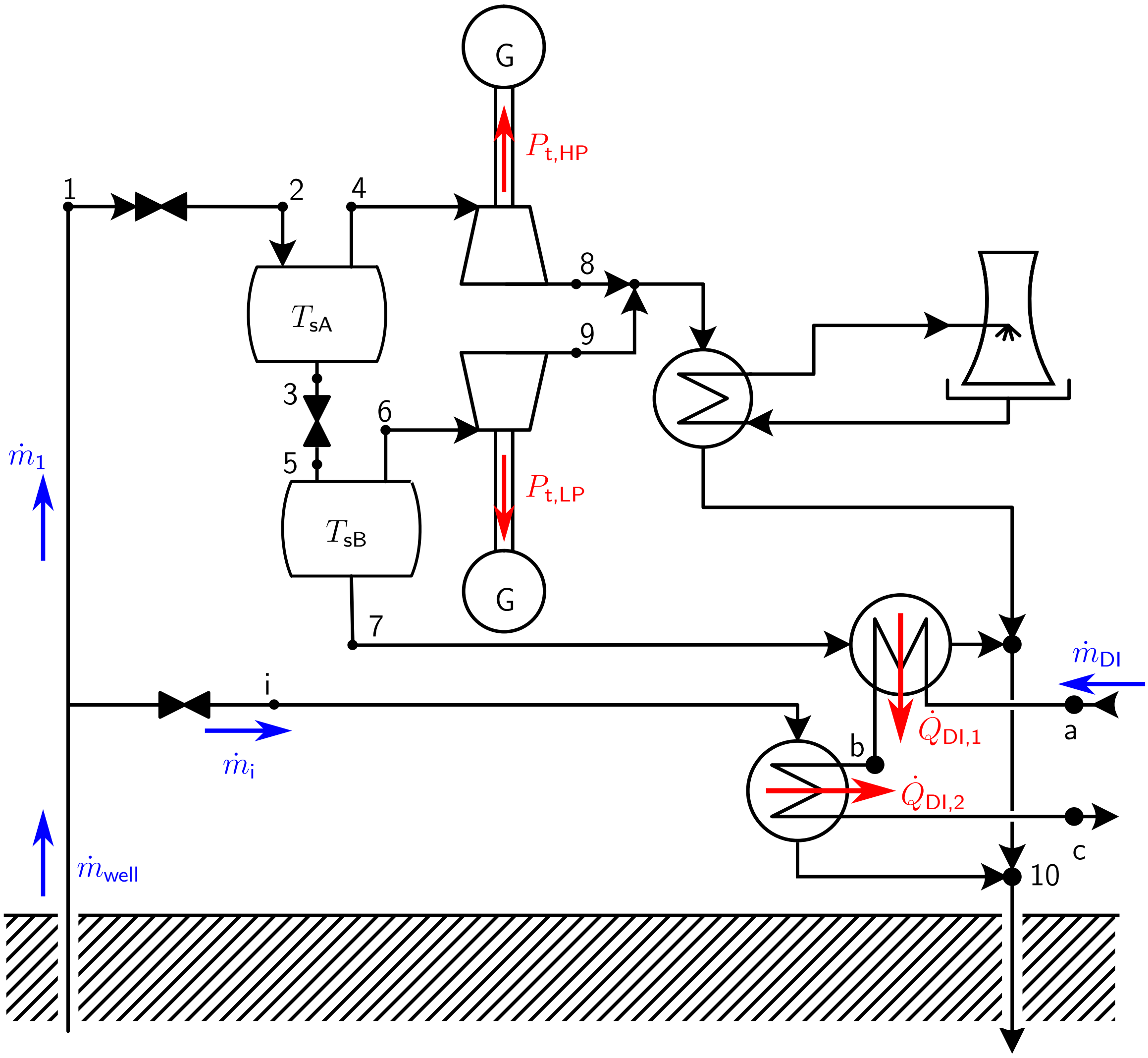


Figure 2: Flow sheet of a double flash power plant.

Summer operation:

1. Calculate the steam qualities (x_{sA}, x_{sB}) in the two separators.

$$x = \frac{h - h_L}{h_{vap} - h_L}$$

$$x_{sA} = \frac{h_2 - h_3}{h_4 - h_3} = \frac{830.04 - 632.20}{2746.5 - 632.20} = \underline{9.36\,\%}$$

$$x_{sB} = \frac{h_5 - h_7}{h_6 - h_7} = \frac{632.20 - 440.17}{2683.8 - 440.17} = \underline{8.56\,\%}$$

2. Calculate the liquid ($\dot{m}_7$) and vapor massflow ($\dot{m}_6$) out of the second separator and the vapor massflow ($\dot{m}_4$) out of the first separator.

$$\dot{m}_3 = (1 - x_{sA})\dot{m}_{Well}$$

$$\dot{m}_4 = x_{sA}\dot{m}_{Well} = \underline{12.16\,\text{kg/s}}$$

$$\dot{m}_6 = x_{sB}\dot{m}_3 = (1 - x_{sA})x_{sB}\dot{m}_{Well} = \underline{10.09\,\text{kg/s}}$$

$$\dot{m}_7 = (1 - x_{sB})\dot{m}_3 = (1 - x_{sA})(1 - x_{sB})\dot{m}_{Well} = \underline{107.75\,\text{kg/s}}$$

3. Assuming an enthalpy of 2503.2 kJ/kg at point 8 and 2508.8 kJ/kg at point 9, calculate the total electric power output of the two turbines.

$$P_{t,HP} = \dot{m}_4\,(h_4 - h_8) = 12.16\,\text{kg/s} \cdot (2746.5 - 2503.2)\,\text{kJ/kg} = 2959.4\,\text{kW}$$

$$P_{t,LP} = \dot{m}_6\,(h_6 - h_9) = 10.09\,\text{kg/s} \cdot (2683.8 - 2508.8)\,\text{kJ/kg} = 1765.4\,\text{kW}$$

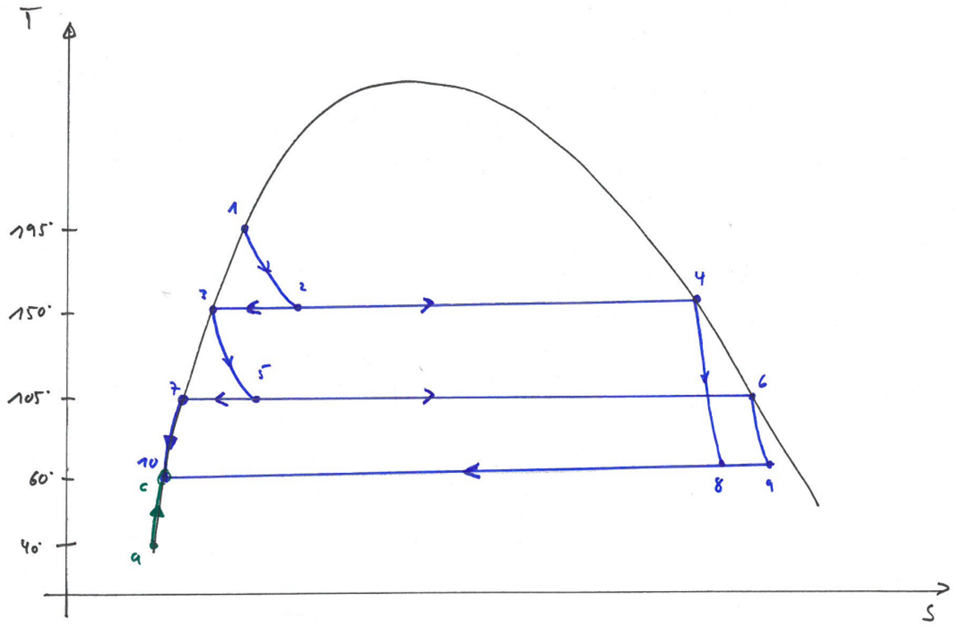
$$P_{el} = \eta_G\,(P_{t,HP} + P_{t,LP}) = 0.98(2959.4\,\text{kW} + 1765.4\,\text{kW}) = \underline{4.63\,\text{MW}}$$

4. Calculate the heat input ($\dot{Q}_{DI,1}$) to the district heating grid. How big is the massflow $\dot{m}_{DI}$ (Assume $T_a = 40\,°\text{C}$ and $T_c = 60\,°\text{C}$).

$$\dot{Q}_{DI,1} = \dot{m}_7\,(h_7 - h_{10}) = 107.75\,\text{kg/s}\,(440.17\,\text{kJ/kg} - 251.13\,\text{kJ/g}) = \underline{20.37\,\text{MW}}$$

$$\dot{m}_{DI} = \frac{\dot{Q}_{DI,1}}{h_c - h_a} = \frac{20.37\,\text{MW}}{251.13\,\text{kJ/g} - 167.57\,\text{kJ/g}} = \underline{243.77\,\text{kg/s}}$$

5. Draw the process in a T-s diagram. Take care to label all points present in Figure 2.



6. Calculate the electric and thermal efficiency of the power plant.

$$\eta_{\text{el}} = \frac{P_{\text{el}}}{\dot{m}_{\text{Well}}(h_1 - h_{10})} = \frac{4.63\,\text{kW}}{130\,\text{kg/s}(830.04 - 251.13)\text{kJ/kg}} = \underline{6.15\,\%}$$

$$\eta_{\text{thermal}} = \frac{\dot{Q}_{\text{DI,1}}}{\dot{m}_{\text{Well}}(h_1 - h_{10})} = \frac{20.37\,\text{MW}}{130\,\text{kg/s}(830.04 - 251.13)\text{kJ/kg}} = \underline{27.06\,\%}$$

$$\eta_{\text{total}} = \frac{P_{\text{el}} + \dot{Q}_{\text{DI,1}}}{\dot{m}_{\text{Well}}(h_1 - h_{10})} = \frac{4.63\,\text{MW} + 20.37\,\text{MW}}{130\,\text{kg/s}(830.04 - 251.13)\text{kJ/kg}} = \underline{33.22\,\%}$$

Winter operation: During winter a minimum heat input to the district heating grid of 40 MW is required.

1. Calculate the maximum possible heat input to the district heating grid. Is it possible to satisfy the requirements for winter operation?

$$\dot{Q}_{\text{DI,max}} = \dot{m}_{\text{Well}}(h_1 - h_{10}) = 130\,\text{kg/s}\,(830.04 - 251.13)\,\text{kJ/kg} = \underline{75.26\,\text{MW}}$$

$\Rightarrow$ it is possible.

2. What is the required bypass massflow ($\dot{m}_{\text{i}}$) to meet the requirement of 40 MW heat input?

$$\dot{Q}_{\text{DI,winter}} = (\dot{m}_{\text{Well}} - \dot{m}_i)(1 - x_{\text{sA}})(1 - x_{\text{sB}})(h_7 - h_{10}) + \dot{m}_i(h_i - h_{10})$$

$$\Rightarrow \dot{m}_i = \frac{\dot{Q}_{\mathrm{DI,winter}} - \dot{m}_{\mathrm{Well}}(1 - x_{\mathrm{sA}})(1 - x_{\mathrm{sB}})(h_7 - h_{10})}{(h_i - h_{10}) - (1 - x_{\mathrm{sA}})(1 - x_{\mathrm{sB}})(h_7 - h_{10})} = \underline{46.49\,\mathrm{kg/s}}$$

3. How do the efficiencies change compared to summer operation?

$$P_{\mathrm{el}}^{\mathrm{w}} = \frac{\dot{m}_{\mathrm{Well}} - \dot{m}_i}{\dot{m}_{\mathrm{Well}}} P_{\mathrm{el}} = 3.04\,\mathrm{MW}$$

$$\eta_{\mathrm{el}}^{\mathrm{w}} = \frac{P_{\mathrm{el}}^{\mathrm{w}}}{\dot{m}_{\mathrm{Well}}\,(h_1 - h_{10})} = \underline{3.95\,\%}$$

$$\eta_{\mathrm{thermal}}^{\mathrm{w}} = \frac{\dot{Q}_{\mathrm{DI,w}}}{\dot{m}_{\mathrm{Well}}\,(h_1 - h_{10})} = \underline{53.14\,\%}$$

$$\eta_{\mathrm{total}}^{\mathrm{w}} = \frac{P_{\mathrm{el}}^{\mathrm{w}} + \dot{Q}_{\mathrm{DI,w}}}{\dot{m}_{\mathrm{Well}}\,(h_1 - h_{10})} = \underline{57.1\,\%}$$