Tutorial 8 – Rankine (and some refrigeration) Cycles

Note: numerical solution are based on one approach to solving the tutorial questions. Other approaches can also be correct and could lead to slightly different numerical answers.

Conceptual Questions:

1. Why can the Carnot refrigeration cycle not be used in reality?

2. What is the ideal Rankine cycle and how does it address practical difficulties associated with implementing the Carnot Rankine Cycle?

3. What approaches can be used to improve the ideal Rankine cycle efficiency?

Problem Solving Questions

4. Consider a solar-powered steam power plant operating on an ideal Rankine cycle. Steam enters the turbine at 3 MPa and 350°C and is condensed at a pressure of 75 kPa.

a) Determine the quality of the steam exiting the turbine

b) Determine the thermal efficiency of the cycle

[ans: a) x_4 = 0.886, b) $\eta_{th} = 26\%$]

5. A small power plant operating on the Rankine cycle with a water boiler at 3.0 MPa. The cycle has the highest and lowest temperatures of 450°C and 45°C, respectively.

a) Determine the power plant thermal efficiency.

b) Compare this efficiency with that of a Carnot cycle operating between the same high and low temperatures.

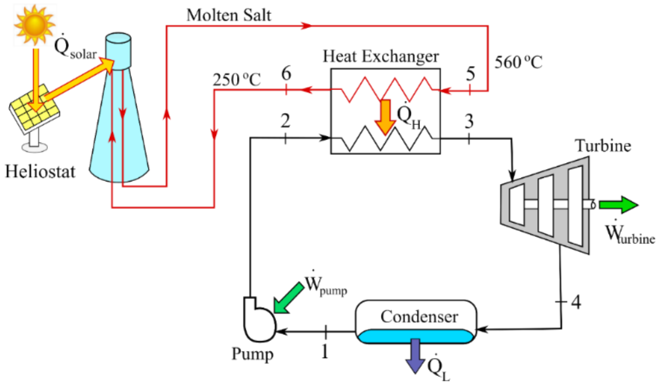
[ans: a) $\eta_{th} = 35\%$, b) $\eta_{Carnot} = 56\%$]

6. Consider an ideal Rankine cycle where a solar heat is used to heat molten salt to 560oC in a collector. Molten salt delivers heat to the water in a heat exchanger. The salt leaves the heat exchanger at 250oC and has a mass flow rate of $\dot{m}$_salt = 20 kg/s. The water has a mass flow rate of 5 kg/s. The lower working pressure of the Rankine cycle is 75 kPa, and the higher working pressure is 5 MPa. Molten salt can be treated with constant specific heats Cp,salt = 1.5 kJ/kgK.

a) What is the heat source delivered to the water (i.e. $\dot{\boldsymbol{Q}}_{\boldsymbol{H}}$, in kW)?

b) If a nearby city consumes 5 MW of electricity, can the solar power plant provide enough power to meet this demand?

c) What is the thermal efficiency?



[ans: a) $\dot{\boldsymbol{Q}}_{\boldsymbol{H}}$ =9300 kW ; b) $\dot{W}_{net}$ =2.37 MW< 5 MW; c) $\boldsymbol{\eta_{th}} = \mathbf{25.5}\%$]

7. Consider the system in 6, but now a boiler is used in combination with the solar heating system. The boiler supplies enough heat such that the quality of the mixture leaving the turbine is x4 = 0.95.
Assuming the turbine to operate reversibly & adiabatically, determine

a) The maximum temperature in the cycle.

b) The power output of the turbine (in kW).

c) The new thermal efficiency.

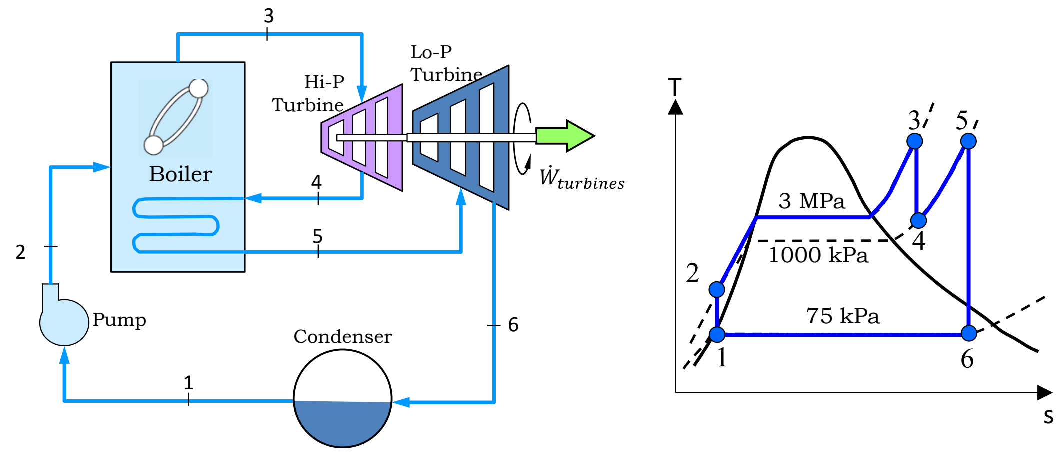
[ans: a) T_3 = 558.2°C ; b) $\dot{W}_{net}$ =5.08 MW > 5 MW; c) $\boldsymbol{\eta_{th}} = \mathbf{31.9}\%$]

8. Consider the same steam power plant in problem (4). You are not satisfied with the semi-low quality of the mixture exiting the turbine. Therefore, you propose to fix this problem by operating this power plant under an ideal reheat Rankine cycle. The steam exits the original turbine (now termed, high-pressure turbine) at 1000 kPa and is reheated in the boiler to a temperature of 350°C. The steam is then sent into a low-pressure turbine and enters the condenser at 75 kPa.

a) Determine the quality of the steam exiting the low-pressure turbine.

  i) Are you satisfied with this quality (i.e. is $x_6 \geq 0.9$)?

b) Determine the thermal efficiency of this reheat Rankine cycle.



[ans: a) x_6 = 0.988, b) $\eta_{th} = 38\%$]

9. A steam power plant operates on a Rankine cycle. The power plant operates with a high pressure of 5000 kPa and has a boiler exit temperature of 600°C. The working temperature inside the condenser is 50°C. There is no pressure loss in the boiler and condenser, and the pump operates adiabatically and reversibly. The turbine operates adiabatically, but the steam exits the turbine as a saturated vapour.

a) Determine the lower working pressure in kPa.

b) Determine the thermal efficiency.

c) Determine the isentropic efficiency.

d) Determine the entropy generation (in kJ/kgK) in the condenser if the heat, q_L, is rejected to a river which has a constant temperature of 20°C.

[ans: a) P = 12.350 kPa; b) $\eta_{th} = 30.9\%$;c) $\eta = 80.2\%$; $s_{gen} = 0.756\ kJ/\mathrm{kgK}$]