Thermodynamics 4
Tutorial 4 – Power Cycles 3 (Questions)

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1) Sketch and label a pinch diagram for a closed feedwater heater. Label the pinch and approach. What factors influence these temperature differences?

2) A Rankine steam power plant is designed to operate with a high pressure of 3 MPa, a low pressure of 10 kPa, and a boiler exit temperature of 500°C. The high-temperature source for this cycle is a gas turbine that produces 175 kg/s of air at 600°C. The boiler operates as a counter-flowing heat exchanger where the temperature difference at the pinch point is 20°C (i.e., the smallest temperature difference between the gas and steam at any point in the heat exchanger is 20°C) and the gas can be assumed to be ideal with Cp = 1.15 kJ/kg·K.

a) Show that subcooled water entering the boiler has a specific enthalpy of around 195 kJ/kg.

b) Find the temperatures at the pinch and, hence, the maximum water mass flow rate possible.

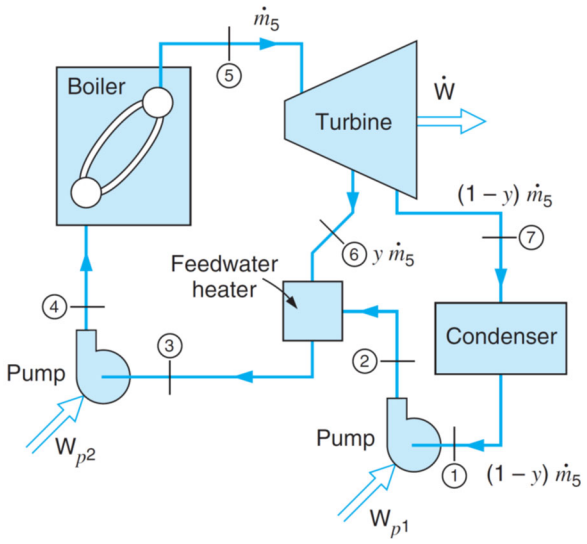
$T_{w,pinch} = 233.9°C,\ T_{g,pinch} = 253.9°C,\ m_w = 28.4\ kg/s$

c) Find the air exit temperature for this flow rate and confirm that this air exit temperature is thermodynamically possible.

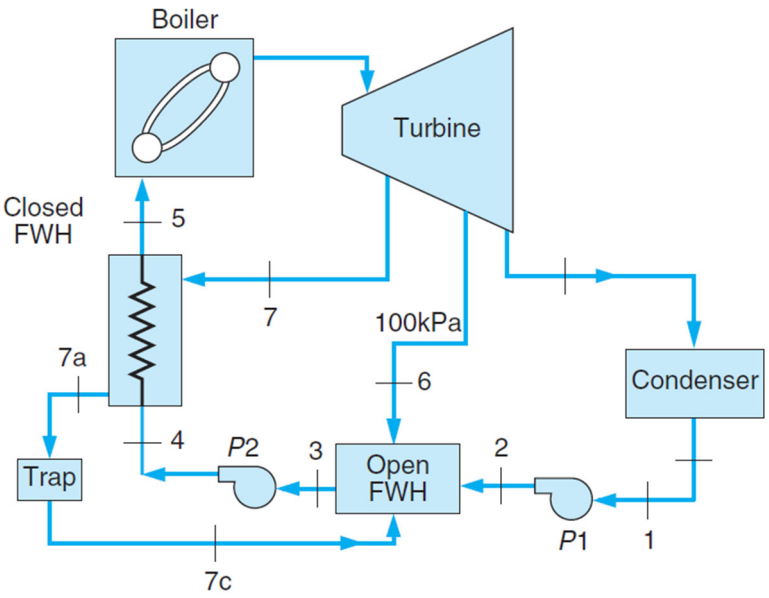
$T_{g,exit} = 140°C$

3) Consider an ideal steam regenerative cycle in which steam enters the turbine at 3.0 MPa, 400°C, and exhausts to the condenser at 10 kPa. Steam is extracted from the turbine at 0.8 MPa for an open FWH. The feedwater leaves the heater as a saturated liquid. The appropriate pumps are used for the water leaving the condenser and the FWH. Calculate the thermal efficiency of the cycle and the specific net work.

35.7%; 896.2 kJ/kg



4) Assume a variation of the cycle in Problem #3 with a closed FWH at 0.8 MPa and one open FWH at 100 kPa. A pump is used to bring the water leaving the condenser up to 100 kPa for an open FWH, and a second pump brings the feedwater up to 3.0 MPa, as shown in the figure. Condensate from the closed FWH is drained through a trap to the open FWH. Calculate the thermal efficiency of the cycle and the specific net work.

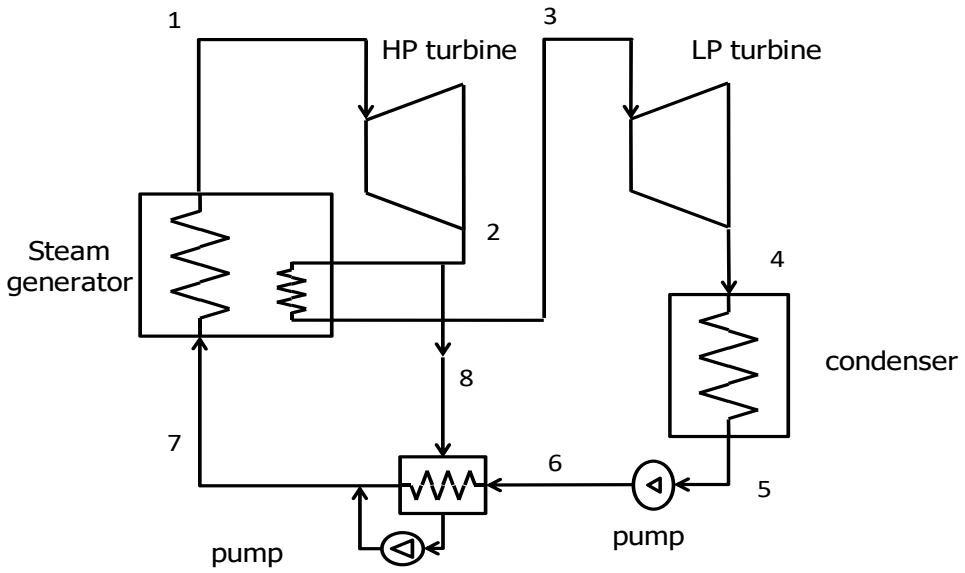


36.6%; 917.39 kJ/kg

5) A steam power plant operates on an ideal regenerative Rankine cycle. Steam enters the turbine at 6 MPa and 450°C and is condensed in the condenser at 20 kPa. Steam is extracted from the turbine at 0.4 MPa to heat the feedwater in an open feedwater heater. Water leaves the feedwater heater as a saturated liquid. Show the cycle on a T-s diagram, and determine (a) the net work output per kilogram of steam flowing through the boiler and (b) the thermal efficiency of the cycle.

(a) 1017 kJ/kg, (b) 37.8 percent

6) The steam cycle in Example 2 of the lecture notes on Rankine cycles is now upgraded with a closed feedwater heater taking steam from the exhaust of the high-pressure turbine at 70 bar, as shown in the diagram. The feedwater heater has an approach temperature at the feedwater water inlet of 7.2 K and a temperature pinch of 5.8 K. Both pumps have an exit pressure of 320 bar, and it can be assumed that there are no significant pressure drops in the feedwater heater.



a) Draw the pinch diagram for the feedwater heater.

b) Using the steam tables, find the specific enthalpy of both streams at the approach and the pinch.

Condensate: h_{app} = 178 kJ/kg, h_{pinch} = 1229.5 kJ/kg; *Extracted steam:* h_{app} = 173.7 kJ/kg, h_{pinch} = 2772.6 kJ/kg

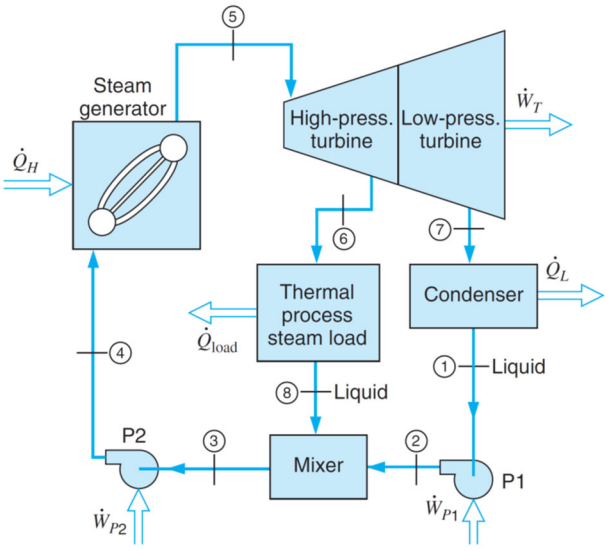
c) Calculate the mass fraction relative to the boiler mass flow of steam entering the feedwater heater.

$y = 0.29$

d) Calculate the new cycle efficiency and compare it to the efficiency of the cycle without feedwater heating (i.e., Example 2 of the lecture notes on Rankine cycles).

$q_{total} = 2854.5$ kJ/kg, $w_{total} = 1296.1$ kJ/kg, $\eta = 45.4\%$

7) Combined Heat and Power: A cogenerating steam power plant, as shown below, operates with a boiler output of 25 kg/s steam at 7 MPa, 500°C. The condenser operates at 7.5 kPa, and the process heat is extracted as 5 kg/s from the turbine at 500 kPa, state 6, and after use is returned as a saturated liquid at 100 kPa, state 8. Assume all components are ideal and find the temperature after pump 1, the total turbine output, and the total process heat transfer.



$T_2 = 40.3°C$; *Turbine output* = 29.185 MW; Process heat = 11.606 MW

8) **Combined Gas–Steam Power Cycle:** Consider the combined gas–steam power cycle shown below. The topping cycle is a gas-turbine cycle that has a pressure ratio of 8. Air enters the compressor at 300 K and the turbine at 1300 K. The isentropic efficiency of the compressor is 80 percent, and that of the gas turbine is 85 percent. The bottoming cycle is a simple ideal Rankine cycle operating between the pressure limits of 7 MPa and 5 kPa. Steam is heated in a heat exchanger by the exhaust gases to a temperature of 500°C. The exhaust gases leave the heat exchanger at 450 K. **Determine (a) the ratio of the mass flow rates of the steam and the combustion gases and (b) the thermal efficiency of the combined cycle.** Assume that the gas-turbine cycle and the steam cycle are already analysed, and the following results are obtained.

Gas cycle:

$h_{4'} = 880.36$ kJ/kg ($T_{4'} = 853$ K)

$q_{in} = 790.58$ kJ/kg $w_{net} = 210.41$ kJ/kg $\eta_{th} = 26.6\%$

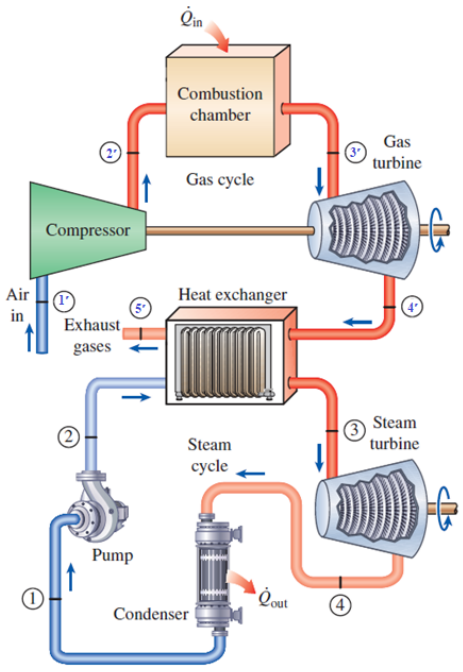
$h_{5'} = h$ @ 450 K = 451.80 kJ/kg

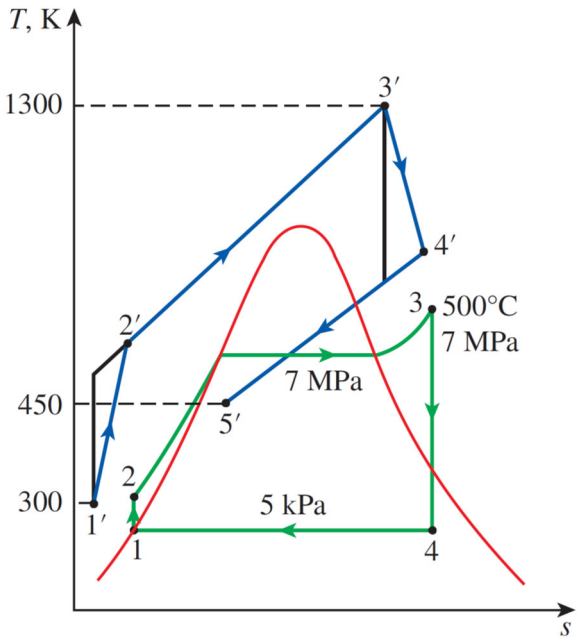
Steam cycle:

$h_2 = 144.78$ kJ/kg ($T_2 = 33°C$)

$h_3 = 34\,11.4$ kJ/kg ($T_3 = 500°C$)

$w_{net} = 1331.4$ kJ/kg $\eta_{th} = 40.8\%$





$\eta = 48.7\%$