Applied Thermodynamics (ME30202)

Problem sheet

1. Consider a steam power plant operating on the ideal Rankine cycle. The steam enters the turbine at 3 MPa and 350°C and is condensed in the condenser at a pressure of 10 kPa. Determine:
   a. Thermal efficiency of this power plant
   b. Thermal efficiency if steam is superheated to 600°C instead of 350°C
   c. Thermal efficiency if boiler pressure is raised to 15 MPa while the turbine inlet temperature is maintained at 600°C

   Answers: (a) 33.5%, (b) 37.3%, (c) 43%

2. Consider a steam power plant operating on the ideal reheat Rankine cycle. Steam enters the high-pressure turbine at 15 MPa and 600°C and is condensed in the condenser at a pressure of 10 kPa. If the moisture content of the steam at the exit of the low pressure turbine is not to exceed 10.4%, determine
   a. Pressure at which steam should be reheated
   b. Thermal efficiency of the cycle

   Assume the steam is reheated to the inlet temperature of the high pressure turbine

   Answers: (a) ≤ 4 MPa, (b) 45%

3. Consider a steam power plant operating on the ideal regenerative Rankine cycle with one open feedwater heater. Steam enters the turbine at 15 MPa and 600°C and is condensed in the condenser and at a pressure of 10 kPa. Some steam leaves the turbine at a pressure of 1.2 MPa and enters the open feedwater heater. Determine
   a. the fraction of steam extracted from the turbine
   b. the thermal efficiency of the cycle

   Further, compare this with the efficiency of the powerplant in Problem.1. What is the impact of regeneration?

   Answers: (a) 0.227, (b) 46.3%

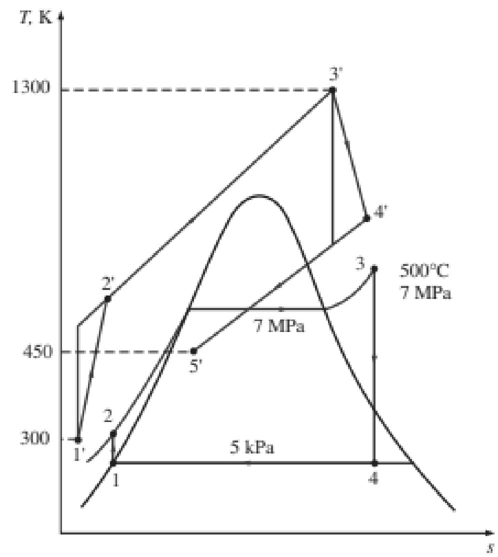
4. Consider a steam power plant that operates on an ideal reheat-regenerative Rankine cycle with one open feedwater heater, one closed feedwater heater, and one reheater. Steam enters the turbine at 15 MPa and 600°C and is condensed in the condenser at a pressure of 10 kPa. Some steam is extracted from the turbine at 4 MPa for the closed feedwater heater, and the remaining steam is reheated at the same pressure to 600°C. The extracted steam is completely condensed in the heater and is pumped to 15 MPa before it mixes

with the feedwater at the same pressure. Steam for the open feedwater heater is extracted from the low-pressure turbine at a pressure of 0.5 MPa. Determine

a. the fraction of steam extracted from the turbine each time
b. the thermal efficiency of the cycle

Answers: (a) CFWH: 0.173, OFWH: 0.131, (b) 48.9%

5. Consider the combined gas-steam power cycle shown in the figure 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 adiabatic 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. Ratio of the mass flow rates of the steam and the combustion gases
b. Thermal efficiency of the combined cycle

Answers: (a) 0.131, (b) 48.7%

6. Consider a 300-MW steam power plant that operates on a simple ideal Rankine cycle. Steam enters the turbine at 10 MPa and 500°C and is cooled in the condenser at a pressure of 10 kPa. Show the cycle on a T-s diagram with respect to saturation lines, and determine

a. Quality of the steam at the turbine exit
b. Thermal efficiency of the cycle
c. Mass flow rate of the steam

Answers: (a) 0.793, (b) 40.2%, (c) 235.4 kg/s

7. Repeat Problem.6 assuming an adiabatic efficiency of 85% for both the turbine and the pump.

Answers: (a) 0.874, (b) 34.1%, (c) 277.8 kg/s

8. Consider a steam power plant that operates on a reheat Rankine cycle and has a net power output of 150 MW. Steam enters the high-pressure turbine at 10 MPa and 500°C and the low-pressure turbine at 1 MPa and 500°C. Steam leaves the condenser as a saturated liquid at a pressure of 10 kPa. The adiabatic efficiency of the turbine is 80 percent, and that of the pump is 95 percent. Show the cycle on a T-s diagram with respect to saturation lines, and determine
   a. Quality (or temperature, if superheated) of the steam at the turbine exit
   b. Thermal efficiency of the cycle
   c. Mass flow rate of the steam

Answers: (a) 87.5°C, (b) 34.1%, (c) 117.5 kg/s

9. Repeat Problem.8 assuming both the pump and the turbine are isentropic.

Answers: (a) 0.948, (b) 41.4%, (c) 93.8 kg/s

10. 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. Net work output per kilogram of steam flowing through the boiler
    b. Thermal efficiency of the cycle

Answers: (a) 1016 kJ/kg, (b) 37.8%

gamma = 1.4
cp = 1.004

11. The gas-turbine portion of a combined gas–steam power plant has a pressure ratio of 16. Air enters the compressor at 300 K at a rate of 14 kg/s and is heated to 1500 K in the combustion chamber. The combustion gases leaving the gas turbine are used to heat the steam to 400°C at 10 MPa in a heat exchanger. The combustion gases leave the heat exchanger at 420 K. The steam leaving the turbine is condensed at 15 kPa. Assuming all the compression and expansion processes to be isentropic, determine
    a. Mass flow rate of the steam
    b. Net power output
    c. Thermal efficiency of the combined cycle

    For air, assume constant specific heats at room temperature.

Answers: (a) 1.275 kg/s, (b) 7818 kW, (c) 66.3%

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