Problems, Chapter 10

Carnot vapor cycle

10-1M A Carnot cycle operates with steam as the working medium. At the end of adiabatic compression the pressure is 1.5 MPa and the quality is 20 percent. Heat is added during the isothermal expansion until the steam becomes a saturated vapor. The fluid then expands adiabatically until the pressure is 0.10 MPa. Determine (a) the quality at the end of adiabatic expansion, (b) the thermal efficiency, (c) the heat input, in kJ/kg, and (d) the net work output, in kJ/kg.

10-2M A Carnot engine operates with steam as the working medium. At the end of adiabatic compression the pressure is 10 bars and the quality is 10 percent. At the end of isothermal heat addition the steam is a saturated vapor, and during isothermal rejection the pressure is 0.3 bar. Determine (a) the quality at the end of adiabatic expansion, (ft) the thermal efficiency, (c) the heat rejected, in kJ/kg, and (d) the net work output per cycle, in kJ/kg.

10-3M A Carnot engine contains 0.10 kg of water. At the beginning of the heat-addition process the fluid is a saturated liquid, and at the end of this process it is a saturated vapor. Heat addition occurs at 120 bars and heat rejection is at 0.3 bar. Determine (a) the quality at the end of adiabatic expansion and at the end of isothermal heat rejection, (b) the thermal efficiency, (c) the heat added per cycle, in kilojoules, and (d) the net work output per cycle.

The Rankine cycle

10-4M A Rankine cycle has steam entering the turbine at 80 bars and 440 °C. If the turbine output is 10,000 kW, determine (1) the quality at the turbine outlet, (2) the thermal efficiency, and (3) the mass flow rate of steam for condenser pressures of (a) 0.08 bar and (b) 0.04 bar.

10-5M A Rankine cycle has an exhaust pressure of 0.08 bar and a turbine-inlet pressure of 60 bars. Determine (1) the moisture content at the turbine outlet, (2) the thermal efficiency, and (3) the mass flow rate of steam for a net power output of 10 MW for turbine-inlet temperatures of (a) 540 °C and (b) 440 °C.

10-6M A Rankine cycle has an exhaust pressure of 0.08 bar and a turbine-inlet temperature of 520 °C. Determine (1) the moisture content at the turbine outlet and (2) the thermal efficiency of the cycle for a turbine-inlet pressure of (a) 120 bars and (b} 80 bars.

10-7M An ideal Rankine cycle generates steam at 140 bars and 560 °C, and condenses steam at 0.06 bar. The net power output is 20 MW. Determine (a) the heat input, in kJ/kg, (b) the thermal efficiency, (c) the mass flow rate of steam, in kg/h, and (d) the mass flow rate of cooling water required in the condenser if the water experiences a 10 °C temperature rise.

10-8M An ideal Rankine steam power cycle which produces 125 MW of turbine power has the following operating conditions: turbine inlet, 80 bars and 560 °C; condenser pressure, 0.06 bar. Determine (a) the heat input, in kJ/kg, (b) the thermal efficiency, (c) the mass flow rate of steam, in kg/h, and (d) the mass flow rate of cooling water required in the condenser if the water experiences an 8 °C temperature rise.

10-9M A steam power unit operating on the Rankine cycle has a mass flow rate of 23,800 kg/h through it. Water enters the boiler at 30 bars, and it leaves the condenser at 0.10 bar and 45.8 °C. Cooling water in the condenser is circulated at a rate of 1.31 x 10^6 kg/h, and it experiences a temperature rise of 8.50 °C Determine (a) the enthalpy and entropy at the turbine outlet, (b) the enthalpy at the turbine inlet, (c) the heat added, in kJ/kg, (d) the thermal efficiency, and (e) the power output of the turbine, in kilowatts.

10-10M A Rankine power cycle uses solar energy for the heat input and refrigerant 134a as the working fluid. Fluid enters the pump as a saturated liquid at 7 bars, and is pumped to 14 bars. The turbine-inlet temperature is 140 °C and the mass flow rate is 1200 kg/h. Determine (a) the net work output, in kJ/kg, (b] the thermal efficiency, and (c) the area, in square meters, of the solar collector needed if the collector picks up 630 J/m^2s.

10-11M A Rankine power cycle uses solar energy for the heat input and refrigerant 134a as the working fluid. The fluid enters the pump as a saturated liquid at 9 bars, and is pumped to 16 bars. The turbine-inlet temperature is (a) 120 °C, and (b) 160 °C and the mass flow rate is 1000 kg/h. Determine (1) the net work output, in kJ/kg, (2) the thermal efficiency, and (3) the area, in square meters, of the solar collector needed if the collector picks up 650 J/m^2s.

Reheat cycles

10-12M Modify the data of Prob. 10-4 in the following manner. The steam in the turbine is expanded to 15 bars, reheated to 440 °C, and then expanded to (a) 0.08 bar, and {b) 0.04 bar. Determine (1) the quality at the condenser inlet, and (2) the thermal efficiency.

10-13M Modify the data of Prob. 10-5 in the following manner, (a) Steam at 60 bars and 540 °C is expanded to 5 bars, reheated to 500 °C, and expanded to 0.08 bar. (b) Steam at 60 bars and 440 °C is expanded to 10 bars, reheated to 440 °C, and expanded to 0.08 bar. Determine (1) the quality at the condenser inlet, and (2) the thermal efficiency.

10-14M Modify the data of Prob. 10-6 in the following manner, (a) Steam at 120 bars and 520 °C is expanded to 10 bars, reheated to 500 °C, and expanded to 0.08 bar. (b) Steam at 80 bars and 520 °C is expanded to 7 bars, reheated to 500 °C, and expanded to 0.08 bar. Calculate (1) the quality at the condenser inlet, and (2) the thermal efficiency.

10-15M The data of Prob. 10-7 are modified in the following manner. Reheat occurs at 10 bars to a temperature of 540 °C. Answer the same questions.

10-16M The data of Prob. 10-8 are modified in the following manner. After expansion to 5 bars, the fluid is reheated to 500 °C. Answer the same questions.

10-17M An ideal reheat cycle operates with turbine-inlet conditions of 160 bars and 560 °C, a condenser pressure of 0.06 bar, and reheat to 560 °C. Determine the thermal efficiency of the cycle for reheat pressures of (a) 20 bars, (b) 30 bars, (c) 40 bars, (d) 60 bars, and (e) 80 bars. Plot the efficiency of the reheat cycle versus reheat pressure.

Regenerative cycles

10-18M Modify the data of Prob. I0-4M as follows. The steam is expanded to 15 bars, where a portion is bled to a single, open feedwater heater operating at this same pressure. Answer the same questions for a condenser pressure of (a) 0.08 bar, and (b) 0.04 bar.

10-19M The data of Prob. 17-5M are modified as follows, (a) Steam at 60 bars and 540 °C is expanded to 5 bars, where a portion is bled to a single open heater and the remainder is expanded to 0.08 bar. (h) Steam at 60 bars and 440 °C is expanded to 10 bars, where a portion is bled to a single open heater and the remainder is expanded to 0.08 bar. Determine (1) the quality at the condenser inlet, and (2) the thermal efficiency.

10-20M Modify the data of Prob. 17-6M as follows, (a) Steam at 120 bars and 520 °C is expanded to 10 bars, where a portion is bled to a single, open heater and the remainder is expanded to 0.08 bar. (b) Steam at 80 bars and 520 °C is expanded to 7 bars, where a portion is bled to a single, open feedwater heater and the remainder is expanded to 0.08 bar. Compute (1) the quality at the turbine outlet, and (2) the thermal efficiency.

10-21M The data of Prob. 17-7M are modified in the following manner. The steam is expanded to 10 bars, where a portion is bled to (a) a single, open feedwater heater, and (b) a single, closed feedwater heater followed by a pump. Determine (1) the fraction of the total flow bled to the heater, (2) the mass flow rate of steam required, and (3) the thermal efficiency.

10-22M The data of Prob. 17-8M are modified as follows. The steam is expanded to 5 bars, where a portion is bled to (a) a single, open feedwater heater, and (b) a single, closed feedwater heater followed by a pump. Determine (1) the fraction of the total flow bled to the heater, (2) the mass flow rate of steam required, (3) the thermal efficiency.

10-23M The boiler-superheater of an ideal regenerative steam cycle produces steam at 120 bars and 600 °C. A closed feedwater heater receives steam from the turbine at 30 bars and an open feedwater heater operates at 10 bars. The condenser operates at 0.08 bars, and the liquid condensate from the closed heater is throttled back into the open heater. There is a pump after the condenser and after the open heater. Determine (a) the fraction of the total flow which goes to the closed heater and to the open heater, (b) the work output of the turbine and the total pump work, in kJ/kg of total flow, and (c) the thermal efficiency.

10-24M Steam enters the turbine of an ideal regenerative cycle at 40 bars and 500 °C. Steam is extracted at 7 and 3 bars and introduced into two open feedwater heaters that are in series. Appropriate pumps are employed after the condenser, which operates at 0.06 bar, and after each heater. Determine (a) the fraction of the total flow which goes to the 7 bars heater and the 3 bars heater, (b) the work output of the turbine and the total pump work, in kJ/kg of total flow, and (c) the thermal efficiency.

10-25M Steam is generated at 140 bars and 520 °C. The steam is expanded through the first stage of a turbine to 40 bars. Part of the exhaust stream from this turbine is supplied to a closed feedwater heater, and the remainder is reheated to 520 °C. The reheated steam is then expanded in a second stage of the turbine to an exhaust pressure of 0.08 bar. Some steam is bled from the second turbine at 7 bars for use in an open feedwater heater. The steam bled from the first turbine condenses as it passes through the closed heater and is throttled back into the open heater at 7 bars. The saturated liquid leaving the open heater first passes through a pump to 140 bars and then through the other side of the closed heater to the boiler. If we assume an ideal cycle and neglect pump work, determine (a) the percent of the steam entering the first turbine which goes to the closed heater, (b} the percent of the steam entering the second turbine which is bled to the open heater, and (c) the thermal efficiency.

Reheat-regenerative cycles

10-26M Consider the following modification of Probs. 17-12M and 17-18M. The steam in the turbine is expanded to 15 bars, where a portion is bled to an open feedwater heater operating at this pressure. The remaining portion is reheated to 440 °C and then expanded to (a) 0.08 bar, and (b) 0.04 bar. Determine the thermal efficiency.

10-27M Consider the following modification of Probs. 17-13M and 17-19M. (a) Steam at 60 bars and 540 °C is expanded to 5 bars, where a portion is bled to an open feedwater heater. The remaining portion is reheated to 500 °C and then expanded to 0.08 bar. (b) Steam at 60 bars and 440 °C is expanded to 10 bars, where a portion is bled to an open feedwater heater. The remaining portion is reheated to 440 °C and then expanded to 0.08 bar. Find the thermal efficiency.

10-28M Consider the following modifications of Probs. 17-14M and 17-20M. (a) Steam at 120 bars and 520 °C is expanded to 10 bars, where a portion is bled to a single, open feedwater heater. The remaining portion is reheated to 500 °C and expanded to 0.08 bar. (b) Steam at 80 bars and 520 °C is expanded to 7 bars, where a portion is bled to a single, open feedwater heater. The remaining portion is reheated to 500°C and expanded to 0.08 bar. Determine the thermal efficiency.

10-29M Consider the following modification of Prob. 17-23M. The portion of the flow which does not go to the closed heater is reheated to 540 °C before it enters the second stage of the turbine. Determine (a) the fraction of the total flow which goes to the open heater, (b) the heat input, in kJ/kg, and (c) the thermal efficiency.

10-30M Consider the following modification of Prob. 17-24M. The portion of the flow which is not extracted to the open heater at 7 bars is reheated to 500 °C before it enters the second stage of the turbine. Find (a) the fraction of the total flow which goes to the open heater at 3 bars, (b) the heat input, in kJ/kg, and (c) the thermal efficiency.

10-31M An ideal, reheat-regenerative cycle operates with conditions at the turbine inlet of 140 bars and 600 °C, and reheat is at 7 bars to 500 °C. A closed feedwater heater operates at 15 bars, and the drain from the closed heater is trapped back into an open feedwater heater which operates at 3 bars. The condenser pressure is 0.06 bar. Determine (a) the thermal efficiency of the cycle, and (b) the mass flow rate through the steam generator required for a turbine output of 100,000 kW.

10-32M The adiabatic efficiency of the turbine is 85 percent and that of the pump is 70 percent in a simple steam power cycle. On this basis determine the thermal efficiency for the data given in (a) Prob. 17-4M(a), (b) Prob. 17-4M(b), (c) Prob. 17-5M(a), (d) Prob. 17-5M(b), (e) Prob. 17-6M(a), (f) Prob. 17-6M(b), (g) Prob. 17-7M, and (h) Prob. 17-8M.

10-33M The adiabatic efficiency of the turbine is 85 percent and that of the pump is 70 percent in a reheat cycle. On this basis determine the thermal efficiency for the data given in (a) Prob. 17-12M(a), (b) Prob. 17-12M(b), (c) Prob. 17-13M(b), (d) Prob. 17-13M(a), (e) Prob. 17-14M(a), (/) Prob. 17- 14M(b), (g) Prob. 17-15M, and (h) Prob. 17-16M.

10-34M The adiabatic efficiencies of the turbine and pump in a regenerative cycle are 85 and 70 percent, respectively. On this basis determine the thermal efficiency of the cycle for the data given in (a) Prob. 17-18M(b), (b) Prob. 17-18M(c), (c) Prob. 17-19M(a), (d) Prob. 17-19M(a), (e) Prob. 17-20M(a), (f) Prob. 17-20M(b), (g) Prob. 17-21M(a), (h) Prob. 17-22M{a), and (i) Prob. 17-23M.

I0-35M The adiabatic efficiencies of the turbine and pump in a reheat-regenerative cycle are 85 and 70 percent, respectively. On this basis determine the thermal efficiency for the data given in (a) Prob. 17-26M(a), (b) Prob. 17-26M(b), (c) Prob. 17-27M(a), (d) Prob. 17-27M(b), (e) Prob. 10-28M(a) (f)Prob. 17-28M(a), (g) Prob. 17-29M, and (h) Prob. 17-30M.

10-36M A simple steam power cycle uses solar energy for the heat input. Water in the cycle enters the pump as a saturated liquid at 40 °C, and is pumped to 2 bars. It then evaporates in the boiler at this pressure, and enters the turbine as saturated vapor. At the turbine exhaust the conditions are 40 °C and 8 percent moisture. The mass flow rate is 1500 kg/h, and the pump is rated at 0.3 kW. Determine (a) the net work output in kJ/kg, (b) the energy-conversion efficiency, and (c) the area, in square meters of the solar collector needed if the collector picks up 700 J/m^2s.

English Units

10-2 A Carnot engine operates with steam as the working medium. At the end of adiabatic compression the pressure is 200 psia and the quality is 10 percent. At the end of isothermal heat addition the steam is a saturated vapor, and during isothermal heat rejection the pressure is 10 psia. Determine (a) the quality at the end of adiabatic expansion, (b) the thermal efficiency, (c) the heat rejected, in Btu/lb_m, and (d) the net work output per cycle, in Btu/lb_m.

10-3 A Carnot engine contains 0.10 Ib_m of water. At the beginning of the heat-addition process the fluid is a saturated liquid, and at the end of this process it is a saturated vapor. Heat addition occurs al 640 °F and heat rejection is at 40 °F. Determine (a) the quality at the end of adiabatic expansion and at the end of isothermal heat rejection, (b) the thermal efficiency, (c) the heat added per cycle, in Btu, and (d) the net work output per cycle.

The Rankine cycle

10-4 A Rankine cycle has steam entering the turbine at 550 psia and 800 °F. If the turbine output is 10,000 kW, determine (1) the quality at the turbine outlet, (2) the thermal efficiency, and (3) the mass flow rate of steam, in Ib_m/hr, for condenser pressures of (a) 1 psia and (b) 0.60 psia.

10-5 A Rankine cycle has an exhaust pressure of 1 psia and a turbine-inlet pressure of 800 psia. Determine (1) the moisture content at the turbine outlet, (2) the thermal efficiency, and (3) the mass flow rate of steam, in Ib_m/hr, for a net power output of 10 MW and for turbine-inlet temperatures of (a) 1000 °F and (b) 800 °F.

10-6 A Rankine cycle has an exhaust pressure of 1 psia and a turbine-inlet temperature of 1000 °F. Determine (1) the moisture content at the turbine outlet and (2) the thermal efficiency of the cycle for a turbine-inlet pressure of (a) 1600 psia and (b) 1200 psia.

10-7 An ideal Rankine cycle generates steam at 2000 psia and 1000 °F, and condenses steam at 0-80 psia. The net power output is 100 MW. Determine (a) the heat input, in Btu/lb, (b) the thermal efficiency, (c) the mass flow rate of steam, in Ib_m/hr, and (d) the mass flow rate of cooling water required in the condenser if the water experiences a 14 °F temperature rise.

10-8 An ideal Rankine steam power cycle which produces 125 MW of turbine power has the following operating conditions: turbine inlet, 1000 psia and 1000 °F; condenser pressure, 1.0 psia. Determine (a) the heat input, in Btu/lb_m, (b) the thermal efficiency, (c) the mass flow rate of steam, in Ib_m/hr, and (d) the mass flow rate of cooling water required in the condenser, in Ib_m/hr, if the water experiences a 12 °F temperature rise.

10-9 A steam power unit operating on the Rankine cycle has a mass flow rate of 52,400 Ib_m/hr through it. Water enters the boiler at 500 psia, and it leaves the condenser at 1.2 psia. Cooling water in the condenser is circulated at a rate of 3.20 x 10^6 Ib_m/hr, and it experiences a temperature rise of 14 °F. Determine (a) the enthalpy and entropy at the turbine outlet, (b) the enthalpy at the turbine inlet, (c) the heat added in Btu/lb, (d) the thermal efficiency, and (e) the power output of the turbine, in kilowatts.

10-10 A Rankine power cycle uses solar energy for the heat input and refrigerant 134a as the working fluid. Fluid enters the pump as a saturated liquid at 100 psia, and is pumped to 300 psia. The turbine-inlet temperature is 240 °F and the mass flow rate is 1200 Ib_m/hr. Determine (a) the net work output, in Btu/lb_m, (b) the thermal efficiency, and (c) the area, in square feet, of the solar collector needed if the collector picks up 200 Btu/ft^2hr.