The Reversed Carnot Cycle

9–132C Why do we study the reversed Carnot cycle even though it is not a realistic model for refrigeration cycles?

9–133C Why is the reversed Carnot cycle executed within the saturation dome not a realistic model for refrigeration cycles?

9–134 A steady-flow Carnot refrigeration cycle uses refrigerant-134a as the working fluid. The refrigerant changes from saturated vapor to saturated liquid at 40°C in the condenser as it rejects heat. The evaporator pressure is 100 kPa. Show the cycle on a *T-s* diagram relative to saturation lines, and determine (*a*) the coefficient of performance, (*b*) the amount of heat absorbed from the refrigerated space, and (*c*) the net work input. *Answers:* (*a*) 3.72, (*b*) 128 kJ/kg, (*c*) 34.6 kJ/kg

9–135 Refrigerant-134a enters the condenser of a steady-flow Carnot refrigerator as a saturated vapor at 0.6 MPa, and it leaves with a quality of 0.05. The heat absorption from the refrigerated space takes place at a pressure of 0.2 MPa. Show the cycle on a *T-s* diagram relative to saturation lines, and determine (*a*) the coefficient of performance, (*b*) the quality at the beginning of the heat absorption process, and (*c*) the net work input.

Ideal and Actual Vapor-Compression Refrigeration Cycles

9–136C Does the ideal vapor-compression refrigeration cycle involve any internal irreversibilities?

9–137C Why is the throttling valve not replaced by an isentropic turbine in the ideal vapor-compression refrigeration cycle?

9–138C It is proposed to use water instead of refrigerant-134a as the working fluid in air-conditioning applications where the minimum temperature never falls below the freezing point. Would you support this proposal? Explain.

9–139C In a refrigeration system, would you recommend condensing the refrigerant-134a at a pressure of 0.7 or 1.0 MPa if heat is to be rejected to a cooling medium at 15°C? Why?

9–140C Does the area enclosed by the cycle on a *T-s* diagram represent the net work input for the reversed Carnot cycle? How about for the ideal vapor-compression refrigeration cycle?

9–141C Consider two vapor-compression refrigeration cycles. The refrigerant enters the throttling valve as a saturated liquid at 30°C in one cycle and as subcooled liquid at 30°C in the other one. The evaporator pressure for both cycles is the same. Which cycle do you think will have a higher COP?

9–142C The COP of vapor-compression refrigeration cycles improves when the refrigerant is subcooled before it enters the throttling valve. Can the refrigerant be subcooled indefinitely to maximize this effect, or is there a lower limit? Explain.

9–143 A refrigerator operates on the ideal vapor-compression refrigeration cycle and uses refrigerant-134a as the working fluid. The condenser operates at 1.6 MPa and the evaporator at −6°C. If an adiabatic, reversible expansion device were available and used to expand the liquid leaving the condenser, how much would the COP improve by using this device instead of the throttle device? *Answer:* 9.7 percent

9–144 An ideal vapor-compression refrigeration cycle that uses refrigerant-134a as its working fluid maintains a condenser at 1000 kPa and the evaporator at 4°C. Determine this system's COP and the amount of power required to service a 400 kW cooling load. *Answers:* 6.46, 61.9 kW

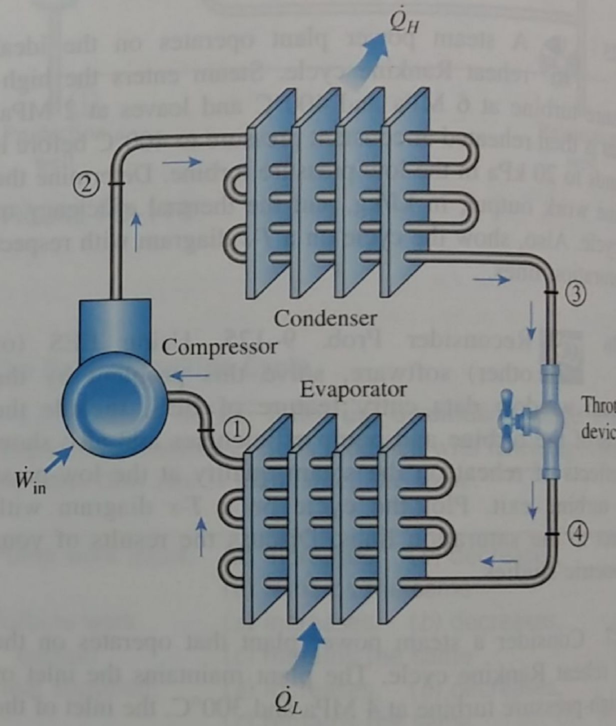

FIGURE P9–144

9–145 A refrigerator uses refrigerant-134a as the working fluid and operates on an ideal vapor-compression refrigeration cycle between 0.12 and 0.7 MPa. The mass flow rate of the refrigerant is 0.05 kg/s. Show the cycle on a *T-s* diagram with respect to saturation lines. Determine (*a*) the rate of heat removal from the refrigerated space and the power input to the compressor, (*b*) the rate of heat rejection to the environment, and (*c*) the coefficient of performance. *Answers:* (*a*) 7.41 kW, 1.83 kW, (*b*) 9.23 kW, (*c*) 4.06

9–146 Repeat Prob. 9–145 for a condenser pressure of 0.9 MPa.

9–147 If the throttling valve in Prob. 9–145 is replaced by an isentropic turbine, determine the percentage increase in the COP and in the rate of heat removal from the refrigerated space. *Answers:* 4.2 percent, 4.2 percent

9–148 Refrigerant-134a enters the compressor of a refrigerator as superheated vapor at 0.20 MPa and −5°C at a rate of 0.07 kg/s, and it leaves at 1.2 MPa and 70°C. The refrigerant is cooled in the condenser to 44°C and 1.15 MPa, and it is throttled to 0.21 MPa. Disregarding any heat transfer and pressure drops in the connecting lines between the components, show the cycle on a *T-s* diagram with respect to saturation lines, and determine (*a*) the rate of heat removal from the refrigerated space and the power input to the compressor, (*b*) the isentropic efficiency of the compressor, and (*c*) the COP of the refrigerator. *Answers:* (a) 9.42 kW, 3.63 kW, (b) 74.1 percent, (c) 2.60

9–149 A commercial refrigerator with refrigerant-134a as the working fluid is used to keep the refrigerated space at −30°C by rejecting its waste heat to cooling water that enters the condenser at 18°C at a rate of 0.25 kg/s and leaves at 26°C. The refrigerant enters the condenser at 1.2 MPa and 65°C and leaves at 42°C. The inlet state of the compressor is 60 kPa and −34°C and the compressor is estimated to gain a net heat of 450 W from the surroundings. Determine (*a*) the quality of the refrigerant at the evaporator inlet, (*b*) the refrigeration load, (*c*) the COP of the refrigerator, and (*d*) the theoretical maximum refrigeration load for the same power input to the compressor.

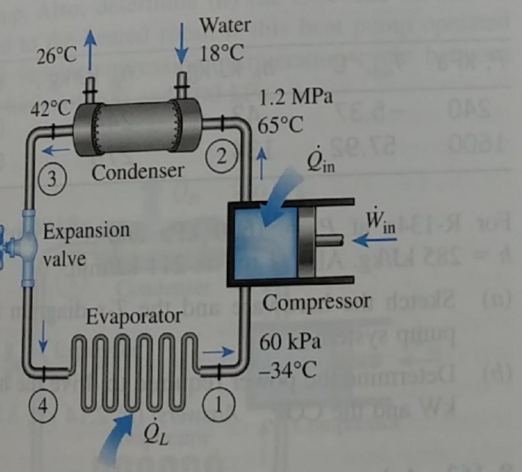

FIGURE P9–149

9–150 Refrigerant-134a enters the compressor of a refrigerator at 100 kPa and −20°C at a rate of 0.5 m³/min and leaves at 0.8 MPa. The isentropic efficiency of the compressor is 78 percent. The refrigerant enters the throttling valve at 0.75 MPa and 26°C and leaves the evaporator as saturated vapor at −26°C. Show the cycle on a *T-s* diagram with respect to saturation lines, and determine (*a*) the power input to the compressor, (*b*) the rate of heat removal from the refrigerated space, and (*c*) the pressure drop and rate of heat gain in the line between the evaporator and the compressor. *Answers:* (a) 2.40 kW, (b) 6.17 kW, (c) 1.73 kPa, 0.203 kW

9–151 EES Reconsider Prob. 9–150. Using EES (or other) software, investigate the effects of varying the compressor isentropic efficiency over the range 60 to 100 percent and the compressor inlet volume flow rate from 0.1 to 1.0 m³/min on the power input and the rate of refrigeration. Plot the rate of refrigeration and the power input to the compressor as functions of compressor efficiency for compressor inlet volume flow rates of 0.1, 0.5, and 1.0 m³/min, and discuss the results.

9–152 A refrigerator uses refrigerant-134a as the working fluid and operates on the ideal vapor-compression refrigeration cycle except for the compression process. The refrigerant enters the evaporator at 120 kPa with a quality of 30 percent and leaves the compressor at 60°C. If the compressor consumes 450 W of power, determine (*a*) the mass flow rate of the refrigerant, (*b*) the condenser pressure, and (*c*) the COP of the refrigerator. *Answers:* (a) 0.00727 kg/s, (b) 672 kPa, (c) 2.43

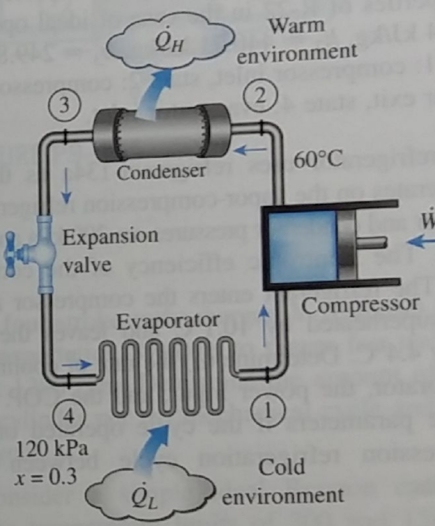

FIGURE P9–152

9–153 The manufacturer of an air conditioner claims a seasonal energy efficiency ratio (SEER) of 16 (Btu/h)/W for one of its units. This unit operates on the normal vapor-compression refrigeration cycle and uses refrigerant-22 as the working fluid. This SEER is for the operating conditions when the evaporator saturation temperature is −5°C and the condenser saturation temperature is 45°C. Selected data for refrigerant-22 are provided in the table below.

T, °C	P_{sat}, kPa	h_f, kJ/kg	h_g, kJ/kg	s_g, kJ/kg·K
−5	421.2	38.76	248.1	0.9344
45	1728	101	261.9	0.8682

(*a*) Sketch the hardware and the *T-s* diagram for this air conditioner.

(b) Determine the heat absorbed by the refrigerant in the evaporator per unit mass of refrigerant-22, in kJ/kg.

(c) Determine the work input to the compressor and the heat rejected in the condenser per unit mass of refrigerant-22, in kJ/kg.

9–154 An actual refrigerator operates on the vapor-compression refrigeration cycle with refrigerant-22 as the working fluid. The refrigerant evaporates at −15°C and condenses at 40°C. The isentropic efficiency of the compressor is 83 percent. The refrigerant is superheated by 5°C at the compressor inlet and subcooled by 5°C at the exit of the condenser. Determine (a) the heat removed from the cooled space and the work input, in kJ/kg and the COP of the cycle. Determine (b) the same parameters if the cycle operated on the ideal vapor-compression refrigeration cycle between the same evaporating and condensing temperatures.

The properties of R-22 in the case of actual operation are: h_1 = 402.49 kJ/kg, h_2 = 454.00 kJ/kg, h_3 = 243.19 kJ/kg

The properties of R-22 in the case of ideal operation are: h_1 = 399.04 kJ/kg, h_2 = 440.71 kJ/kg, h_3 = 249.80 kJ/kg

Note: state 1: compressor inlet, state 2: compressor exit, state 3: condenser exit, state 4: evaporator inlet.

9–155 A refrigerator uses refrigerant-134a as the working fluid and operates on the vapor-compression refrigeration cycle. The evaporator and condenser pressures are 200 kPa and 1400 kPa, respectively. The isentropic efficiency of the compressor is 88 percent. The refrigerant enters the compressor at a rate of 0.025 kg/s superheated by 10.1°C and leaves the condenser subcooled by 4.4°C. Determine (a) the rate of cooling provided by the evaporator, the power input, and the COP. Determine (b) the same parameters if the cycle operated on the ideal vapor-compression refrigeration cycle between the same pressure limits.

Heat Pump Systems

9–156C Do you think a heat pump system will be more cost effective in New York or in Miami? Why?

9–157C What is a water-source heat pump? How does the COP of a water-source heat pump system compare to that of an air-source system?

9–158 A heat pump uses refrigerant-134a as the working fluid and operates on the ideal vapor-compression refrigeration cycle. The condenser pressure is 700 kPa while the evaporator temperature is 4°C. What is the COP of this heat pump?

9–159 A heat pump operates on the ideal vapor-compression refrigeration cycle and uses refrigerant-134a as the working fluid. The condenser operates at 1000 kPa and the evaporator at 200 kPa. Determine this system's COP and the rate of heat supplied to the evaporator when the compressor consumes 6 kW.

9–160 A heat pump operates on the ideal vapor-compression refrigeration cycle with refrigerant-134a as the working fluid. This heat pump is used to keep a space at 25°C by absorbing heat at the rate of 2.7 kW from geothermal water flowing through the evaporator. The evaporator operates at 20°C, and the condenser operates at 1400 kPa. The compressor receives work equal to 20 kJ for each kilogram of refrigerant flowing into it.

(a) Sketch the hardware and the T-s diagram for this heat pump.

(b) Determine the rate of heat transfer to the heated space at 25°C.

(c) Determine the COP of the heat pump.

Refrigerant-134a data: T = 20°C: h_f = 79.3 kJ/kg, h_g = 261.6 kJ/kg; P = 1400 kPa: h_f = 127.2 kJ/kg, h_g = 276.2 kJ/kg

9–161 A building requires a 2-ton heat pump for maintaining the interior space at 27°C when the outside temperature is 5°C. The heat pump operates on the normal vapor-compression refrigeration cycle and uses refrigerant-134a as the working fluid. The heat pump operating conditions require an evaporator pressure of 240 kPa and a condenser pressure of 1600 kPa while the compressor has an isentropic efficiency of 85 percent. Selected data for refrigerant-134a are provided in the table below.

P, kPa	T_{sat}, °C	h_f, kJ/kg	h_g, kJ/kg	s_g, kJ/kg·K
240	−5.37	43	244	0.9222
1600	57.92	134	275	0.8982

For R-134a at P = 1600 kPa and s = 0.9222 kJ/kg·K, h = 285 kJ/kg. Also, 1 ton = 211 kJ/min.

(a) Sketch the hardware and the T-s diagram for this heat pump system.

(b) Determine the power required to drive the heat pump, in kW and the COP. *Answers: (b) 2.14 kW, 3.29*

9–162 A heat pump with refrigerant-134a as the working fluid is used to keep a space at 25°C by absorbing heat from geothermal water that enters the evaporator at 50°C at a rate of 0.065 kg/s and leaves at 40°C. The refrigerant enters the evaporator at 20°C with a quality of 23 percent and leaves at the inlet pressure as saturated vapor. The refrigerant loses 300 W of heat to the surroundings as it flows through the compressor and the refrigerant leaves the compressor at 1.4 MPa at the same entropy as the inlet. Determine (a) the degrees of subcooling of the refrigerant in the condenser, (b) the mass flow rate of the refrigerant, (c) the heating load and the COP of the heat pump, and (d) the theoretical minimum power input to the compressor for the same heating load. *Answers: (a) 3.8°C, (b) 0.0194 kg/s, (c) 3.07 kW, 4.68, (d) 0.238 kW*