12.63 A stream of air (stream 1) at 60°F, 1 atm, 30% relative humidity is mixed adiabatically with a stream of air (stream 2) at 90°F, 1 atm, 80% relative humidity. A single stream (stream 3) exits the mixing chamber at temperature $T_3$ and 1 atm. Assume steady state and ignore kinetic and potential energy effects. Letting $r$ denote the ratio of dry air mass flow rates $\dot{m}_{a1}/\dot{m}_{a2}$

**a.** determine $T_3$, in °F, for $r = 2$.

**b.** plot $T_3$, in °F, versus $r$ ranging from 0 to 10.

12.67 Liquid water enters a cooling tower operating at steady state at 40°C with a mass flow rate of $10^5$ kg/h. Cooled water at 25°C exits the cooling tower at the same mass flow rate. Makeup water is supplied at 23°C. Atmospheric air enters the tower at 30°C, 1 bar, 35% relative humidity. A saturated moist air stream exits at 34°C, 1 bar. Determine

**a.** the mass flow rates of the dry air and makeup water, each in kg/h.

**b.** the rate of exergy destruction within the cooling tower, in kW, for $T_0 = 23°C$. Ignore kinetic and potential energy effects.
SP-16
An air-conditioning system operates at a pressure of 1 atm and consists of a heating coil and a humidifier. Air enters the heating section at 10°C and 70% relative humidity with a dry air mass flow rate of 0.7 kg/s. The rate of heat transfer to the air from the heating coil is 7 kJ/s. The humidifier supplies 0.003 kg/s of saturated water vapor at 100°C to the air.

(a) Find the air temperature, in °C, and relative humidity, in %, when air leaves the heating section (state 2).

(b) Determine the air temperature, in °C, and relative humidity, in %, when air leaves the air-conditioning system (state 3).

(c) Label the air-conditioning processes on a psychrometric chart with the state numbers.

(d) Determine the specific entropy change of water vapor between states 3 and 1, in kJ/kmol·K.

Answers: (b) 21°C, 60%
10.7 Figure P10.7 provides steady-state operating data for an ideal vapor-compression refrigeration cycle with Refrigerant 134a as the working fluid. The mass flow rate of refrigerant is 30.59 lb/min. Sketch the T–s diagram for the cycle and determine

![Diagram of the refrigeration cycle]

- the compressor power, in horsepower.
- the rate of heat transfer, from the working fluid passing through the condenser, in Btu/min.
- the coefficient of performance.

10.17 In a vapor-compression refrigeration cycle, ammonia exits the evaporator as saturated vapor at −22°C. The refrigerant enters the condenser at 16 bar and 160°C, and saturated liquid exits at 16 bar. There is no significant heat transfer between the compressor and its surroundings, and the refrigerant passes through the evaporator with a negligible change in pressure. If the refrigerating capacity is 150 kW, determine

- the mass flow rate of the refrigerant, in kg/s.
- the power input to the compressor, in kW.
- the coefficient of performance.
- the isentropic compressor efficiency.
- the rate of entropy production, in kW/K, for the compressor.
A vapor-compression air-conditioning system operates at steady state as shown in the figure. The system maintains a cool region at 15°C and discharges energy by heat transfer to the surroundings at 32°C. Refrigerant 134a enters the compressor as a saturated vapor at 4°C and is compressed adiabatically to 12 bar. The isentropic compressor efficiency is 80%. Refrigerant exits the condenser as a saturated liquid at 12 bar. The mass flow rate of the refrigerant is 0.07 kg/s. Kinetic and potential energy changes are negligible as are changes in pressure for flow through the evaporator and condenser. Determine:

(a) the power required by the compressor, in kJ/s.

(b) the coefficient of performance.

(c) the rates of exergy destruction in the compressor and expansion valve, each in kJ/s.

(d) the rates of exergy destruction and exergy transfer accompanying heat transfer, each in kJ/s, for a control volume comprising the evaporator and a portion of the cool region such that heat transfer takes place at $T_C = 15°C$.

(e) the rates of exergy destruction and exergy transfer accompanying heat transfer, each in kJ/s, for a control volume enclosing the condenser and a portion of the surroundings such that heat transfer takes place at $T_H = 32°C$.

Let $T_0 = 32°C$.

Answers: (b) 4.09
An office building requires a heat transfer rate of 20 kW to maintain the inside temperature at 21°C when the outside temperature is 0°C. A vapor-compression heat pump with Refrigerant 134a as the working fluid is to be used to provide the necessary heating. The compressor operates adiabatically with an isentropic efficiency of 82%. Specify appropriate evaporator and condenser pressures of a cycle for this purpose assuming \( \Delta T_{\text{cond}} = \Delta T_{\text{evap}} = 10^\circ\text{C} \), as shown in Figure P10.32. The states are numbered as in Fig. 10.13. The refrigerant exits the evaporator as saturated vapor and exits the condenser as saturated liquid at the respective pressures. Determine the

a. mass flow rate of refrigerant, in kg/s.

b. compressor power, in kW.

c. coefficient of performance and compare with the coefficient of performance for a Carnot heat pump cycle operating between reservoirs at the inside and outside temperatures, respectively.
SP-18

A process requires a heat transfer rate of $3.2 \times 10^6$ kJ/hr at 75°C. It is proposed that a Refrigerant 134a vapor-compression heat pump be used to develop the process heating using a wastewater stream at 50°C as the lower-temperature source. The figure provides data for this cycle operating at steady state. The compressor isentropic efficiency is 80%.

(a) Find the specific enthalpy at the compressor exit, in kJ/kg.
(b) Find the temperatures at each of the principal states, in °C.
(c) Sketch the $T$–$s$ diagram for the cycle.
(d) Find the mass flow rate of the refrigerant, in kg/hr.
(e) Find the compressor power, in kJ/hr.
(f) Find the coefficient of performance and compare with the coefficient of performance for a Carnot heat pump cycle operating between reservoirs at the process temperature and the wastewater temperature, respectively.
(g) Find the second-law efficiency of the heat pump.

---

**Table:**

<table>
<thead>
<tr>
<th>State</th>
<th>P (bar)</th>
<th>h (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>261.85</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>134.02</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>134.02</td>
</tr>
</tbody>
</table>
A rocket engine using liquid-methane and gaseous oxygen operates with gaseous oxygen flow tube that is at $P = 202$ bar and $T = 170$ K with a volume flow rate of 1 L/s. Find the mass flow rate of gaseous oxygen in the flow tube in kg/s using:

(a) The ideal gas equation of state.

(b) The van der Waals equation of state.

(c) The compressibility chart.

(d) The Redlich-Kwong equation of state.

(e) Discuss what might happen to the rocket engine if the development engineer had the wrong mass flow rate of oxygen.