

Solutions Manual
for
Introduction to Thermodynamics and Heat Transfer
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Chapter 4
PROPERTIES OF PURE
SUBSTANCES

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Pure Substances, Phase Change Processes, Property Diagrams

4-1C Yes, since the chemical composition throughout the tank remain the same.

4-2C A liquid that is about to vaporize is saturated liquid; otherwise it is compressed liquid.

4-3C A vapor that is about to condense is saturated vapor; otherwise it is superheated vapor.

4-4C No.

4-5C The temperature will also increase since the boiling or saturation temperature of a pure substance depends on pressure.

4-6C Because one cannot be varied while holding the other constant. In other words, when one changes, so does the other one.

4-7C At critical point the saturated liquid and the saturated vapor states are identical. At triple point the three phases of a pure substance coexist in equilibrium.

4-8C Yes.

4-9C Case (c) when the pan is covered with a heavy lid. Because the heavier the lid, the greater the pressure in the pan, and thus the greater the cooking temperature.

4-10C At supercritical pressures, there is no distinct phase change process. The liquid uniformly and gradually expands into a vapor. At subcritical pressures, there is always a distinct surface between the phases.

Property Tables

4-11C A perfectly fitting pot and its lid often stick after cooking as a result of the vacuum created inside as the temperature and thus the corresponding saturation pressure inside the pan drops. An easy way of removing the lid is to reheat the food. When the temperature rises to boiling level, the pressure rises to atmospheric value and thus the lid will come right off.

4-12C The molar mass of gasoline (C_8H_{18}) is 114 kg/kmol, which is much larger than the molar mass of air that is 29 kg/kmol. Therefore, the gasoline vapor will settle down instead of rising even if it is at a much higher temperature than the surrounding air. As a result, the warm mixture of air and gasoline on top of an open gasoline will most likely settle down instead of rising in a cooler environment

4-13C Ice can be made by evacuating the air in a water tank. During evacuation, vapor is also thrown out, and thus the vapor pressure in the tank drops, causing a difference between the vapor pressures at the water surface and in the tank. This pressure difference is the driving force of vaporization, and forces the liquid to evaporate. But the liquid must absorb the heat of vaporization before it can vaporize, and it absorbs it from the liquid and the air in the neighborhood, causing the temperature in the tank to drop. The process continues until water starts freezing. The process can be made more efficient by insulating the tank well so that the entire heat of vaporization comes essentially from the water.

4-14C Yes. Otherwise we can create energy by alternately vaporizing and condensing a substance.

4-15C No. Because in the thermodynamic analysis we deal with the changes in properties; and the changes are independent of the selected reference state.

4-16C The term h_{fg} represents the amount of energy needed to vaporize a unit mass of saturated liquid at a specified temperature or pressure. It can be determined from $h_{fg} = h_g - h_f$.

4-17C Yes; the higher the temperature the lower the h_{fg} value.

4-18C Quality is the fraction of vapor in a saturated liquid-vapor mixture. It has no meaning in the superheated vapor region.

4-19C Completely vaporizing 1 kg of saturated liquid at 1 atm pressure since the higher the pressure, the lower the h_{fg} .

4-20C Yes. It decreases with increasing pressure and becomes zero at the critical pressure.

4-21C No. Quality is a mass ratio, and it is not identical to the volume ratio.

4-22C The compressed liquid can be approximated as a saturated liquid at the given temperature. Thus $v_{T,P} \cong v_f @ T$.

4-23 CD EES Complete the following table for H_2O :

<i>T, °C</i>	<i>P, kPa</i>	<i>v, m³/kg</i>	<i>Phase description</i>
50	<i>12.352</i>	4.16	<i>Saturated mixture</i>
<i>120.21</i>	200	<i>0.8858</i>	Saturated vapor
250	400	<i>0.5952</i>	<i>Superheated vapor</i>
110	600	<i>0.001051</i>	<i>Compressed liquid</i>

4-24 EES Problem 4-23 is reconsidered. The missing properties of water are to be determined using EES, and the solution is to be repeated for refrigerant-134a, refrigerant-22, and ammonia.

Analysis The problem is solved using EES, and the solution is given below.

\$Warning off

{\$Arrays off}

Procedure Find(Fluid\$, Prop1\$, Prop2\$, Value1, Value2: T, p, h, s, v, u, x, State\$)

"Due to the very general nature of this problem, a large number of 'if-then-else' statements are necessary."

If Prop1\$='Temperature, C' Then

 T=Value1

 If Prop2\$='Temperature, C' then Call Error('Both properties cannot be Temperature, T=xxxF2', T)

 if Prop2\$='Pressure, kPa' then

 p=value2

 h=enthalpy(Fluid\$, T=T, P=p)

 s=entropy(Fluid\$, T=T, P=p)

 v=volume(Fluid\$, T=T, P=p)

 u=intenergy(Fluid\$, T=T, P=p)

 x=quality(Fluid\$, T=T, P=p)

 endif

 if Prop2\$='Enthalpy, kJ/kg' then

 h=value2

 p=Pressure(Fluid\$, T=T, h=h)

 s=entropy(Fluid\$, T=T, h=h)

 v=volume(Fluid\$, T=T, h=h)

 u=intenergy(Fluid\$, T=T, h=h)

 x=quality(Fluid\$, T=T, h=h)

 endif

 if Prop2\$='Entropy, kJ/kg-K' then

 s=value2

 p=Pressure(Fluid\$, T=T, s=s)

 h=enthalpy(Fluid\$, T=T, s=s)

 v=volume(Fluid\$, T=T, s=s)

 u=intenergy(Fluid\$, T=T, s=s)

 x=quality(Fluid\$, T=T, s=s)

 endif

 if Prop2\$='Volume, m³/kg' then

 v=value2

 p=Pressure(Fluid\$, T=T, v=v)

 h=enthalpy(Fluid\$, T=T, v=v)

 s=entropy(Fluid\$, T=T, v=v)

 u=intenergy(Fluid\$, T=T, v=v)

 x=quality(Fluid\$, T=T, v=v)

 endif

 if Prop2\$='Internal Energy, kJ/kg' then

 u=value2

 p=Pressure(Fluid\$, T=T, u=u)

 h=enthalpy(Fluid\$, T=T, u=u)

 s=entropy(Fluid\$, T=T, u=u)

 v=volume(Fluid\$, T=T, s=s)

 x=quality(Fluid\$, T=T, u=u)

 endif

 if Prop2\$='Quality' then

```

    x=value2
    p=Pressure(Fluid$,T=T,x=x)
    h=enthalpy(Fluid$,T=T,x=x)
    s=entropy(Fluid$,T=T,x=x)
    v=volume(Fluid$,T=T,x=x)
    u=IntEnergy(Fluid$,T=T,x=x)
  endif
Endif
If Prop1$='Pressure, kPa' Then
  p=Value1
  If Prop2$='Pressure, kPa' then Call Error('Both properties cannot be Pressure, p=xxxF2',p)
  if Prop2$='Temperature, C' then
    T=value2
    h=enthalpy(Fluid$,T=T,P=p)
    s=entropy(Fluid$,T=T,P=p)
    v=volume(Fluid$,T=T,P=p)
    u=intenergy(Fluid$,T=T,P=p)
    x=quality(Fluid$,T=T,P=p)
  endif
  if Prop2$='Enthalpy, kJ/kg' then
    h=value2
    T=Temperature(Fluid$,p=p,h=h)
    s=entropy(Fluid$,p=p,h=h)
    v=volume(Fluid$,p=p,h=h)
    u=intenergy(Fluid$,p=p,h=h)
    x=quality(Fluid$,p=p,h=h)
  endif
  if Prop2$='Entropy, kJ/kg-K' then
    s=value2
    T=Temperature(Fluid$,p=p,s=s)
    h=enthalpy(Fluid$,p=p,s=s)
    v=volume(Fluid$,p=p,s=s)
    u=intenergy(Fluid$,p=p,s=s)
    x=quality(Fluid$,p=p,s=s)
  endif
  if Prop2$='Volume, m^3/kg' then
    v=value2
    T=Temperature(Fluid$,p=p,v=v)
    h=enthalpy(Fluid$,p=p,v=v)
    s=entropy(Fluid$,p=p,v=v)
    u=intenergy(Fluid$,p=p,v=v)
    x=quality(Fluid$,p=p,v=v)
  endif
  if Prop2$='Internal Energy, kJ/kg' then
    u=value2
    T=Temperature(Fluid$,p=p,u=u)
    h=enthalpy(Fluid$,p=p,u=u)
    s=entropy(Fluid$,p=p,u=u)
    v=volume(Fluid$,p=p,s=s)
    x=quality(Fluid$,p=p,u=u)
  endif
  if Prop2$='Quality' then
    x=value2
    T=Temperature(Fluid$,p=p,x=x)
    h=enthalpy(Fluid$,p=p,x=x)
    s=entropy(Fluid$,p=p,x=x)
  endif

```

```

        v=volume(Fluid$,p=p,x=x)
        u=IntEnergy(Fluid$,p=p,x=x)
    endif
Endif
If Prop1$='Enthalpy, kJ/kg' Then
    h=Value1
    If Prop2$='Enthalpy, kJ/kg' then Call Error('Both properties cannot be Enthalpy, h=xxxF2',h)
    if Prop2$='Pressure, kPa' then
        p=value2
        T=Temperature(Fluid$,h=h,P=p)
        s=entropy(Fluid$,h=h,P=p)
        v=volume(Fluid$,h=h,P=p)
        u=intenergy(Fluid$,h=h,P=p)
        x=quality(Fluid$,h=h,P=p)
    endif
    if Prop2$='Temperature, C' then
        T=value2
        p=Pressure(Fluid$,T=T,h=h)
        s=entropy(Fluid$,T=T,h=h)
        v=volume(Fluid$,T=T,h=h)
        u=intenergy(Fluid$,T=T,h=h)
        x=quality(Fluid$,T=T,h=h)
    endif
    if Prop2$='Entropy, kJ/kg-K' then
        s=value2
        p=Pressure(Fluid$,h=h,s=s)
        T=Temperature(Fluid$,h=h,s=s)
        v=volume(Fluid$,h=h,s=s)
        u=intenergy(Fluid$,h=h,s=s)
        x=quality(Fluid$,h=h,s=s)
    endif
    if Prop2$='Volume, m^3/kg' then
        v=value2
        p=Pressure(Fluid$,h=h,v=v)
        T=Temperature(Fluid$,h=h,v=v)
        s=entropy(Fluid$,h=h,v=v)
        u=intenergy(Fluid$,h=h,v=v)
        x=quality(Fluid$,h=h,v=v)
    endif
    if Prop2$='Internal Energy, kJ/kg' then
        u=value2
        p=Pressure(Fluid$,h=h,u=u)
        T=Temperature(Fluid$,h=h,u=u)
        s=entropy(Fluid$,h=h,u=u)
        v=volume(Fluid$,h=h,s=s)
        x=quality(Fluid$,h=h,u=u)
    endif
    if Prop2$='Quality' then
        x=value2
        p=Pressure(Fluid$,h=h,x=x)
        T=Temperature(Fluid$,h=h,x=x)
        s=entropy(Fluid$,h=h,x=x)
        v=volume(Fluid$,h=h,x=x)
        u=IntEnergy(Fluid$,h=h,x=x)
    endif
endif
endif

```

```

If Prop1$='Entropy, kJ/kg-K' Then
  s=Value1
  If Prop2$='Entropy, kJ/kg-K' then Call Error('Both properties cannot be Entropy, h=xxxF2',s)
  if Prop2$='Pressure, kPa' then
    p=value2
    T=Temperature(Fluid$,s=s,P=p)
    h=enthalpy(Fluid$,s=s,P=p)
    v=volume(Fluid$,s=s,P=p)
    u=intenergy(Fluid$,s=s,P=p)
    x=quality(Fluid$,s=s,P=p)
  endif
  if Prop2$='Temperature, C' then
    T=value2
    p=Pressure(Fluid$,T=T,s=s)
    h=enthalpy(Fluid$,T=T,s=s)
    v=volume(Fluid$,T=T,s=s)
    u=intenergy(Fluid$,T=T,s=s)
    x=quality(Fluid$,T=T,s=s)
  endif
  if Prop2$='Enthalpy, kJ/kg' then
    h=value2
    p=Pressure(Fluid$,h=h,s=s)
    T=Temperature(Fluid$,h=h,s=s)
    v=volume(Fluid$,h=h,s=s)
    u=intenergy(Fluid$,h=h,s=s)
    x=quality(Fluid$,h=h,s=s)
  endif
  if Prop2$='Volume, m^3/kg' then
    v=value2
    p=Pressure(Fluid$,s=s,v=v)
    T=Temperature(Fluid$,s=s,v=v)
    h=enthalpy(Fluid$,s=s,v=v)
    u=intenergy(Fluid$,s=s,v=v)
    x=quality(Fluid$,s=s,v=v)
  endif
  if Prop2$='Internal Energy, kJ/kg' then
    u=value2
    p=Pressure(Fluid$,s=s,u=u)
    T=Temperature(Fluid$,s=s,u=u)
    h=enthalpy(Fluid$,s=s,u=u)
    v=volume(Fluid$,s=s,s=s)
    x=quality(Fluid$,s=s,u=u)
  endif
  if Prop2$='Quality' then
    x=value2
    p=Pressure(Fluid$,s=s,x=x)
    T=Temperature(Fluid$,s=s,x=x)
    h=enthalpy(Fluid$,s=s,x=x)
    v=volume(Fluid$,s=s,x=x)
    u=IntEnergy(Fluid$,s=s,x=x)
  endif
Endif
if x<0 then State$='in the compressed liquid region.'
if x>1 then State$='in the superheated region.'
If (x<1) and (X>0) then State$='in the two-phase region.'
If (x=1) then State$='a saturated vapor.'

```

```

if (x=0) then State$='a saturated liquid.'
end
"Input from the diagram window"
{Fluid$='Steam'
Prop1$='Temperature'
Prop2$='Pressure'
Value1=50
value2=101.3}

```

```
Call Find(Fluid$,Prop1$,Prop2$,Value1,Value2:T,p,h,s,v,u,x,State$)
```

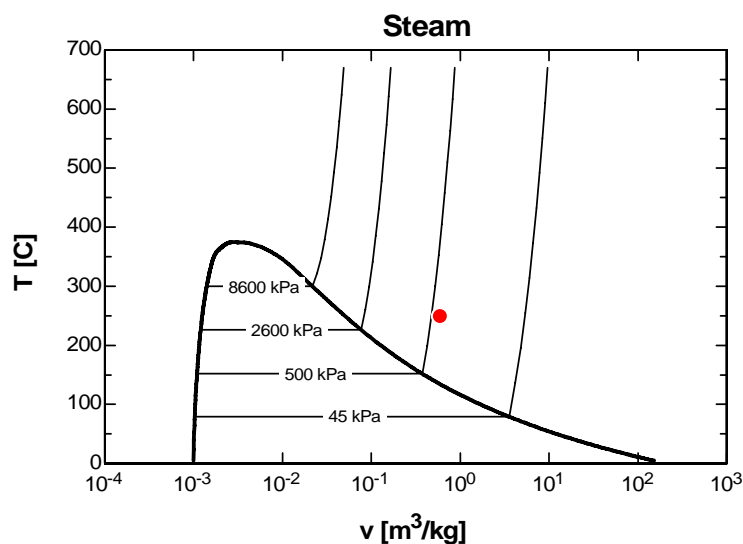
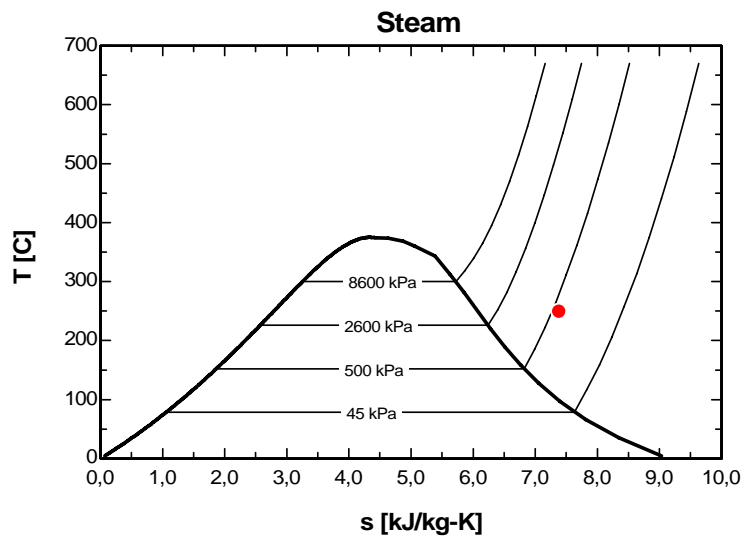
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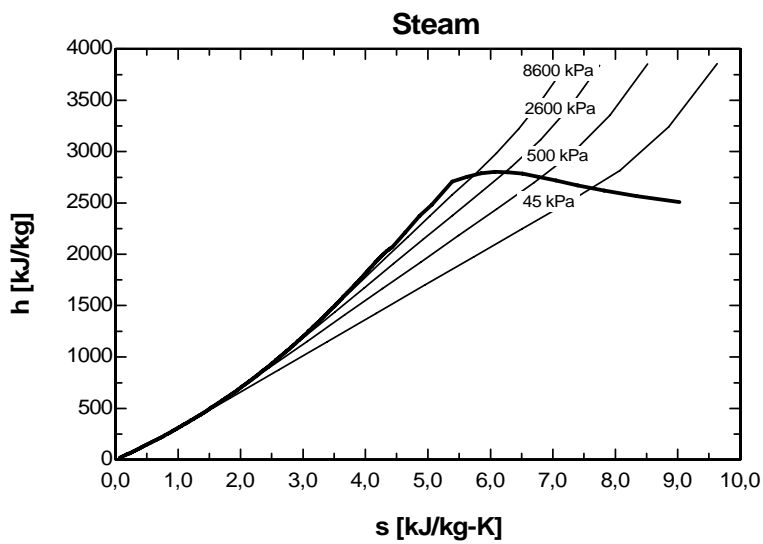
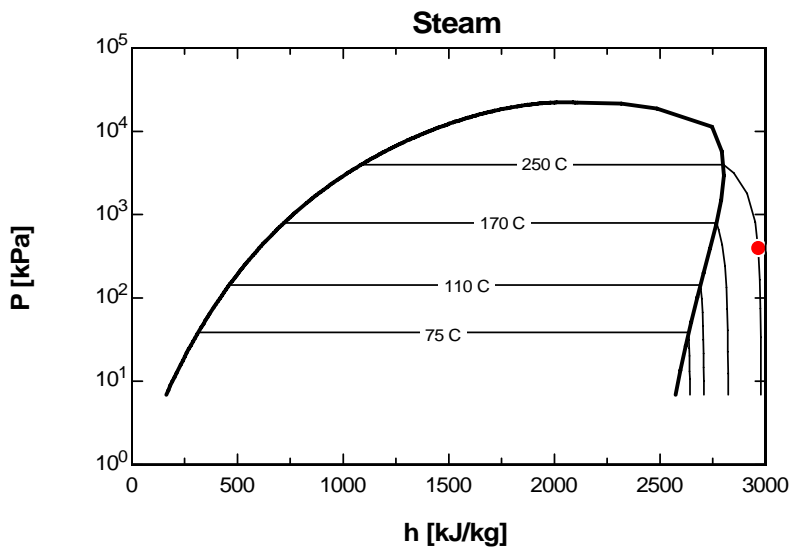
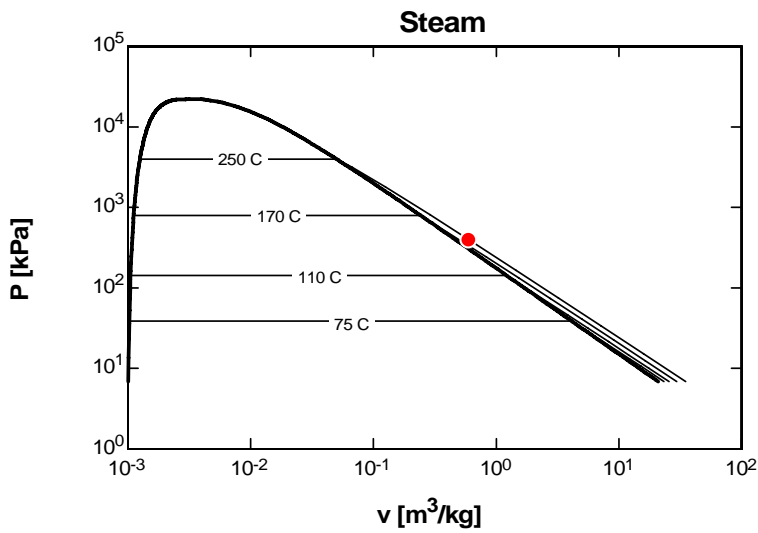
T[1]=T ; p[1]=p ; h[1]=h ; s[1]=s ; v[1]=v ; u[1]=u ; x[1]=x
"Array variables were used so the states can be plotted on property plots."

```

ARRAYS TABLE

h kJ/kg	P kPa	s kJ/kgK	T C	u kJ/kg	v m ³ /kg	x
2964.5	400	7.3804	250	2726.4	0.5952	100





4-25E Complete the following table for H_2O :

T, °F	P, psia	u, Btu / lbm	Phase description
300	67.03	782	<i>Saturated mixture</i>
267.22	40	236.02	Saturated liquid
500	120	1174.4	<i>Superheated vapor</i>
400	400	373.84	<i>Compressed liquid</i>

4-26E EES Problem 4-25E is reconsidered. The missing properties of water are to be determined using EES, and the solution is to be repeated for refrigerant-134a, refrigerant-22, and ammonia.

Analysis The problem is solved using EES, and the solution is given below.

"Given"

T[1]=300 [F]
u[1]=782 [Btu/lbm]
P[2]=40 [psia]
x[2]=0
T[3]=500 [F]
P[3]=120 [psia]
T[4]=400 [F]
P[4]=420 [psia]

"Analysis"

Fluid\$='steam_iapws'
P[1]=pressure(Fluid\$, T=T[1], u=u[1])
x[1]=quality(Fluid\$, T=T[1], u=u[1])
T[2]=temperature(Fluid\$, P=P[2], x=x[2])
u[2]=intenergy(Fluid\$, P=P[2], x=x[2])
u[3]=intenergy(Fluid\$, P=P[3], T=T[3])
x[3]=quality(Fluid\$, P=P[3], T=T[3])
u[4]=intenergy(Fluid\$, P=P[4], T=T[4])
x[4]=quality(Fluid\$, P=P[4], T=T[4])
"x = 100 for superheated vapor and x = -100 for compressed liquid"

Solution for steam

T, °F	P, psia	x	u, Btu/lbm
300	67.028	0.6173	782
267.2	40	0	236
500	120	100	1174
400	400	-100	373.8

4-27 Complete the following table for H_2O :

T, °C	P, kPa	h, kJ / kg	x	Phase description
<i>120.21</i>	200	<i>2045.8</i>	0.7	<i>Saturated mixture</i>
140	<i>361.53</i>	1800	<i>0.565</i>	<i>Saturated mixture</i>
<i>177.66</i>	950	<i>752.74</i>	0.0	<i>Saturated liquid</i>
80	500	<i>335.37</i>	- - -	<i>Compressed liquid</i>
<i>350.0</i>	800	3162.2	- - -	<i>Superheated vapor</i>

4-28 Complete the following table for Refrigerant-134a:

T, °C	P, kPa	ν, m³ / kg	Phase description
-8	320	<i>0.0007569</i>	<i>Compressed liquid</i>
30	<i>770.64</i>	0.015	<i>Saturated mixture</i>
<i>-12.73</i>	180	<i>0.11041</i>	Saturated vapor
80	600	<i>0.044710</i>	<i>Superheated vapor</i>

4-29 Complete the following table for Refrigerant-134a:

T, °C	P, kPa	u, kJ / kg	Phase description
20	<i>572.07</i>	95	<i>Saturated mixture</i>
-12	<i>185.37</i>	<i>35.78</i>	Saturated liquid
<i>86.24</i>	400	300	<i>Superheated vapor</i>
8	600	<i>62.26</i>	<i>Compressed liquid</i>

4-30E Complete the following table for Refrigerant-134a:

T, °F	P, psia	h, Btu / lbm	x	Phase description
65.89	80	78	0.566	<i>Saturated mixture</i>
15	29.759	69.92	0.6	<i>Saturated mixture</i>
10	70	15.35	- - -	<i>Compressed liquid</i>
160	180	129.46	- - -	<i>Superheated vapor</i>
110	161.16	117.23	1.0	<i>Saturated vapor</i>

4-31 A piston-cylinder device contains R-134a at a specified state. Heat is transferred to R-134a. The final pressure, the volume change of the cylinder, and the enthalpy change are to be determined.

Analysis (a) The final pressure is equal to the initial pressure, which is determined from

$$P_2 = P_1 = P_{\text{atm}} + \frac{m_p g}{\pi D^2 / 4} = 88 \text{ kPa} + \frac{(12 \text{ kg})(9.81 \text{ m/s}^2)}{\pi(0.25 \text{ m})^2 / 4} \left(\frac{1 \text{ kN}}{1000 \text{ kg}\cdot\text{m/s}^2} \right) = \mathbf{90.4 \text{ kPa}}$$

(b) The specific volume and enthalpy of R-134a at the initial state of 90.4 kPa and -10°C and at the final state of 90.4 kPa and 15°C are (from EES)

$$v_1 = 0.2302 \text{ m}^3/\text{kg} \quad h_1 = 247.76 \text{ kJ/kg}$$

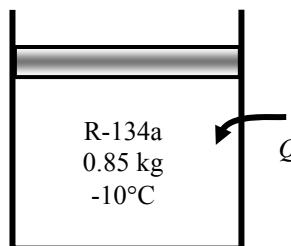
$$v_2 = 0.2544 \text{ m}^3/\text{kg} \quad h_2 = 268.16 \text{ kJ/kg}$$

The initial and the final volumes and the volume change are

$$V_1 = m v_1 = (0.85 \text{ kg})(0.2302 \text{ m}^3/\text{kg}) = 0.1957 \text{ m}^3$$

$$V_2 = m v_2 = (0.85 \text{ kg})(0.2544 \text{ m}^3/\text{kg}) = 0.2162 \text{ m}^3$$

$$\Delta V = 0.2162 - 0.1957 = \mathbf{0.0205 \text{ m}^3}$$



(c) The total enthalpy change is determined from

$$\Delta H = m(h_2 - h_1) = (0.85 \text{ kg})(268.16 - 247.76) \text{ kJ/kg} = \mathbf{17.4 \text{ kJ/kg}}$$

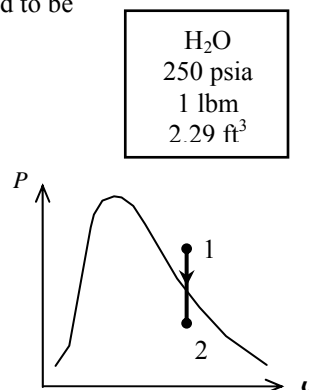
4-32E A rigid container that is filled with water is cooled. The initial temperature and final pressure are to be determined.

Analysis The initial state is superheated vapor. The temperature is determined to be

$$\left. \begin{array}{l} P_1 = 250 \text{ psia} \\ \nu_1 = 2.29 \text{ ft}^3/\text{lbm} \end{array} \right\} T_1 = \mathbf{550^\circ\text{F}} \quad (\text{Table A - 6E})$$

This is a constant volume cooling process ($\nu = \nu/m =$ constant). The final state is saturated mixture and thus the pressure is the saturation pressure at the final temperature:

$$\left. \begin{array}{l} T_2 = 100^\circ\text{F} \\ \nu_2 = \nu_1 = 2.29 \text{ ft}^3/\text{lbm} \end{array} \right\} P_2 = P_{\text{sat}@100^\circ\text{F}} = \mathbf{0.9505 \text{ psia}} \quad (\text{Table A - 4E})$$



4-33 A piston-cylinder device that is filled with R-134a is heated. The final volume is to be determined.

Analysis The initial specific volume is

$$\nu_1 = \frac{V_1}{m} = \frac{0.14 \text{ m}^3}{1 \text{ kg}} = 0.14 \text{ m}^3/\text{kg}$$

This is a constant-pressure process. The initial state is determined to be a mixture, and thus the pressure is the saturation pressure at the given temperature

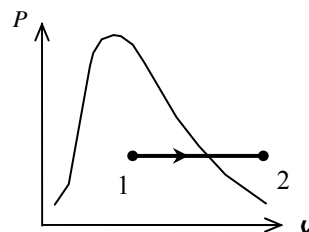
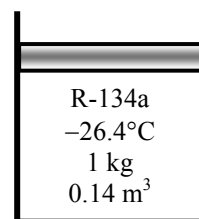
$$P_1 = P_2 = P_{\text{sat}@-26.4^\circ\text{C}} = 100 \text{ kPa} \quad (\text{Table A - 12})$$

The final state is superheated vapor and the specific volume is

$$\left. \begin{array}{l} P_2 = 100 \text{ kPa} \\ T_2 = 100^\circ\text{C} \end{array} \right\} \nu_2 = 0.30138 \text{ m}^3/\text{kg} \quad (\text{Table A - 13})$$

The final volume is then

$$\nu_2 = m\nu_2 = (1 \text{ kg})(0.30138 \text{ m}^3/\text{kg}) = \mathbf{0.30138 \text{ m}^3}$$



4-34 Left chamber of a partitioned system contains water at a specified state while the right chamber is evacuated. The partition is now ruptured and heat is transferred from the water. The pressure at the final state is to be determined.

Analysis The initial specific volume is

$$\nu_1 = \frac{V_1}{m} = \frac{1.1989 \text{ m}^3}{1 \text{ kg}} = 1.1989 \text{ m}^3/\text{kg}$$

Water 200 kPa 1 kg 1.1989 m ³	Evacuated
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At the final state, the water occupies three times the initial volume. Then,

$$\nu_2 = 3\nu_1 = 3(1.1989 \text{ m}^3/\text{kg}) = 3.5967 \text{ m}^3/\text{kg}$$

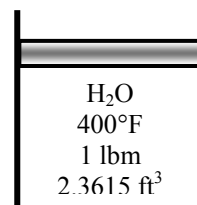
Based on this specific volume and the final temperature, the final state is a saturated mixture and the pressure is

$$P_2 = P_{\text{sat}@3^\circ\text{C}} = \mathbf{0.768 \text{ kPa}} \quad (\text{Table A - 4})$$

4-35E A piston-cylinder device that is filled with water is cooled. The final pressure and volume of the water are to be determined.

Analysis The initial specific volume is

$$\nu_1 = \frac{V_1}{m} = \frac{2.3615 \text{ ft}^3}{1 \text{ lbm}} = 2.3615 \text{ ft}^3/\text{lbm}$$



This is a constant-pressure process. The initial state is determined to be superheated vapor and thus the pressure is determined to be

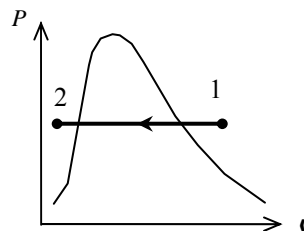
$$\left. \begin{array}{l} T_1 = 400^\circ\text{F} \\ \nu_1 = 2.3615 \text{ ft}^3/\text{lbm} \end{array} \right\} P_1 = P_2 = \mathbf{200 \text{ psia}} \quad (\text{Table A - 6E})$$

The saturation temperature at 200 psia is 381.8°F. Since the final temperature is less than this temperature, the final state is compressed liquid. Using the incompressible liquid approximation,

$$\nu_2 = \nu_f @ 100^\circ\text{F} = 0.01613 \text{ ft}^3/\text{lbm} \quad (\text{Table A - 4E})$$

The final volume is then

$$V_2 = m\nu_2 = (1 \text{ lbm})(0.01613 \text{ ft}^3/\text{lbm}) = \mathbf{0.01613 \text{ ft}^3}$$



4-36 A piston-cylinder device that is filled with R-134a is heated. The final volume is to be determined.

Analysis This is a constant pressure process. The initial specific volume is

$$\nu_1 = \frac{V}{m} = \frac{1.595 \text{ m}^3}{10 \text{ kg}} = 0.1595 \text{ m}^3/\text{kg}$$

The initial state is determined to be a mixture, and thus the pressure is the saturation pressure at the given temperature

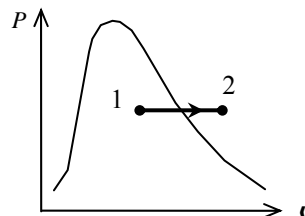
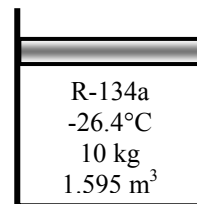
$$P_1 = P_{\text{sat}@-26.4^\circ\text{C}} = 100 \text{ kPa} \quad (\text{Table A - 12})$$

The final state is superheated vapor and the specific volume is

$$\left. \begin{array}{l} P_2 = 100 \text{ kPa} \\ T_2 = 100^\circ\text{C} \end{array} \right\} \nu_2 = 0.30138 \text{ m}^3/\text{kg} \quad (\text{Table A - 13})$$

The final volume is then

$$V_2 = m\nu_2 = (10 \text{ kg})(0.30138 \text{ m}^3/\text{kg}) = \mathbf{3.0138 \text{ m}^3}$$



4-37 The internal energy of water at a specified state is to be determined.

Analysis The state of water is superheated vapor. From the steam tables,

$$\left. \begin{array}{l} P = 50 \text{ kPa} \\ T = 200^\circ\text{C} \end{array} \right\} u = \mathbf{2660.0 \text{ kJ/kg}} \quad (\text{Table A - 6})$$

4-38 The specific volume of water at a specified state is to be determined using the incompressible liquid approximation and it is to be compared to the more accurate value.

Analysis The state of water is compressed liquid. From the steam tables,

$$\left. \begin{array}{l} P = 5 \text{ MPa} \\ T = 100^\circ\text{C} \end{array} \right\} \nu = \mathbf{0.001041 \text{ m}^3/\text{kg}} \quad (\text{Table A - 7})$$

Based upon the incompressible liquid approximation,

$$\left. \begin{array}{l} P = 2 \text{ MPa} \\ T = 100^\circ\text{C} \end{array} \right\} \nu \cong \nu_f @ 100^\circ\text{C} = \mathbf{0.001043 \text{ m}^3/\text{kg}} \quad (\text{Table A - 4})$$

The error involved is

$$\text{Percent Error} = \frac{0.001043 - 0.001041}{0.001041} \times 100 = \mathbf{0.19\%}$$

which is quite acceptable in most engineering calculations.

4-39E The total internal energy and enthalpy of water in a container are to be determined.

Analysis The specific volume is

$$\nu = \frac{V}{m} = \frac{2 \text{ ft}^3}{1 \text{ lbm}} = 2 \text{ ft}^3/\text{lbm}$$

At this specific volume and the given pressure, the state is a saturated mixture. The quality, internal energy, and enthalpy at this state are (Table A-5E)

Water 100 psia 2 ft ³
--

$$x = \frac{\nu - \nu_f}{\nu_{fg}} = \frac{(2 - 0.01774) \text{ ft}^3/\text{lbm}}{(4.4327 - 0.01774) \text{ ft}^3/\text{lbm}} = 0.4490$$

$$u = u_f + xu_{fg} = 298.19 + (0.4490)(807.29) = 660.7 \text{ Btu/lbm}$$

$$h = h_f + xh_{fg} = 298.51 + (0.4490)(888.99) = 697.7 \text{ Btu/lbm}$$

The total internal energy and enthalpy are then

$$U = mu = (1 \text{ lbm})(660.7 \text{ Btu/lbm}) = \mathbf{660.7 \text{ Btu}}$$

$$H = mh = (1 \text{ lbm})(697.7 \text{ Btu/lbm}) = \mathbf{697.7 \text{ Btu}}$$

4-40 The volume of a container that contains water at a specified state is to be determined.

Analysis The specific volume is determined from steam tables by interpolation to be

$$\left. \begin{array}{l} P = 100 \text{ kPa} \\ T = 360^\circ\text{C} \end{array} \right\} \nu = 2.9172 \text{ m}^3/\text{kg} \text{ (Table A - 6)}$$

The volume of the container is then

$$V = m\nu = (3 \text{ kg})(2.9172 \text{ m}^3/\text{kg}) = \mathbf{8.752 \text{ m}^3}$$

Water 3 kg 100 kPa 360°C

4-41 A rigid container that is filled with R-134a is heated. The temperature and total enthalpy are to be determined at the initial and final states.

Analysis This is a constant volume process. The specific volume is

$$v_1 = v_2 = \frac{V}{m} = \frac{0.014 \text{ m}^3}{10 \text{ kg}} = 0.0014 \text{ m}^3/\text{kg}$$

The initial state is determined to be a mixture, and thus the temperature is the saturation temperature at the given pressure. From Table A-12 by interpolation

$$T_1 = T_{\text{sat}@300 \text{ kPa}} = \mathbf{0.61^\circ\text{C}}$$

and

$$x_1 = \frac{v_1 - v_f}{v_{fg}} = \frac{(0.0014 - 0.0007736) \text{ m}^3/\text{kg}}{(0.067978 - 0.0007736) \text{ m}^3/\text{kg}} = 0.009321$$

$$h_1 = h_f + x_1 h_{fg} = 52.67 + (0.009321)(198.13) = 54.52 \text{ kJ/kg}$$

The total enthalpy is then

$$H_1 = mh_1 = (10 \text{ kg})(54.52 \text{ kJ/kg}) = \mathbf{545.2 \text{ kJ}}$$

The final state is also saturated mixture. Repeating the calculations at this state,

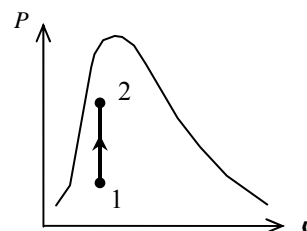
$$T_2 = T_{\text{sat}@600 \text{ kPa}} = \mathbf{21.55^\circ\text{C}}$$

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{(0.0014 - 0.0008199) \text{ m}^3/\text{kg}}{(0.034295 - 0.0008199) \text{ m}^3/\text{kg}} = 0.01733$$

$$h_2 = h_f + x_2 h_{fg} = 81.51 + (0.01733)(180.90) = 84.64 \text{ kJ/kg}$$

$$H_2 = mh_2 = (10 \text{ kg})(84.64 \text{ kJ/kg}) = \mathbf{846.4 \text{ kJ}}$$

R-134a
300 kPa
10 kg
14 L



4-42 A piston-cylinder device that is filled with R-134a is cooled at constant pressure. The final temperature and the change of total internal energy are to be determined.

Analysis The initial specific volume is

$$v_1 = \frac{V}{m} = \frac{12.322 \text{ m}^3}{100 \text{ kg}} = 0.12322 \text{ m}^3/\text{kg}$$

The initial state is superheated and the internal energy at this state is

$$\left. \begin{array}{l} P_1 = 200 \text{ kPa} \\ v_1 = 0.12322 \text{ m}^3/\text{kg} \end{array} \right\} u_1 = 263.08 \text{ kJ/kg (Table A -13)}$$

The final specific volume is

$$v_2 = \frac{v_1}{2} = \frac{0.12322 \text{ m}^3/\text{kg}}{2} = 0.06161 \text{ m}^3/\text{kg}$$

This is a constant pressure process. The final state is determined to be saturated mixture whose temperature is

$$T_2 = T_{\text{sat @ 200 kPa}} = -10.09^\circ\text{C (Table A -12)}$$

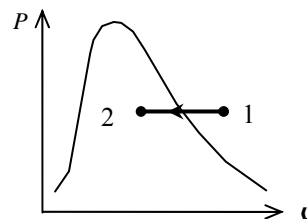
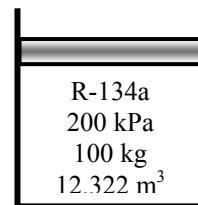
The internal energy at the final state is (Table A-12)

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{(0.06161 - 0.0007533) \text{ m}^3/\text{kg}}{(0.099867 - 0.0007533) \text{ m}^3/\text{kg}} = 0.6140$$

$$u_2 = u_f + x_2 u_{fg} = 38.28 + (0.6140)(186.21) = 152.61 \text{ kJ/kg}$$

Hence, the change in the internal energy is

$$\Delta u = u_2 - u_1 = 152.61 - 263.08 = -110.47 \text{ kJ/kg}$$



4-43 A spring-loaded piston-cylinder device is filled with water. The water now undergoes a process until its volume is one-half of the original volume. The final temperature and the entropy are to be determined.

Analysis From the steam tables,

$$\left. \begin{array}{l} P_1 = 4 \text{ MPa} \\ T_1 = 400^\circ\text{C} \end{array} \right\} \nu_1 = 0.07343 \text{ m}^3/\text{kg} \text{ (Table A - 6)}$$

The process experienced by this system is a linear P - ν process. The equation for this line is

$$P - P_1 = c(\nu - \nu_1)$$

where P_1 is the system pressure when its specific volume is ν_1 . The spring equation may be written as

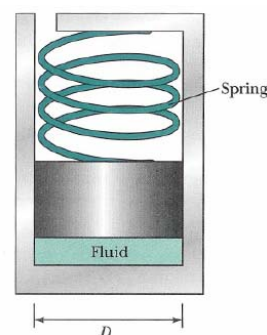
$$P - P_1 = \frac{F_s - F_{s,1}}{A} = k \frac{x - x_1}{A} = \frac{kA}{A^2} (x - x_1) = \frac{k}{A^2} (\nu - \nu_1) = \frac{km}{A^2} (\nu - \nu_1)$$

Constant c is hence

$$c = \frac{km}{A^2} = \frac{4^2 km}{\pi^2 D^4} = \frac{(16)(90 \text{ kN/m})(0.5 \text{ kg})}{\pi^2 (0.2 \text{ m})^4} = 45,595 \text{ kN} \cdot \text{kg}/\text{m}^5$$

The final pressure is then

$$\begin{aligned} P_2 &= P_1 + c(\nu_2 - \nu_1) = P_1 + c\left(\frac{\nu_1}{2} - \nu_1\right) = P_1 - \frac{c}{2}\nu_1 \\ &= 4000 \text{ kPa} - \frac{45,595 \text{ kN} \cdot \text{kg}/\text{m}^5}{2} (0.07343 \text{ m}^3/\text{kg}) = 2326 \text{ kPa} \end{aligned}$$



and

$$\nu_2 = \frac{\nu_1}{2} = \frac{0.07343 \text{ m}^3/\text{kg}}{2} = 0.03672 \text{ m}^3/\text{kg}$$

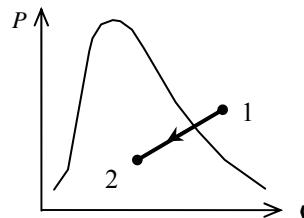
The final state is a mixture and the temperature is

$$T_2 = T_{\text{sat @ } 2326 \text{ kPa}} \cong \mathbf{220^\circ\text{C}} \text{ (Table A - 5)}$$

The quality and the entropy at the final state are

$$x_2 = \frac{\nu_2 - \nu_f}{\nu_{fg}} = \frac{(0.03672 - 0.001190) \text{ m}^3/\text{kg}}{(0.086094 - 0.001190) \text{ m}^3/\text{kg}} = 0.4185$$

$$h_2 = h_f + x_2 h_{fg} = 943.55 + (0.4185)(1857.4) = \mathbf{1720.9 \text{ kJ/kg}}$$



4-44E The local atmospheric pressure, and thus the boiling temperature, changes with the weather conditions. The change in the boiling temperature corresponding to a change of 0.3 in of mercury in atmospheric pressure is to be determined.

Properties The saturation pressures of water at 200 and 212°F are 11.538 and 14.709 psia, respectively (Table A-4E). One in. of mercury is equivalent to 1 inHg = 3.387 kPa = 0.491 psia (inner cover page).

Analysis A change of 0.3 in of mercury in atmospheric pressure corresponds to

$$\Delta P = (0.3 \text{ inHg}) \left(\frac{0.491 \text{ psia}}{1 \text{ inHg}} \right) = 0.147 \text{ psia}$$

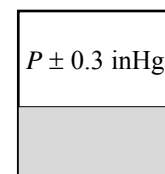
At about boiling temperature, the change in boiling temperature per 1 psia change in pressure is determined using data at 200 and 212°F to be

$$\frac{\Delta T}{\Delta P} = \frac{(212 - 200)^\circ\text{F}}{(14.709 - 11.538) \text{ psia}} = 3.783 \text{ }^\circ\text{F/psia}$$

Then the change in saturation (boiling) temperature corresponding to a change of 0.147 psia becomes

$$\Delta T_{\text{boiling}} = (3.783 \text{ }^\circ\text{F/psia})\Delta P = (3.783 \text{ }^\circ\text{F/psia})(0.147 \text{ psia}) = \mathbf{0.56^\circ\text{F}}$$

which is very small. Therefore, the effect of variation of atmospheric pressure on the boiling temperature is negligible.



4-45 A person cooks a meal in a pot that is covered with a well-fitting lid, and leaves the food to cool to the room temperature. It is to be determined if the lid will open or the pan will move up together with the lid when the person attempts to open the pan by lifting the lid up.

Assumptions 1 The local atmospheric pressure is 1 atm = 101.325 kPa. **2** The weight of the lid is small and thus its effect on the boiling pressure and temperature is negligible. **3** No air has leaked into the pan during cooling.

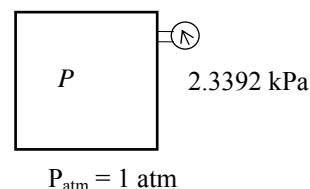
Properties The saturation pressure of water at 20°C is 2.3392 kPa (Table A-4).

Analysis Noting that the weight of the lid is negligible, the reaction force F on the lid after cooling at the pan-lid interface can be determined from a force balance on the lid in the vertical direction to be

$$PA + F = P_{\text{atm}}A$$

or,

$$\begin{aligned} F &= A(P_{\text{atm}} - P) = (\pi D^2 / 4)(P_{\text{atm}} - P) \\ &= \frac{\pi(0.3 \text{ m})^2}{4}(101,325 - 2339.2) \text{ Pa} \\ &= 6997 \text{ m}^2\text{Pa} = \mathbf{6997 \text{ N}} \quad (\text{since } 1 \text{ Pa} = 1 \text{ N/m}^2) \end{aligned}$$



The weight of the pan and its contents is

$$W = mg = (8 \text{ kg})(9.81 \text{ m/s}^2) = \mathbf{78.5 \text{ N}}$$

which is much less than the reaction force of 6997 N at the pan-lid interface. Therefore, the pan will **move up** together with the lid when the person attempts to open the pan by lifting the lid up. In fact, it looks like the lid will not open even if the mass of the pan and its contents is several hundred kg.

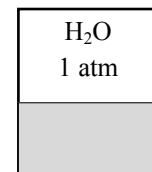
4-46 Water is boiled at 1 atm pressure in a pan placed on an electric burner. The water level drops by 10 cm in 45 min during boiling. The rate of heat transfer to the water is to be determined.

Properties The properties of water at 1 atm and thus at a saturation temperature of $T_{\text{sat}} = 100^\circ\text{C}$ are $h_{\text{fg}} = 2256.5 \text{ kJ/kg}$ and $\nu_f = 0.001043 \text{ m}^3/\text{kg}$ (Table A-4).

Analysis The rate of evaporation of water is

$$m_{\text{evap}} = \frac{V_{\text{evap}}}{\nu_f} = \frac{(\pi D^2 / 4)L}{\nu_f} = \frac{[\pi(0.25 \text{ m})^2 / 4](0.10 \text{ m})}{0.001043} = 4.704 \text{ kg}$$

$$\dot{m}_{\text{evap}} = \frac{m_{\text{evap}}}{\Delta t} = \frac{4.704 \text{ kg}}{45 \times 60 \text{ s}} = 0.001742 \text{ kg/s}$$



Then the rate of heat transfer to water becomes

$$\dot{Q} = \dot{m}_{\text{evap}} h_{\text{fg}} = (0.001742 \text{ kg/s})(2256.5 \text{ kJ/kg}) = \mathbf{3.93 \text{ kW}}$$

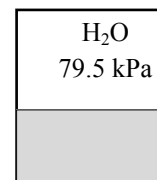
4-47 Water is boiled at a location where the atmospheric pressure is 79.5 kPa in a pan placed on an electric burner. The water level drops by 10 cm in 45 min during boiling. The rate of heat transfer to the water is to be determined.

Properties The properties of water at 79.5 kPa are $T_{\text{sat}} = 93.3^\circ\text{C}$, $h_{\text{fg}} = 2273.9 \text{ kJ/kg}$ and $\nu_f = 0.001038 \text{ m}^3/\text{kg}$ (Table A-5).

Analysis The rate of evaporation of water is

$$m_{\text{evap}} = \frac{V_{\text{evap}}}{\nu_f} = \frac{(\pi D^2 / 4)L}{\nu_f} = \frac{[\pi(0.25 \text{ m})^2 / 4](0.10 \text{ m})}{0.001038} = 4.727 \text{ kg}$$

$$\dot{m}_{\text{evap}} = \frac{m_{\text{evap}}}{\Delta t} = \frac{4.727 \text{ kg}}{45 \times 60 \text{ s}} = 0.001751 \text{ kg/s}$$



Then the rate of heat transfer to water becomes

$$\dot{Q} = \dot{m}_{\text{evap}} h_{\text{fg}} = (0.001751 \text{ kg/s})(2273.9 \text{ kJ/kg}) = \mathbf{3.98 \text{ kW}}$$

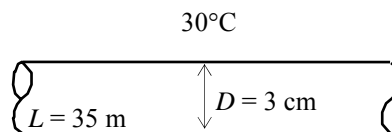
4-48 Saturated steam at $T_{\text{sat}} = 30^\circ\text{C}$ condenses on the outer surface of a cooling tube at a rate of 45 kg/h. The rate of heat transfer from the steam to the cooling water is to be determined.

Assumptions 1 Steady operating conditions exist. **2** The condensate leaves the condenser as a saturated liquid at 30°C .

Properties The properties of water at the saturation temperature of 30°C are $h_{fg} = 2429.8 \text{ kJ/kg}$ (Table A-4).

Analysis Noting that 2429.8 kJ of heat is released as 1 kg of saturated vapor at 30°C condenses, the rate of heat transfer from the steam to the cooling water in the tube is determined directly from

$$\begin{aligned}\dot{Q} &= \dot{m}_{\text{evap}} h_{fg} \\ &= (45 \text{ kg/h})(2429.8 \text{ kJ/kg}) = 109,341 \text{ kJ/h} \\ &= \mathbf{30.4 \text{ kW}}\end{aligned}$$



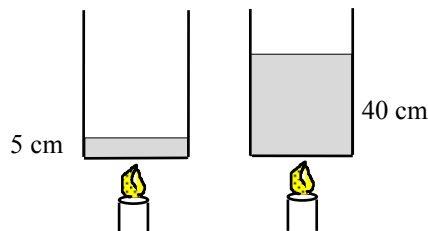
4-49 The boiling temperature of water in a 5-cm deep pan is given. The boiling temperature in a 40-cm deep pan is to be determined.

Assumptions Both pans are full of water.

Properties The density of liquid water is approximately $\rho = 1000 \text{ kg/m}^3$.

Analysis The pressure at the bottom of the 5-cm pan is the saturation pressure corresponding to the boiling temperature of 98°C :

$$P = P_{\text{sat}@98^\circ\text{C}} = 94.39 \text{ kPa} \quad (\text{Table A-4})$$



The pressure difference between the bottoms of two pans is

$$\Delta P = \rho g h = (1000 \text{ kg/m}^3)(9.807 \text{ m/s}^2)(0.35 \text{ m}) \left(\frac{1 \text{ kPa}}{1000 \text{ kg/m} \cdot \text{s}^2} \right) = 3.43 \text{ kPa}$$

Then the pressure at the bottom of the 40-cm deep pan is

$$P = 94.39 + 3.43 = 97.82 \text{ kPa}$$

Then the boiling temperature becomes

$$T_{\text{boiling}} = T_{\text{sat}@97.82 \text{ kPa}} = \mathbf{99.0^\circ\text{C}} \quad (\text{Table A-5})$$

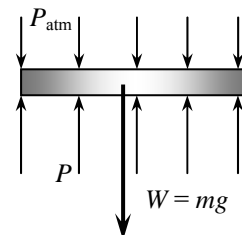
4-50 A vertical piston-cylinder device is filled with water and covered with a 20-kg piston that serves as the lid. The boiling temperature of water is to be determined.

Analysis The pressure in the cylinder is determined from a force balance on the piston,

$$PA = P_{\text{atm}}A + W$$

or,

$$\begin{aligned} P &= P_{\text{atm}} + \frac{mg}{A} \\ &= (100 \text{ kPa}) + \frac{(20 \text{ kg})(9.81 \text{ m/s}^2)}{0.01 \text{ m}^2} \left(\frac{1 \text{ kPa}}{1000 \text{ kg/m} \cdot \text{s}^2} \right) \\ &= 119.61 \text{ kPa} \end{aligned}$$



The boiling temperature is the saturation temperature corresponding to this pressure,

$$T = T_{\text{sat}@119.61 \text{ kPa}} = \mathbf{104.7^\circ\text{C}} \quad (\text{Table A-5})$$

4-51 A rigid tank that is filled with saturated liquid-vapor mixture is heated. The temperature at which the liquid in the tank is completely vaporized is to be determined, and the T - ν diagram is to be drawn.

Analysis This is a constant volume process ($\nu = \nu/m = \text{constant}$),

and the specific volume is determined to be

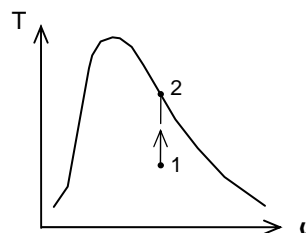
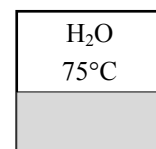
$$\nu = \frac{\nu}{m} = \frac{2.5 \text{ m}^3}{15 \text{ kg}} = 0.1667 \text{ m}^3/\text{kg}$$

When the liquid is completely vaporized the tank will contain saturated vapor only. Thus,

$$\nu_2 = \nu_g = 0.1667 \text{ m}^3/\text{kg}$$

The temperature at this point is the temperature that corresponds to this ν_g value,

$$T = T_{\text{sat}@ \nu_g = 0.1667 \text{ m}^3/\text{kg}} = \mathbf{187.0^\circ\text{C}} \quad (\text{Table A-4})$$



4-52 A rigid vessel is filled with refrigerant-134a. The total volume and the total internal energy are to be determined.

Properties The properties of R-134a at the given state are (Table A-13).

$$\left. \begin{array}{l} P = 800 \text{ kPa} \\ T = 120^\circ \text{C} \end{array} \right\} \begin{array}{l} u = 327.87 \text{ kJ/kg} \\ \nu = 0.037625 \text{ m}^3/\text{kg} \end{array}$$

R-134a
2 kg
800 kPa
120°C

Analysis The total volume and internal energy are determined from

$$\begin{aligned} \mathcal{V} &= m\nu = (2 \text{ kg})(0.037625 \text{ m}^3/\text{kg}) = \mathbf{0.0753 \text{ m}^3} \\ U &= mu = (2 \text{ kg})(327.87 \text{ kJ/kg}) = \mathbf{655.7 \text{ kJ}} \end{aligned}$$

4-53 A rigid vessel contains R-134a at specified temperature. The pressure, total internal energy, and the volume of the liquid phase are to be determined.

Analysis (a) The specific volume of the refrigerant is

$$\nu = \frac{\mathcal{V}}{m} = \frac{0.5 \text{ m}^3}{10 \text{ kg}} = 0.05 \text{ m}^3/\text{kg}$$

At -20°C , $\nu_f = 0.0007362 \text{ m}^3/\text{kg}$ and $\nu_g = 0.14729 \text{ m}^3/\text{kg}$ (Table A-11). Thus the tank contains saturated liquid-vapor mixture since $\nu_f < \nu < \nu_g$, and the pressure must be the saturation pressure at the specified temperature,

R-134a
10 kg
-20°C

$$P = P_{\text{sat}@-20^\circ\text{C}} = \mathbf{132.82 \text{ kPa}}$$

(b) The quality of the refrigerant-134a and its total internal energy are determined from

$$\begin{aligned} x &= \frac{\nu - \nu_f}{\nu_{fg}} = \frac{0.05 - 0.0007362}{0.14729 - 0.0007362} = 0.3361 \\ u &= u_f + xu_{fg} = 25.39 + 0.3361 \times 193.45 = 90.42 \text{ kJ/kg} \\ U &= mu = (10 \text{ kg})(90.42 \text{ kJ/kg}) = \mathbf{904.2 \text{ kJ}} \end{aligned}$$

(c) The mass of the liquid phase and its volume are determined from

$$\begin{aligned} m_f &= (1-x)m_t = (1-0.3361) \times 10 = 6.639 \text{ kg} \\ \mathcal{V}_f &= m_f \nu_f = (6.639 \text{ kg})(0.0007362 \text{ m}^3/\text{kg}) = \mathbf{0.00489 \text{ m}^3} \end{aligned}$$

4-54 CD EES A piston-cylinder device contains a saturated liquid-vapor mixture of water at 800 kPa pressure. The mixture is heated at constant pressure until the temperature rises to 350°C. The initial temperature, the total mass of water, the final volume are to be determined, and the P - v diagram is to be drawn.

Analysis (a) Initially two phases coexist in equilibrium, thus we have a saturated liquid-vapor mixture. Then the temperature in the tank must be the saturation temperature at the specified pressure,

$$T = T_{\text{sat}@800 \text{ kPa}} = \mathbf{170.41^\circ\text{C}}$$

(b) The total mass in this case can easily be determined by adding the mass of each phase,

$$m_f = \frac{V_f}{v_f} = \frac{0.1 \text{ m}^3}{0.001115 \text{ m}^3/\text{kg}} = 89.704 \text{ kg}$$

$$m_g = \frac{V_g}{v_g} = \frac{0.9 \text{ m}^3}{0.24035 \text{ m}^3/\text{kg}} = 3.745 \text{ kg}$$

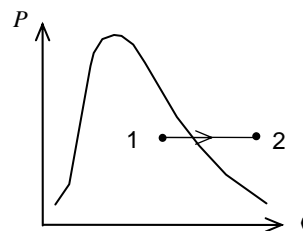
$$m_t = m_f + m_g = 89.704 + 3.745 = \mathbf{93.45 \text{ kg}}$$

(c) At the final state water is superheated vapor, and its specific volume is

$$\left. \begin{array}{l} P_2 = 800 \text{ kPa} \\ T_2 = 350^\circ\text{C} \end{array} \right\} v_2 = 0.35442 \text{ m}^3/\text{kg} \quad (\text{Table A-6})$$

Then,

$$V_2 = m_t v_2 = (93.45 \text{ kg})(0.35442 \text{ m}^3/\text{kg}) = \mathbf{33.12 \text{ m}^3}$$



4-55 EES Problem 4-54 is reconsidered. The effect of pressure on the total mass of water in the tank as the pressure varies from 0.1 MPa to 1 MPa is to be investigated. The total mass of water is to be plotted against pressure, and results are to be discussed.

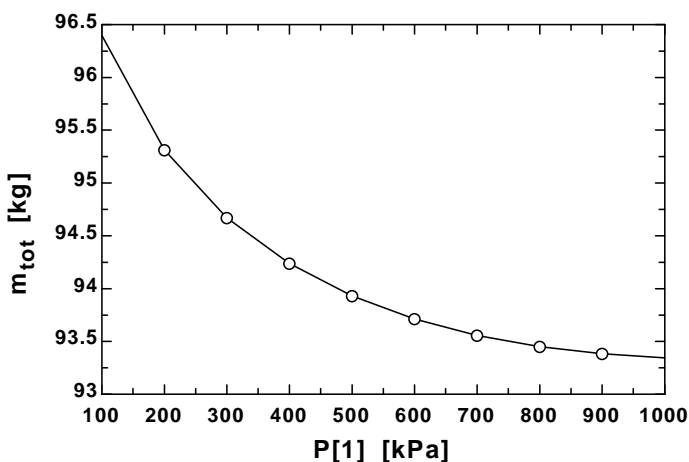
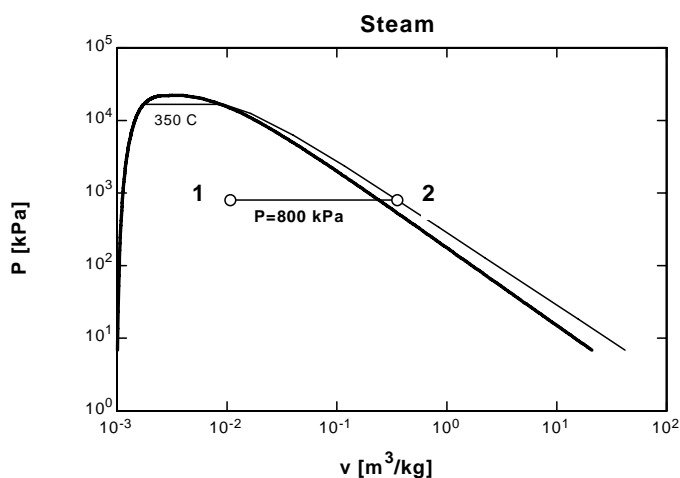
Analysis The problem is solved using EES, and the solution is given below.

```

P[1]=800 [kPa]
P[2]=P[1]
T[2]=350 [C]
V_f1 = 0.1 [m^3]
V_g1=0.9 [m^3]
spvsat_f1=volume(Steam_iapws, P=P[1],x=0) "sat. liq. specific volume, m^3/kg"
spvsat_g1=volume(Steam_iapws,P=P[1],x=1) "sat. vap. specific volume, m^3/kg"
m_f1=V_f1/spvsat_f1 "sat. liq. mass, kg"
m_g1=V_g1/spvsat_g1 "sat. vap. mass, kg"
m_tot=m_f1+m_g1
V[1]=V_f1+V_g1
spvol[1]=V[1]/m_tot "specific volume1, m^3"
T[1]=temperature(Steam_iapws, P=P[1],v=spvol[1])"C"
"The final volume is calculated from the specific volume at the final T and P"
spvol[2]=volume(Steam_iapws, P=P[2], T=T[1]) "specific volume2, m^3/kg"
V[2]=m_tot*spvol[2]

```

m_{tot} [kg]	P_1 [kPa]
96.39	100
95.31	200
94.67	300
94.24	400
93.93	500
93.71	600
93.56	700
93.45	800
93.38	900
93.34	1000



4-56E Superheated water vapor cools at constant volume until the temperature drops to 250°F. At the final state, the pressure, the quality, and the enthalpy are to be determined.

Analysis This is a constant volume process ($\nu = \nu/m = \text{constant}$), and the initial specific volume is determined to be

$$\left. \begin{array}{l} P_1 = 180 \text{ psia} \\ T_1 = 500^\circ \text{F} \end{array} \right\} \nu_1 = 3.0433 \text{ ft}^3/\text{lbm} \quad (\text{Table A-6E})$$

At 250°F, $\nu_f = 0.01700 \text{ ft}^3/\text{lbm}$ and $\nu_g = 13.816 \text{ ft}^3/\text{lbm}$. Thus at the final state, the tank will contain saturated liquid-vapor mixture since $\nu_f < \nu < \nu_g$, and the final pressure must be the saturation pressure at the final temperature,

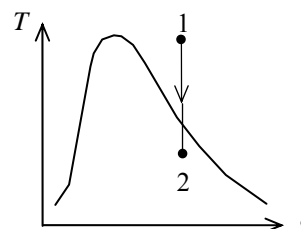
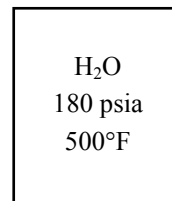
$$P = P_{\text{sat}@250^\circ \text{F}} = \mathbf{29.84 \text{ psia}}$$

(b) The quality at the final state is determined from

$$x_2 = \frac{\nu_2 - \nu_f}{\nu_{fg}} = \frac{3.0433 - 0.01700}{13.816 - 0.01700} = \mathbf{0.219}$$

(c) The enthalpy at the final state is determined from

$$h = h_f + xh_{fg} = 218.63 + 0.219 \times 945.41 = \mathbf{426.0 \text{ Btu/lbm}}$$

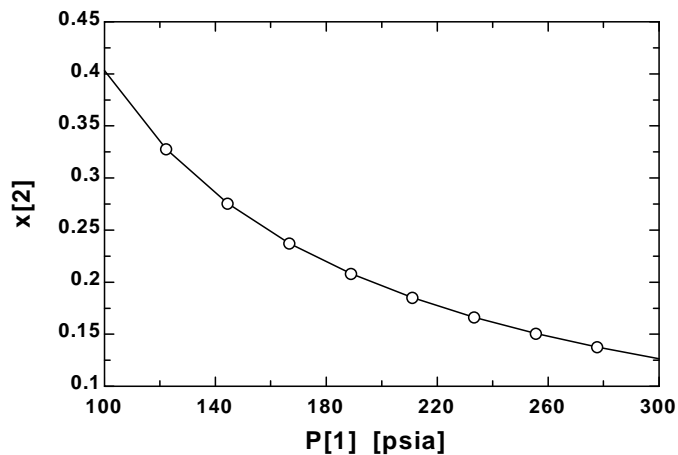
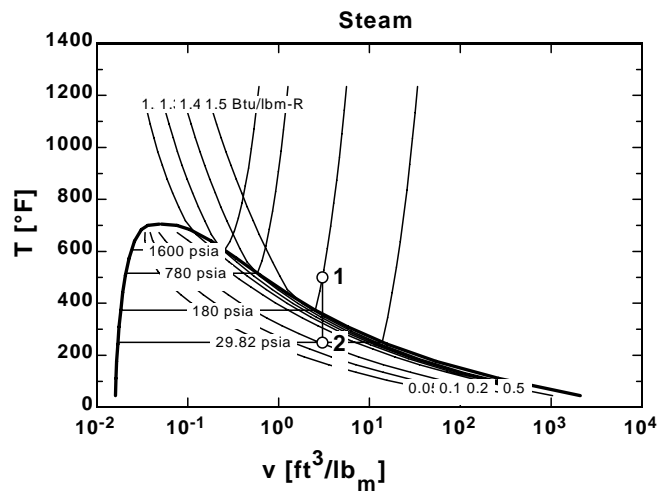


4-57E EES Problem 4-56E is reconsidered. The effect of initial pressure on the quality of water at the final state as the pressure varies from 100 psi to 300 psi is to be investigated. The quality is to be plotted against initial pressure, and the results are to be discussed.

Analysis The problem is solved using EES, and the solution is given below.

```
T[1]=500 [F]
P[1]=180 [psia]
T[2]=250 [F]
v[1]=volume(steam_iapws,T=T[1],P=P[1])
v[2]=v[1]
P[2]=pressure(steam_iapws,T=T[2],v=v[2])
h[2]=enthalpy(steam_iapws,T=T[2],v=v[2])
x[2]=quality(steam_iapws,T=T[2],v=v[2])
```

P_1 [psia]	x_2
100	0.4037
122.2	0.3283
144.4	0.2761
166.7	0.2378
188.9	0.2084
211.1	0.1853
233.3	0.1665
255.6	0.1510
277.8	0.1379
300	0.1268



4-58 A rigid vessel that contains a saturated liquid-vapor mixture is heated until it reaches the critical state. The mass of the liquid water and the volume occupied by the liquid at the initial state are to be determined.

Analysis This is a constant volume process ($v = V/m = \text{constant}$) to the critical state, and thus the initial specific volume will be equal to the final specific volume, which is equal to the critical specific volume of water,

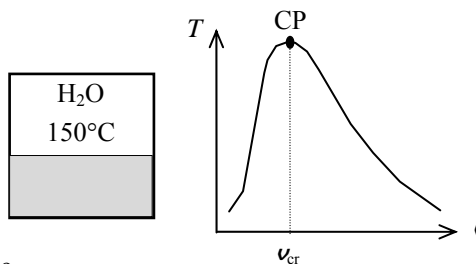
$$v_1 = v_2 = v_{cr} = 0.003106 \text{ m}^3/\text{kg} \quad (\text{last row of Table A-4})$$

The total mass is

$$m = \frac{V}{v} = \frac{0.3 \text{ m}^3}{0.003106 \text{ m}^3/\text{kg}} = 96.60 \text{ kg}$$

At 150°C , $v_f = 0.001091 \text{ m}^3/\text{kg}$ and $v_g = 0.39248 \text{ m}^3/\text{kg}$ (Table A-4). Then the quality of water at the initial state is

$$x_1 = \frac{v_1 - v_f}{v_{fg}} = \frac{0.003106 - 0.001091}{0.39248 - 0.001091} = 0.005149$$



Then the mass of the liquid phase and its volume at the initial state are determined from

$$m_f = (1 - x_1)m_t = (1 - 0.005149)(96.60) = \mathbf{96.10 \text{ kg}}$$

$$V_f = m_f v_f = (96.10 \text{ kg})(0.001091 \text{ m}^3/\text{kg}) = \mathbf{0.105 \text{ m}^3}$$

4-59 The properties of compressed liquid water at a specified state are to be determined using the compressed liquid tables, and also by using the saturated liquid approximation, and the results are to be compared.

Analysis Compressed liquid can be approximated as saturated liquid at the given temperature. Then from Table A-4,

$$T = 100^\circ\text{C} \Rightarrow v \cong v_f @ 100^\circ\text{C} = 0.001043 \text{ m}^3/\text{kg} \quad (0.72\% \text{ error})$$

$$u \cong u_f @ 100^\circ\text{C} = 419.06 \text{ kJ/kg} \quad (1.02\% \text{ error})$$

$$h \cong h_f @ 100^\circ\text{C} = 419.17 \text{ kJ/kg} \quad (2.61\% \text{ error})$$

From compressed liquid table (Table A-7),

$$\left. \begin{array}{l} P = 15 \text{ MPa} \\ T = 100^\circ\text{C} \end{array} \right\} \begin{array}{l} v = 0.001036 \text{ m}^3/\text{kg} \\ u = 414.85 \text{ kJ/kg} \\ h = 430.39 \text{ kJ/kg} \end{array}$$

The percent errors involved in the saturated liquid approximation are listed above in parentheses.

4-60 EES Problem 4-59 is reconsidered. Using EES, the indicated properties of compressed liquid are to be determined, and they are to be compared to those obtained using the saturated liquid approximation.

Analysis The problem is solved using EES, and the solution is given below.

```
Fluid$='Steam_IAPWS'
T = 100 [C]
P = 15000 [kPa]
v = VOLUME(Fluid$,T=T,P=P)
u = INTENERGY(Fluid$,T=T,P=P)
h = ENTHALPY(Fluid$,T=T,P=P)
v_app = VOLUME(Fluid$,T=T,x=0)
u_app = INTENERGY(Fluid$,T=T,x=0)
h_app_1 = ENTHALPY(Fluid$,T=T,x=0)
h_app_2 = ENTHALPY(Fluid$,T=T,x=0)+v_app*(P-pressure(Fluid$,T=T,x=0))
```

SOLUTION

```
Fluid$='Steam_IAPWS'
h=430.4 [kJ/kg]
h_app_1=419.2 [kJ/kg]
h_app_2=434.7 [kJ/kg]
P=15000 [kPa]
T=100 [C]
u=414.9 [kJ/kg]
u_app=419.1 [kJ/kg]
v=0.001036 [m^3/kg]
v_app=0.001043 [m^3/kg]
```

4-61 Superheated steam in a piston-cylinder device is cooled at constant pressure until half of the mass condenses. The final temperature and the volume change are to be determined, and the process should be shown on a T - v diagram.

Analysis (b) At the final state the cylinder contains saturated liquid-vapor mixture, and thus the final temperature must be the saturation temperature at the final pressure,

$$T = T_{\text{sat}@1 \text{ MPa}} = \mathbf{179.88^\circ\text{C}} \quad (\text{Table A-5})$$

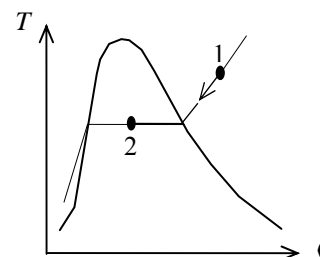
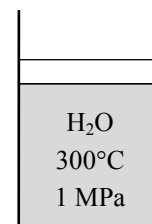
(c) The quality at the final state is specified to be $x_2 = 0.5$. The specific volumes at the initial and the final states are

$$\left. \begin{array}{l} P_1 = 1.0 \text{ MPa} \\ T_1 = 300^\circ\text{C} \end{array} \right\} v_1 = 0.25799 \text{ m}^3/\text{kg} \quad (\text{Table A-6})$$

$$\left. \begin{array}{l} P_2 = 1.0 \text{ MPa} \\ x_2 = 0.5 \end{array} \right\} \begin{aligned} v_2 &= v_f + x_2 v_{fg} \\ &= 0.001127 + 0.5 \times (0.19436 - 0.001127) \\ &= 0.09775 \text{ m}^3/\text{kg} \end{aligned}$$

Thus,

$$\Delta V = m(v_2 - v_1) = (0.8 \text{ kg})(0.09775 - 0.25799) \text{ m}^3/\text{kg} = \mathbf{-0.1282 \text{ m}^3}$$



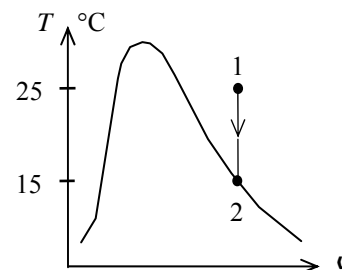
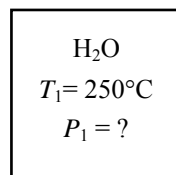
4-62 The water in a rigid tank is cooled until the vapor starts condensing. The initial pressure in the tank is to be determined.

Analysis This is a constant volume process ($v = V/m = \text{constant}$), and the initial specific volume is equal to the final specific volume that is

$$v_1 = v_2 = v_{g@150^\circ\text{C}} = 0.39248 \text{ m}^3/\text{kg} \quad (\text{Table A-4})$$

since the vapor starts condensing at 150°C . Then from Table A-6,

$$\left. \begin{array}{l} T_1 = 250^\circ\text{C} \\ v_1 = 0.39248 \text{ m}^3/\text{kg} \end{array} \right\} P_1 = \mathbf{0.60 \text{ MPa}}$$



4-63 Heat is supplied to a piston-cylinder device that contains water at a specified state. The volume of the tank, the final temperature and pressure, and the internal energy change of water are to be determined.

Properties The saturated liquid properties of water at 200°C are: $v_f = 0.001157 \text{ m}^3/\text{kg}$ and $u_f = 850.46 \text{ kJ/kg}$ (Table A-4).

Analysis (a) The cylinder initially contains saturated liquid water. The volume of the cylinder at the initial state is

$$V_1 = m v_1 = (1.4 \text{ kg})(0.001157 \text{ m}^3/\text{kg}) = 0.001619 \text{ m}^3$$

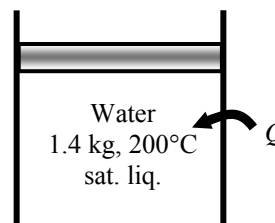
The volume at the final state is

$$V = 4(0.001619) = \mathbf{0.006476 \text{ m}^3}$$

(b) The final state properties are

$$v_2 = \frac{V}{m} = \frac{0.006476 \text{ m}^3}{1.4 \text{ kg}} = 0.004626 \text{ m}^3/\text{kg}$$

$$\left. \begin{array}{l} v_2 = 0.004626 \text{ m}^3/\text{kg} \\ x_2 = 1 \end{array} \right\} \begin{array}{l} T_2 = \mathbf{371.3^\circ\text{C}} \\ P_2 = \mathbf{21,367 \text{ kPa}} \\ u_2 = 2201.5 \text{ kJ/kg} \end{array} \quad (\text{Table A-4 or A-5 or EES})$$



(c) The total internal energy change is determined from

$$\Delta U = m(u_2 - u_1) = (1.4 \text{ kg})(2201.5 - 850.46) \text{ kJ/kg} = \mathbf{1892 \text{ kJ}}$$

4-64 Heat is lost from a piston-cylinder device that contains steam at a specified state. The initial temperature, the enthalpy change, and the final pressure and quality are to be determined.

Analysis (a) The saturation temperature of steam at 3.5 MPa is

$$T_{\text{sat}@3.5 \text{ MPa}} = 242.6^\circ\text{C} \quad (\text{Table A-5})$$

Then, the initial temperature becomes

$$T_1 = 242.6 + 5 = \mathbf{247.6^\circ\text{C}}$$

Also,
$$\left. \begin{array}{l} P_1 = 3.5 \text{ MPa} \\ T_1 = 247.6^\circ\text{C} \end{array} \right\} h_1 = 2821.1 \text{ kJ/kg} \quad (\text{Table A-6})$$

(b) The properties of steam when the piston first hits the stops are

$$\left. \begin{array}{l} P_2 = P_1 = 3.5 \text{ MPa} \\ x_2 = 0 \end{array} \right\} \left. \begin{array}{l} h_2 = 1049.7 \text{ kJ/kg} \\ v_2 = 0.001235 \text{ m}^3/\text{kg} \end{array} \right\} \quad (\text{Table A-5})$$

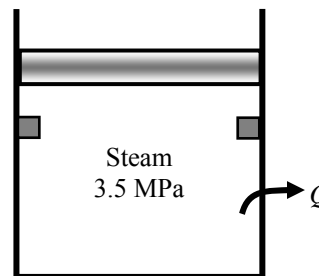
Then, the enthalpy change of steam becomes

$$\Delta h = h_2 - h_1 = 1049.7 - 2821.1 = \mathbf{-1771 \text{ kJ/kg}}$$

(c) At the final state

$$\left. \begin{array}{l} v_3 = v_2 = 0.001235 \text{ m}^3/\text{kg} \\ T_3 = 200^\circ\text{C} \end{array} \right\} \left. \begin{array}{l} P_3 = \mathbf{1555 \text{ kPa}} \\ x_3 = \mathbf{0.0006} \end{array} \right\} \quad (\text{Table A-4 or EES})$$

The cylinder contains saturated liquid-vapor mixture with a small mass of vapor at the final state.



4-65E The error involved in using the enthalpy of water by the incompressible liquid approximation is to be determined.

Analysis The state of water is compressed liquid. From the steam tables,

$$\left. \begin{array}{l} P = 1500 \text{ psia} \\ T = 400^\circ\text{F} \end{array} \right\} h = 376.51 \text{ Btu/lbm} \quad (\text{Table A - 7E})$$

Based upon the incompressible liquid approximation,

$$\left. \begin{array}{l} P = 1500 \text{ psia} \\ T = 400^\circ\text{F} \end{array} \right\} h \cong h_f @ 400^\circ\text{F} = 375.04 \text{ Btu/lbm} \quad (\text{Table A - 4E})$$

The error involved is

$$\text{Percent Error} = \frac{376.51 - 375.04}{376.51} \times 100 = \mathbf{0.39\%}$$

which is quite acceptable in most engineering calculations.

4-66 The errors involved in using the specific volume and enthalpy of water by the incompressible liquid approximation are to be determined.

Analysis The state of water is compressed liquid. From the steam tables,

$$\left. \begin{array}{l} P = 10 \text{ MPa} \\ T = 100^\circ\text{C} \end{array} \right\} \begin{array}{l} \nu = 0.0010385 \text{ m}^3/\text{kg} \\ h = 426.62 \text{ kJ/kg} \end{array} \quad (\text{Table A - 7})$$

Based upon the incompressible liquid approximation,

$$\left. \begin{array}{l} P = 10 \text{ MPa} \\ T = 100^\circ\text{C} \end{array} \right\} \begin{array}{l} \nu \cong \nu_f @ 100^\circ\text{C} = 0.001043 \text{ m}^3/\text{kg} \\ h \cong h_f @ 100^\circ\text{C} = 419.17 \text{ kJ/kg} \end{array} \quad (\text{Table A - 4})$$

The errors involved are

$$\text{Percent Error (specific volume)} = \frac{0.001043 - 0.0010385}{0.0010385} \times 100 = \mathbf{0.43\%}$$

$$\text{Percent Error (enthalpy)} = \frac{426.62 - 419.17}{426.62} \times 100 = \mathbf{1.75\%}$$

which are quite acceptable in most engineering calculations.

4-67 The specific volume and internal energy of R-134a at a specified state are to be determined.

Analysis The state of R-134a is compressed liquid. Based upon the incompressible liquid approximation,

$$\left. \begin{array}{l} P = 700 \text{ kPa} \\ T = 20^\circ\text{C} \end{array} \right\} \begin{array}{l} \nu \cong \nu_f @ 20^\circ\text{C} = 0.0008161 \text{ m}^3/\text{kg} \\ u \cong u_f @ 20^\circ\text{C} = 78.86 \text{ kJ/kg} \end{array} \quad (\text{Table A - 11})$$

4-68 A piston-cylinder device that is filled with R-134a is heated. The volume change is to be determined.

Analysis The initial specific volume is

$$\left. \begin{array}{l} P_1 = 60 \text{ kPa} \\ T_1 = -20^\circ\text{C} \end{array} \right\} \nu_1 = 0.33608 \text{ m}^3/\text{kg} \text{ (Table A-13)}$$

and the initial volume is

$$V_1 = m\nu_1 = (0.100 \text{ kg})(0.33608 \text{ m}^3/\text{kg}) = 0.033608 \text{ m}^3$$

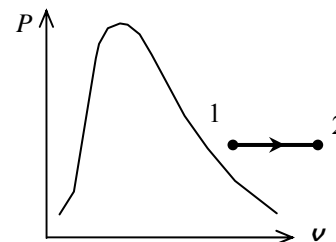
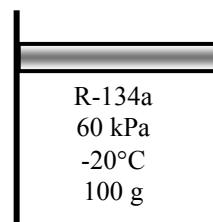
At the final state, we have

$$\left. \begin{array}{l} P_2 = 60 \text{ kPa} \\ T_2 = 100^\circ\text{C} \end{array} \right\} \nu_2 = 0.50410 \text{ m}^3/\text{kg} \text{ (Table A-13)}$$

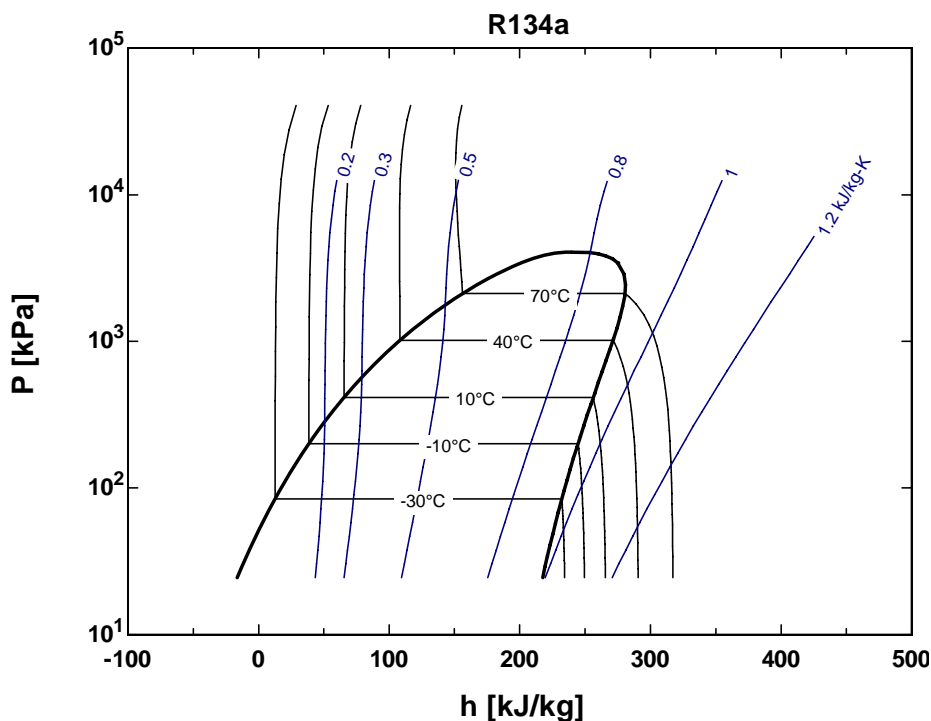
$$V_2 = m\nu_2 = (0.100 \text{ kg})(0.50410 \text{ m}^3/\text{kg}) = 0.050410 \text{ m}^3$$

The volume change is then

$$\Delta V = V_2 - V_1 = 0.050410 - 0.033608 = \mathbf{0.0168 \text{ m}^3}$$



4-69 EES The Pressure-Enthalpy diagram of R-134a showing some constant-temperature and constant-entropy lines are obtained using Property Plot feature of EES.



Ideal Gas

4-70C Propane (molar mass = 44.1 kg/kmol) poses a greater fire danger than methane (molar mass = 16 kg/kmol) since propane is heavier than air (molar mass = 29 kg/kmol), and it will settle near the floor. Methane, on the other hand, is lighter than air and thus it will rise and leak out.

4-71C A gas can be treated as an ideal gas when it is at a high temperature or low pressure relative to its critical temperature and pressure.

4-72C R_u is the universal gas constant that is the same for all gases whereas R is the specific gas constant that is different for different gases. These two are related to each other by $R = R_u / M$, where M is the molar mass of the gas.

4-73C Mass m is simply the amount of matter; molar mass M is the mass of one mole in grams or the mass of one kmol in kilograms. These two are related to each other by $m = NM$, where N is the number of moles.

4-74E The specific volume of oxygen at a specified state is to be determined.

Assumptions At specified conditions, oxygen behaves as an ideal gas.

Properties The gas constant of oxygen is $R = 0.3353 \text{ psia}\cdot\text{ft}^3/\text{lbm}\cdot\text{R}$ (Table A-1E).

Analysis According to the ideal gas equation of state,

$$\nu = \frac{RT}{P} = \frac{(0.3353 \text{ psia}\cdot\text{ft}^3/\text{lbm}\cdot\text{R})(80 + 460 \text{ R})}{25 \text{ psia}} = \mathbf{7.242 \text{ ft}^3/\text{lbm}}$$

4-75 The pressure in a container that is filled with air is to be determined.

Assumptions At specified conditions, air behaves as an ideal gas.

Properties The gas constant of air is $R = 0.287 \text{ kJ/kg}\cdot\text{K}$ (Table A-1).

Analysis The definition of the specific volume gives

$$\nu = \frac{V}{m} = \frac{0.100 \text{ m}^3}{1 \text{ kg}} = 0.100 \text{ m}^3/\text{kg}$$

Using the ideal gas equation of state, the pressure is

$$P = \frac{RT}{\nu} = \frac{(0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(27 + 273 \text{ K})}{0.100 \text{ m}^3/\text{kg}} = \mathbf{861 \text{ kPa}}$$

4-76E The volume of a tank that is filled with argon at a specified state is to be determined.

Assumptions At specified conditions, argon behaves as an ideal gas.

Properties The gas constant of argon is $R = 0.2686 \text{ psia}\cdot\text{ft}^3/\text{lbm}\cdot\text{R}$ (Table A-1E)

Analysis According to the ideal gas equation of state,

$$V = \frac{mRT}{P} = \frac{(1 \text{ lbm})(0.2686 \text{ psia}\cdot\text{ft}^3/\text{lbm}\cdot\text{R})(100 + 460 \text{ R})}{200 \text{ psia}} = \mathbf{0.7521 \text{ ft}^3}$$

4-77 A balloon is filled with helium gas. The mole number and the mass of helium in the balloon are to be determined.

Assumptions At specified conditions, helium behaves as an ideal gas.

Properties The universal gas constant is $R_u = 8.314 \text{ kPa}\cdot\text{m}^3/\text{kmol}\cdot\text{K}$. The molar mass of helium is $4.0 \text{ kg}/\text{kmol}$ (Table A-1).

Analysis The volume of the sphere is

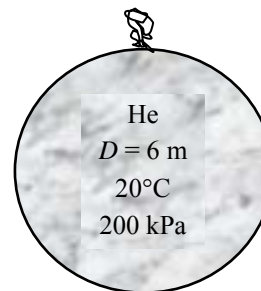
$$V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(3 \text{ m})^3 = 113.1 \text{ m}^3$$

Assuming ideal gas behavior, the mole numbers of He is determined from

$$N = \frac{PV}{R_u T} = \frac{(200 \text{ kPa})(113.1 \text{ m}^3)}{(8.314 \text{ kPa}\cdot\text{m}^3/\text{kmol}\cdot\text{K})(293 \text{ K})} = \mathbf{9.28 \text{ kmol}}$$

Then the mass of He can be determined from

$$m = NM = (9.28 \text{ kmol})(4.0 \text{ kg}/\text{kmol}) = \mathbf{37.15 \text{ kg}}$$



4-78 EES Problem 4-77 is to be reconsidered. The effect of the balloon diameter on the mass of helium contained in the balloon is to be determined for the pressures of (a) 100 kPa and (b) 200 kPa as the diameter varies from 5 m to 15 m. The mass of helium is to be plotted against the diameter for both cases.

Analysis The problem is solved using EES, and the solution is given below.

"Given Data"

{D=6 [m]}

{P=200 [kPa]}

T=20 [C]

P=200 [kPa]

R_u=8.314 [kJ/kmol-K]

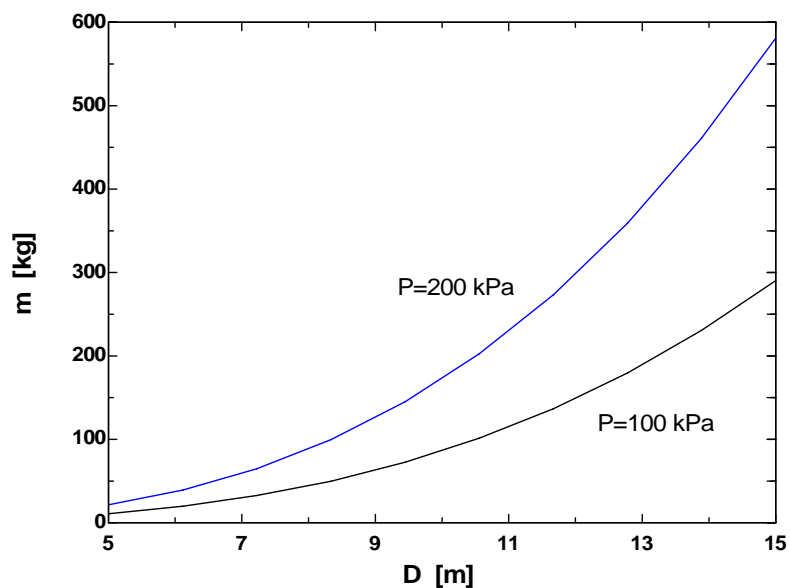
"Solution"

$P \cdot V = N \cdot R_u \cdot (T + 273)$

$V = 4 \cdot \pi \cdot (D/2)^3 / 3$

$m = N \cdot \text{MOLARMASS}(\text{Helium})$

D [m]	m [kg]
5	21.51
6.111	39.27
7.222	64.82
8.333	99.57
9.444	145
10.56	202.4
11.67	273.2
12.78	359
13.89	461
15	580.7



4-79 An automobile tire is inflated with air. The pressure rise of air in the tire when the tire is heated and the amount of air that must be bled off to reduce the temperature to the original value are to be determined.

Assumptions **1** At specified conditions, air behaves as an ideal gas. **2** The volume of the tire remains constant.

Properties The gas constant of air is $R = 0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K}$ (Table A-1).

Analysis Initially, the absolute pressure in the tire is

$$P_1 = P_g + P_{\text{atm}} = 210 + 100 = 310 \text{ kPa}$$

Treating air as an ideal gas and assuming the volume of the tire to remain constant, the final pressure in the tire can be determined from

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \longrightarrow P_2 = \frac{T_2}{T_1} P_1 = \frac{323 \text{ K}}{298 \text{ K}} (310 \text{ kPa}) = 336 \text{ kPa}$$

Thus the pressure rise is

$$\Delta P = P_2 - P_1 = 336 - 310 = \mathbf{26 \text{ kPa}}$$

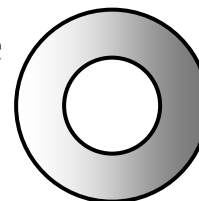
The amount of air that needs to be bled off to restore pressure to its original value is

$$m_1 = \frac{P_1 V}{RT_1} = \frac{(310 \text{ kPa})(0.025 \text{ m}^3)}{(0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(298 \text{ K})} = 0.0906 \text{ kg}$$

$$m_2 = \frac{P_1 V}{RT_2} = \frac{(310 \text{ kPa})(0.025 \text{ m}^3)}{(0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(323 \text{ K})} = 0.0836 \text{ kg}$$

$$\Delta m = m_1 - m_2 = 0.0906 - 0.0836 = \mathbf{0.0070 \text{ kg}}$$

Tire
25°C



4-80 Two rigid tanks connected by a valve to each other contain air at specified conditions. The volume of the second tank and the final equilibrium pressure when the valve is opened are to be determined.

Assumptions At specified conditions, air behaves as an ideal gas.

Properties The gas constant of air is $R = 0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K}$ (Table A-1).

Analysis Let's call the first and the second tanks A and B. Treating air as an ideal gas, the volume of the second tank and the mass of air in the first tank are determined to be

$$V_B = \left(\frac{m_1 R T_1}{P_1} \right)_B = \frac{(5 \text{ kg})(0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(308 \text{ K})}{200 \text{ kPa}} = 2.21 \text{ m}^3$$

$$m_A = \left(\frac{P_1 V}{R T_1} \right)_A = \frac{(500 \text{ kPa})(1.0 \text{ m}^3)}{(0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(298 \text{ K})} = 5.846 \text{ kg}$$

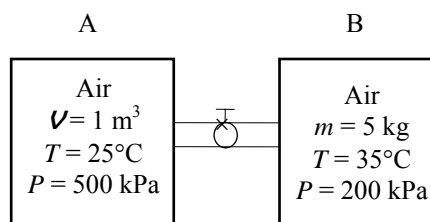
Thus,

$$V = V_A + V_B = 1.0 + 2.21 = 3.21 \text{ m}^3$$

$$m = m_A + m_B = 5.846 + 5.0 = 10.846 \text{ kg}$$

Then the final equilibrium pressure becomes

$$P_2 = \frac{m R T_2}{V} = \frac{(10.846 \text{ kg})(0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(293 \text{ K})}{3.21 \text{ m}^3} = 284.1 \text{ kPa}$$



4-81E The validity of a statement that tires lose roughly 1 psi of pressure for every 10°F drop in outside temperature is to be investigated.

Assumptions **1**The air in the tire is an ideal gas. **2** The volume of air in the tire is constant. **3** The tire is in thermal equilibrium with the outside air. **4** The atmospheric conditions are 70°F and 1 atm = 14.7 psia.

Analysis The pressure in a tire should be checked at least once a month when a vehicle has sat for at least one hour to ensure that the tires are cool. The recommended gage pressure in cool tires is typically above 30 psi. Taking the initial gage pressure to be 32 psi, the gage pressure after the outside temperature drops by 10°F is determined from the ideal gas relation to be

$$\frac{P_1 V}{T_1} = \frac{P_2 V}{T_2} \rightarrow P_2 = \frac{T_2}{T_1} P_1 = \frac{(60 + 460) \text{ R}}{(70 + 460) \text{ R}} (32 + 14.7 \text{ psia}) = 45.8 \text{ psia} = 31.1 \text{ psig (gage)}$$

Then the drop in pressure corresponding to a drop of 10°F in temperature becomes

$$\Delta P = P_1 - P_2 = 32.0 - 31.1 = 0.9 \text{ psi}$$

which is sufficiently close to 1 psi. Therefore, the statement is **valid**.

Discussion Note that we used *absolute* temperatures and pressures in ideal gas calculations. Using gage pressures would result in pressure drop of 0.6 psi, which is considerably lower than 1 psi. Therefore, it is important to use absolute temperatures and pressures in the ideal gas relation.

4-82 A piston-cylinder device containing oxygen is cooled. The change of the volume is to be determined.

Assumptions At specified conditions, oxygen behaves as an ideal gas.

Properties The gas constant of oxygen is $R = 0.2598 \text{ kJ/kg}\cdot\text{K}$ (Table A-1).

Analysis According to the ideal gas equation of state, the initial volume of the oxygen is

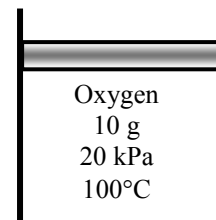
$$v_1 = \frac{mRT_1}{P_1} = \frac{(0.010 \text{ kg})(0.2598 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(100 + 273 \text{ K})}{20 \text{ kPa}} = 0.04845 \text{ m}^3$$

Similarly, the final volume is

$$v_2 = \frac{mRT_2}{P_2} = \frac{(0.010 \text{ kg})(0.2598 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(0 + 273 \text{ K})}{20 \text{ kPa}} = 0.03546 \text{ m}^3$$

The change of volume is then

$$\Delta v = v_2 - v_1 = 0.03546 - 0.04845 = -0.013 \text{ m}^3$$



4-83 A rigid vessel containing helium is heated. The temperature change is to be determined.

Assumptions At specified conditions, helium behaves as an ideal gas.

Properties The gas constant of helium is $R = 2.0769 \text{ kJ/kg}\cdot\text{K}$ (Table A-1).

Analysis According to the ideal gas equation of state, the initial temperature is

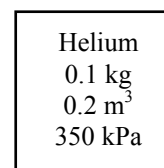
$$T_1 = \frac{P_1 v}{mR} = \frac{(350 \text{ kPa})(0.2 \text{ m}^3)}{(0.1 \text{ kg})(2.0769 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})} = 337 \text{ K}$$

Since the specific volume remains constant, the ideal gas equation gives

$$v_1 = \frac{RT_1}{P_1} = v_2 = \frac{RT_2}{P_2} \longrightarrow T_2 = T_1 \frac{P_2}{P_1} = (337 \text{ K}) \frac{700 \text{ kPa}}{350 \text{ kPa}} = 674 \text{ K}$$

The temperature change is then

$$\Delta T = T_2 - T_1 = 674 - 337 = 337 \text{ K}$$



4-84 A piston-cylinder device containing argon undergoes an isothermal process. The final pressure is to be determined.

Assumptions At specified conditions, argon behaves as an ideal gas.

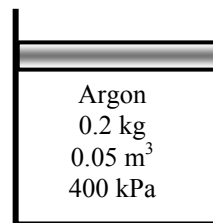
Properties The gas constant of argon is $R = 0.2081$ kJ/kg·K (Table A-1).

Analysis Since the temperature remains constant, the ideal gas equation gives

$$m = \frac{P_1 V_1}{RT} = \frac{P_2 V_2}{RT} \longrightarrow P_1 V_1 = P_2 V_2$$

which when solved for final pressure becomes

$$P_2 = P_1 \frac{V_1}{V_2} = P_1 \frac{V_1}{2V_1} = 0.5P_1 = 0.5(400 \text{ kPa}) = \mathbf{200 \text{ kPa}}$$



Compressibility Factor

4-85C It represent the deviation from ideal gas behavior. The further away it is from 1, the more the gas deviates from ideal gas behavior.

4-86C All gases have the same compressibility factor Z at the same reduced temperature and pressure.

4-87C Reduced pressure is the pressure normalized with respect to the critical pressure; and reduced temperature is the temperature normalized with respect to the critical temperature.

4-88 The specific volume of steam is to be determined using the ideal gas relation, the compressibility chart, and the steam tables. The errors involved in the first two approaches are also to be determined.

Properties The gas constant, the critical pressure, and the critical temperature of water are, from Table A-1,

$$R = 0.4615 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K}, \quad T_{cr} = 647.1 \text{ K}, \quad P_{cr} = 22.06 \text{ MPa}$$

Analysis (a) From the ideal gas equation of state,

$$\nu = \frac{RT}{P} = \frac{(0.4615 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(673 \text{ K})}{(10,000 \text{ kPa})} = \mathbf{0.03106 \text{ m}^3/\text{kg} \text{ (17.6\% error)}}$$

(b) From the compressibility chart (Fig. A-15),

$$\left. \begin{aligned} P_R = \frac{P}{P_{cr}} = \frac{10 \text{ MPa}}{22.06 \text{ MPa}} = 0.453 \\ T_R = \frac{T}{T_{cr}} = \frac{673 \text{ K}}{647.1 \text{ K}} = 1.04 \end{aligned} \right\} Z = 0.84$$

H ₂ O
10 MPa
400°C

Thus,

$$\nu = Z\nu_{ideal} = (0.84)(0.03106 \text{ m}^3/\text{kg}) = \mathbf{0.02609 \text{ m}^3/\text{kg} \text{ (1.2\% error)}}$$

(c) From the superheated steam table (Table A-6),

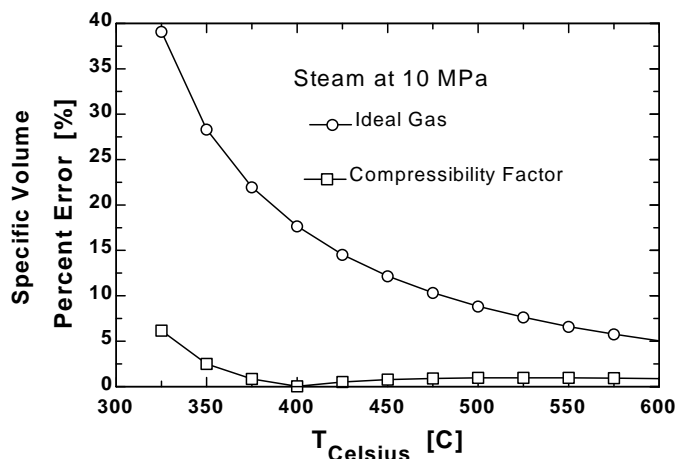
$$\left. \begin{aligned} P = 10 \text{ MPa} \\ T = 400^\circ\text{C} \end{aligned} \right\} \nu = \mathbf{0.02644 \text{ m}^3/\text{kg}}$$

4-89 EES Problem 4-88 is reconsidered. The problem is to be solved using the general compressibility factor feature of EES (or other) software. The specific volume of water for the three cases at 10 MPa over the temperature range of 325°C to 600°C in 25°C intervals is to be compared, and the %error involved in the ideal gas approximation is to be plotted against temperature.

Analysis The problem is solved using EES, and the solution is given below.

```
P=10 [MPa]*Convert(MPa,kPa)
{T_Celsius= 400 [C]}
T=T_Celsius+273 "[K]"
T_critical=T_CRIT(Steam_iapws)
P_critical=P_CRIT(Steam_iapws)
{v=Vol/m}
P_table=P; P_comp=P;P_idealgas=P
T_table=T; T_comp=T;T_idealgas=T
v_table=volume(Steam_iapws,P=P_table,T=T_table) "EES data for steam as a real gas"
{P_table=pressure(Steam_iapws, T=T_table,v=v)}
{T_sat=temperature(Steam_iapws,P=P_table,v=v)}
MM=MOLARMASS(water)
R_u=8.314 [kJ/kmol-K] "Universal gas constant"
R=R_u/MM "[kJ/kg-K], Particular gas constant"
P_idealgas*v_idealgas=R*T_idealgas "Ideal gas equation"
z = COMPRESS(T_comp/T_critical,P_comp/P_critical)
P_comp*v_comp=z*R*T_comp "generalized Compressibility factor"
Error_idealgas=Abs(v_table-v_idealgas)/v_table*Convert(, %)
Error_comp=Abs(v_table-v_comp)/v_table*Convert(, %)
```

Error _{comp} [%]	Error _{ideal gas} [%]	T _{Celsius} [C]
6.088	38.96	325
2.422	28.2	350
0.7425	21.83	375
0.129	17.53	400
0.6015	14.42	425
0.8559	12.07	450
0.9832	10.23	475
1.034	8.755	500
1.037	7.55	525
1.01	6.55	550
0.9652	5.712	575
0.9093	5	600



4-90 The specific volume of R-134a is to be determined using the ideal gas relation, the compressibility chart, and the R-134a tables. The errors involved in the first two approaches are also to be determined.

Properties The gas constant, the critical pressure, and the critical temperature of refrigerant-134a are, from Table A-1,

$$R = 0.08149 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K}, \quad T_{cr} = 374.2 \text{ K}, \quad P_{cr} = 4.059 \text{ MPa}$$

Analysis (a) From the ideal gas equation of state,

$$\nu = \frac{RT}{P} = \frac{(0.08149 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(343 \text{ K})}{900 \text{ kPa}} = \mathbf{0.03105 \text{ m}^3/\text{kg}} \quad (13.3\% \text{ error})$$

(b) From the compressibility chart (Fig. A-15),

$$\left. \begin{aligned} P_R &= \frac{P}{P_{cr}} = \frac{0.9 \text{ MPa}}{4.059 \text{ MPa}} = 0.222 \\ T_R &= \frac{T}{T_{cr}} = \frac{343 \text{ K}}{374.2 \text{ K}} = 0.917 \end{aligned} \right\} Z = 0.894$$

R-134a
0.9 MPa
70°C

Thus,

$$\nu = Z\nu_{ideal} = (0.894)(0.03105 \text{ m}^3/\text{kg}) = \mathbf{0.02776 \text{ m}^3/\text{kg}} \quad (1.3\% \text{ error})$$

(c) From the superheated refrigerant table (Table A-13),

$$\left. \begin{aligned} P &= 0.9 \text{ MPa} \\ T &= 70^\circ\text{C} \end{aligned} \right\} \nu = \mathbf{0.027413 \text{ m}^3/\text{kg}}$$

4-91 The specific volume of nitrogen gas is to be determined using the ideal gas relation and the compressibility chart. The errors involved in these two approaches are also to be determined.

Properties The gas constant, the critical pressure, and the critical temperature of nitrogen are, from Table A-1,

$$R = 0.2968 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K}, \quad T_{cr} = 126.2 \text{ K}, \quad P_{cr} = 3.39 \text{ MPa}$$

Analysis (a) From the ideal gas equation of state,

$$\nu = \frac{RT}{P} = \frac{(0.2968 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(150 \text{ K})}{10,000 \text{ kPa}} = \mathbf{0.004452 \text{ m}^3/\text{kg}} \quad (86.4\% \text{ error})$$

(b) From the compressibility chart (Fig. A-15),

$$\left. \begin{aligned} P_R &= \frac{P}{P_{cr}} = \frac{10 \text{ MPa}}{3.39 \text{ MPa}} = 2.95 \\ T_R &= \frac{T}{T_{cr}} = \frac{150 \text{ K}}{126.2 \text{ K}} = 1.19 \end{aligned} \right\} Z = 0.54$$

N ₂
10 MPa
150 K

Thus,

$$\nu = Z\nu_{ideal} = (0.54)(0.004452 \text{ m}^3/\text{kg}) = \mathbf{0.002404 \text{ m}^3/\text{kg}} \quad (0.7\% \text{ error})$$

4-92 The specific volume of steam is to be determined using the ideal gas relation, the compressibility chart, and the steam tables. The errors involved in the first two approaches are also to be determined.

Properties The gas constant, the critical pressure, and the critical temperature of water are, from Table A-1,

$$R = 0.4615 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K}, \quad T_{cr} = 647.1 \text{ K}, \quad P_{cr} = 22.06 \text{ MPa}$$

Analysis (a) From the ideal gas equation of state,

$$\nu = \frac{RT}{P} = \frac{(0.4615 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(723 \text{ K})}{3500 \text{ kPa}} = \mathbf{0.09533 \text{ m}^3/\text{kg}} \quad \mathbf{(3.7\% \text{ error})}$$

(b) From the compressibility chart (Fig. A-15),

$$\left. \begin{aligned} P_R &= \frac{P}{P_{cr}} = \frac{3.5 \text{ MPa}}{22.06 \text{ MPa}} = 0.159 \\ T_R &= \frac{T}{T_{cr}} = \frac{723 \text{ K}}{647.1 \text{ K}} = 1.12 \end{aligned} \right\} Z = 0.961$$

H ₂ O
3.5 MPa
450°C

Thus,

$$\nu = Z\nu_{ideal} = (0.961)(0.09533 \text{ m}^3/\text{kg}) = \mathbf{0.09161 \text{ m}^3/\text{kg}} \quad \mathbf{(0.4\% \text{ error})}$$

(c) From the superheated steam table (Table A-6),

$$\left. \begin{aligned} P &= 3.5 \text{ MPa} \\ T &= 450^\circ\text{C} \end{aligned} \right\} \nu = \mathbf{0.09196 \text{ m}^3/\text{kg}}$$

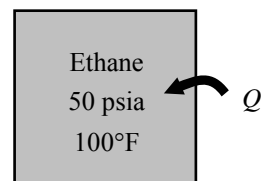
4-93E Ethane in a rigid vessel is heated. The final pressure is to be determined using the compressibility chart.

Properties The gas constant, the critical pressure, and the critical temperature of ethane are, from Table A-1E,

$$R = 0.3574 \text{ psia}\cdot\text{ft}^3/\text{lbm}\cdot\text{R}, \quad T_{\text{cr}} = 549.8 \text{ R}, \quad P_{\text{cr}} = 708 \text{ psia}$$

Analysis From the compressibility chart at the initial state (Fig. A-15),

$$\left. \begin{aligned} T_{R1} &= \frac{T_1}{T_{\text{cr}}} = \frac{560 \text{ R}}{549.8 \text{ R}} = 1.019 \\ P_{R1} &= \frac{P_1}{P_{\text{cr}}} = \frac{50 \text{ psia}}{708 \text{ psia}} = 0.0706 \end{aligned} \right\} Z_1 = 0.977$$



The specific volume does not change during the process. Then,

$$\nu_1 = \nu_2 = \frac{Z_1 R T_1}{P_1} = \frac{(0.977)(0.3574 \text{ psia}\cdot\text{ft}^3/\text{lbm}\cdot\text{R})(560 \text{ R})}{50 \text{ psia}} = 3.911 \text{ ft}^3/\text{lbm}$$

At the final state,

$$\left. \begin{aligned} T_{R2} &= \frac{T_2}{T_{\text{cr}}} = \frac{1060 \text{ R}}{549.8 \text{ R}} = 1.928 \\ \nu_{R2} &= \frac{\nu_{2,\text{actual}}}{R T_{\text{cr}}/P_{\text{cr}}} = \frac{3.911 \text{ ft}^3/\text{lbm}}{(0.3574 \text{ psia}\cdot\text{ft}^3/\text{lbm}\cdot\text{R})(549.8 \text{ R})/(708 \text{ psia})} = 14.09 \end{aligned} \right\} Z_2 = 1.0$$

Thus,

$$P_2 = \frac{Z_2 R T_2}{\nu_2} = \frac{(1.0)(0.3574 \text{ psia}\cdot\text{ft}^3/\text{lbm}\cdot\text{R})(1060 \text{ R})}{3.911 \text{ ft}^3/\text{lbm}} = \mathbf{96.9 \text{ psia}}$$

4-94 Ethylene is heated at constant pressure. The specific volume change of ethylene is to be determined using the compressibility chart.

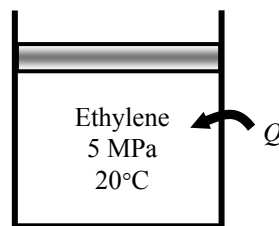
Properties The gas constant, the critical pressure, and the critical temperature of ethane are, from Table A-1,

$$R = 0.2964 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K}, \quad T_{\text{cr}} = 282.4 \text{ K}, \quad P_{\text{cr}} = 5.12 \text{ MPa}$$

Analysis From the compressibility chart at the initial and final states (Fig. A-15),

$$\left. \begin{aligned} T_{R1} &= \frac{T_1}{T_{\text{cr}}} = \frac{293 \text{ K}}{282.4 \text{ K}} = 1.038 \\ P_{R1} &= \frac{P_1}{P_{\text{cr}}} = \frac{5 \text{ MPa}}{5.12 \text{ MPa}} = 0.977 \end{aligned} \right\} Z_1 = 0.56$$

$$\left. \begin{aligned} T_{R2} &= \frac{T_2}{T_{\text{cr}}} = \frac{473 \text{ K}}{282.4 \text{ K}} = 1.675 \\ P_{R2} &= P_{R1} = 0.977 \end{aligned} \right\} Z_2 = 0.961$$



The specific volume change is

$$\begin{aligned} \Delta v &= \frac{R}{P} (Z_2 T_2 - Z_1 T_1) \\ &= \frac{0.2964 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K}}{5000 \text{ kPa}} [(0.961)(473 \text{ K}) - (0.56)(293 \text{ K})] \\ &= \mathbf{0.0172 \text{ m}^3/\text{kg}} \end{aligned}$$

4-95 Water vapor is heated at constant pressure. The final temperature is to be determined using ideal gas equation, the compressibility charts, and the steam tables.

Properties The gas constant, the critical pressure, and the critical temperature of water are, from Table A-1,

$$R = 0.4615 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K}, \quad T_{\text{cr}} = 647.1 \text{ K}, \quad P_{\text{cr}} = 22.06 \text{ MPa}$$

Analysis (a) From the ideal gas equation,

$$T_2 = T_1 \frac{\nu_2}{\nu_1} = (350 + 273 \text{ K})(2) = \mathbf{1246 \text{ K}}$$

(b) The pressure of the steam is

$$P_1 = P_2 = P_{\text{sat}@350^\circ\text{C}} = 16,529 \text{ kPa}$$

From the compressibility chart at the initial state (Fig. A-15),

$$\left. \begin{aligned} T_{R1} &= \frac{T_1}{T_{\text{cr}}} = \frac{623 \text{ K}}{647.1 \text{ K}} = 0.963 \\ P_{R1} &= \frac{P_1}{P_{\text{cr}}} = \frac{16.529 \text{ MPa}}{22.06 \text{ MPa}} = 0.749 \end{aligned} \right\} Z_1 = 0.593, \nu_{R1} = 0.75$$

At the final state,

$$\left. \begin{aligned} P_{R2} &= P_{R1} = 0.749 \\ \nu_{R2} &= 2\nu_{R1} = 2(0.75) = 1.50 \end{aligned} \right\} Z_2 = 0.88$$

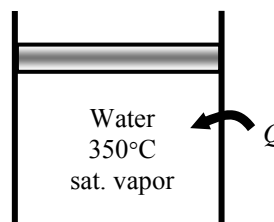
Thus,

$$T_2 = \frac{P_2 \nu_2}{Z_2 R} = \frac{P_2}{Z_2} \frac{\nu_{R2} T_{\text{cr}}}{P_{\text{cr}}} = \frac{16,529 \text{ kPa}}{0.88} \frac{(1.50)(647.1 \text{ K})}{22,060 \text{ kPa}} = \mathbf{826 \text{ K}}$$

(c) From the superheated steam table,

$$\left. \begin{aligned} T_1 &= 350^\circ\text{C} \\ x_1 &= 1 \end{aligned} \right\} \nu_1 = 0.008806 \text{ m}^3/\text{kg} \quad (\text{Table A-4})$$

$$\left. \begin{aligned} P_2 &= 16,529 \text{ kPa} \\ \nu_2 &= 2\nu_1 = 0.01761 \text{ m}^3/\text{kg} \end{aligned} \right\} T_2 = 477^\circ\text{C} = \mathbf{750 \text{ K}} \quad (\text{from Table A-6 or EES})$$



4-96E Water vapor is heated at constant pressure. The final temperature is to be determined using ideal gas equation, the compressibility charts, and the steam tables.

Properties The critical pressure and the critical temperature of water are, from Table A-1E,

$$R = 0.5956 \text{ psia}\cdot\text{ft}^3/\text{lbm}\cdot\text{R}, \quad T_{\text{cr}} = 1164.8 \text{ R}, \quad P_{\text{cr}} = 3200 \text{ psia}$$

Analysis (a) From the ideal gas equation,

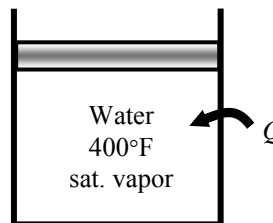
$$T_2 = T_1 \frac{\nu_2}{\nu_1} = (400 + 460 \text{ R})(2) = \mathbf{1720 \text{ R}}$$

(b) The properties of steam are (Table A-4E)

$$P_1 = P_2 = P_{\text{sat}@400^\circ\text{F}} = 247.26 \text{ psia}$$

$$\nu_1 = \nu_{\text{g}@400^\circ\text{F}} = 1.8639 \text{ ft}^3/\text{lbm}$$

$$\nu_2 = 2\nu_1 = 3.7278 \text{ ft}^3/\text{lbm}$$



At the final state, from the compressibility chart (Fig. A-15),

$$\left. \begin{aligned} P_{R2} &= \frac{P_2}{P_{\text{cr}}} = \frac{247.26 \text{ psia}}{3200 \text{ psia}} = 0.0773 \\ \nu_{R2} &= \frac{\nu_{2,\text{actual}}}{RT_{\text{cr}}/P_{\text{cr}}} = \frac{3.7278 \text{ ft}^3/\text{lbm}}{(0.5956 \text{ psia}\cdot\text{ft}^3/\text{lbm}\cdot\text{R})(1164.8 \text{ R})/(3200 \text{ psia})} = 17.19 \end{aligned} \right\} Z_2 = 0.985$$

Thus,

$$T_2 = \frac{P_2 \nu_2}{Z_2 R} = \frac{(247.26 \text{ psia})(3.7278 \text{ ft}^3/\text{lbm})}{(0.985)(0.5956 \text{ psia}\cdot\text{ft}^3/\text{lbm}\cdot\text{R})} = \mathbf{1571 \text{ R}}$$

(c) From the superheated steam table,

$$\left. \begin{aligned} P_2 &= 247.26 \text{ psia} \\ \nu_2 &= 3.7278 \text{ ft}^3/\text{lbm} \end{aligned} \right\} T_2 = 1100^\circ\text{F} = \mathbf{1560 \text{ R}} \quad (\text{from Table A-6E or EES})$$

4-97 Methane is heated at constant pressure. The final temperature is to be determined using ideal gas equation and the compressibility charts.

Properties The gas constant, the critical pressure, and the critical temperature of methane are, from Table A-1,

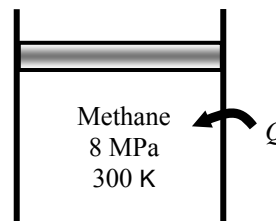
$$R = 0.5182 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K}, \quad T_{\text{cr}} = 191.1 \text{ K}, \quad P_{\text{cr}} = 4.64 \text{ MPa}$$

Analysis From the ideal gas equation,

$$T_2 = T_1 \frac{\nu_2}{\nu_1} = (300 \text{ K})(1.5) = \mathbf{450 \text{ K}}$$

From the compressibility chart at the initial state (Fig. A-15),

$$\left. \begin{aligned} T_{R1} &= \frac{T_1}{T_{\text{cr}}} = \frac{300 \text{ K}}{191.1 \text{ K}} = 1.570 \\ P_{R1} &= \frac{P_1}{P_{\text{cr}}} = \frac{8 \text{ MPa}}{4.64 \text{ MPa}} = 1.724 \end{aligned} \right\} Z_1 = 0.88, \nu_{R1} = 0.80$$



At the final state,

$$\left. \begin{aligned} P_{R2} &= P_{R1} = 1.724 \\ \nu_{R2} &= 1.5\nu_{R1} = 1.5(0.80) = 1.2 \end{aligned} \right\} Z_2 = 0.975$$

Thus,

$$T_2 = \frac{P_2 \nu_2}{Z_2 R} = \frac{P_2}{Z_2} \frac{\nu_{R2} T_{\text{cr}}}{P_{\text{cr}}} = \frac{8000 \text{ kPa}}{0.975} \frac{(1.2)(191.1 \text{ K})}{4640 \text{ kPa}} = \mathbf{406 \text{ K}}$$

Of these two results, the accuracy of the second result is limited by the accuracy with which the charts may be read. Accepting the error associated with reading charts, the second temperature is the more accurate.

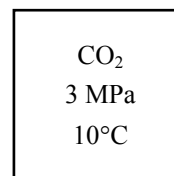
4-98 The percent error involved in treating CO_2 at a specified state as an ideal gas is to be determined.

Properties The critical pressure, and the critical temperature of CO_2 are, from Table A-1,

$$T_{\text{cr}} = 304.2 \text{ K} \text{ and } P_{\text{cr}} = 7.39 \text{ MPa}$$

Analysis From the compressibility chart (Fig. A-15),

$$\left. \begin{aligned} P_R &= \frac{P}{P_{\text{cr}}} = \frac{3 \text{ MPa}}{7.39 \text{ MPa}} = 0.406 \\ T_R &= \frac{T}{T_{\text{cr}}} = \frac{283 \text{ K}}{304.2 \text{ K}} = 0.93 \end{aligned} \right\} Z = 0.80$$



Then the error involved in treating CO_2 as an ideal gas is

$$\text{Error} = \frac{\nu - \nu_{\text{ideal}}}{\nu} = 1 - \frac{1}{Z} = 1 - \frac{1}{0.80} = -0.25 \text{ or } \mathbf{25.0\%}$$

4-99 CO₂ gas flows through a pipe. The volume flow rate and the density at the inlet and the volume flow rate at the exit of the pipe are to be determined.



Properties The gas constant, the critical pressure, and the critical temperature of CO₂ are (Table A-1)

$$R = 0.1889 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K}, \quad T_{cr} = 304.2 \text{ K}, \quad P_{cr} = 7.39 \text{ MPa}$$

Analysis (a) From the ideal gas equation of state,

$$\dot{V}_1 = \frac{\dot{m}RT_1}{P_1} = \frac{(2 \text{ kg/s})(0.1889 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(500 \text{ K})}{(3000 \text{ kPa})} = \mathbf{0.06297 \text{ m}^3/\text{kg} \text{ (2.1\% error)}}$$

$$\rho_1 = \frac{P_1}{RT_1} = \frac{(3000 \text{ kPa})}{(0.1889 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(500 \text{ K})} = \mathbf{31.76 \text{ kg/m}^3 \text{ (2.1\% error)}}$$

$$\dot{V}_2 = \frac{\dot{m}RT_2}{P_2} = \frac{(2 \text{ kg/s})(0.1889 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(450 \text{ K})}{(3000 \text{ kPa})} = \mathbf{0.05667 \text{ m}^3/\text{kg} \text{ (3.6\% error)}}$$

(b) From the compressibility chart (EES function for compressibility factor is used)

$$\left. \begin{aligned} P_R &= \frac{P_1}{P_{cr}} = \frac{3 \text{ MPa}}{7.39 \text{ MPa}} = 0.407 \\ T_{R,1} &= \frac{T_1}{T_{cr}} = \frac{500 \text{ K}}{304.2 \text{ K}} = 1.64 \end{aligned} \right\} Z_1 = 0.9791$$

$$\left. \begin{aligned} P_R &= \frac{P_2}{P_{cr}} = \frac{3 \text{ MPa}}{7.39 \text{ MPa}} = 0.407 \\ T_{R,2} &= \frac{T_2}{T_{cr}} = \frac{450 \text{ K}}{304.2 \text{ K}} = 1.48 \end{aligned} \right\} Z_2 = 0.9656$$

Thus,
$$\dot{V}_1 = \frac{Z_1 \dot{m}RT_1}{P_1} = \frac{(0.9791)(2 \text{ kg/s})(0.1889 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(500 \text{ K})}{(3000 \text{ kPa})} = \mathbf{0.06165 \text{ m}^3/\text{kg}}$$

$$\rho_1 = \frac{P_1}{Z_1 RT_1} = \frac{(3000 \text{ kPa})}{(0.9791)(0.1889 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(500 \text{ K})} = \mathbf{32.44 \text{ kg/m}^3}$$

$$\dot{V}_2 = \frac{Z_2 \dot{m}RT_2}{P_2} = \frac{(0.9656)(2 \text{ kg/s})(0.1889 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(450 \text{ K})}{(3000 \text{ kPa})} = \mathbf{0.05472 \text{ m}^3/\text{kg}}$$

Other Equations of State

4-100C The constant a represents the increase in pressure as a result of intermolecular forces; the constant b represents the volume occupied by the molecules. They are determined from the requirement that the critical isotherm has an inflection point at the critical point.

4-101E Carbon dioxide is heated in a constant pressure apparatus. The final volume of the carbon dioxide is to be determined using the ideal gas equation and the Benedict-Webb-Rubin equation of state.

Properties The gas constant and molar mass of CO₂ are (Table A-1E)

$$R = 0.2438 \text{ psia}\cdot\text{ft}^3/\text{lbm}\cdot\text{R}, \quad M = 44.01 \text{ lbm/lbmol}$$

Analysis (a) From the ideal gas equation of state,

$$v_2 = \frac{mRT_2}{P} = \frac{(1 \text{ lbm})(0.2438 \text{ psia}\cdot\text{ft}^3/\text{lbm}\cdot\text{R})(1260 \text{ R})}{1000 \text{ psia}} = \mathbf{0.3072 \text{ ft}^3}$$

(b) Using the coefficients of Table 4-4 for carbon dioxide and the given data in SI units, the Benedict-Webb-Rubin equation of state for state 2 is

$$P_2 = \frac{R_u T_2}{\bar{v}_2} + \left(B_0 R_u T_2 - A_0 - \frac{C_0}{T_2} \right) \frac{1}{\bar{v}_2^2} + \frac{b R_u T_2 - a}{\bar{v}_2^3} + \frac{a\alpha}{\bar{v}_2^6} + \frac{c}{\bar{v}_2^3 T_2} \left(1 + \frac{\gamma}{\bar{v}_2^2} \right) \exp(-\gamma/\bar{v}_2^2)$$

$$6895 = \frac{(8.314)(700)}{\bar{v}_2} + \left(0.04991 \times 8.314 \times 700 - 277.30 - \frac{1.404 \times 10^7}{700^2} \right) \frac{1}{\bar{v}_2^2} + \frac{0.007210 \times 8.314 \times 700 - 13.86}{\bar{v}_2^3}$$

$$+ \frac{13.86 \times 8.470 \times 10^{-5}}{\bar{v}_2^6} + \frac{1.511 \times 10^6}{\bar{v}_2^3 (700)^2} \left(1 + \frac{0.00539}{\bar{v}_2^2} \right) \exp(-0.00539/\bar{v}_2^2)$$

The solution of this equation by an equation solver such as EES gives

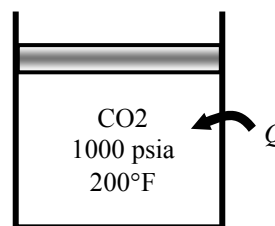
$$\bar{v}_2 = 0.8477 \text{ m}^3/\text{kmol}$$

Then,

$$v_2 = \frac{\bar{v}_2}{M} = \frac{0.8477 \text{ m}^3/\text{kmol}}{44.01 \text{ kg/kmol}} = 0.01926 \text{ m}^3/\text{kg}$$

$$V_2 = m v_2 = (1/2.2046 \text{ kg})(0.01926 \text{ m}^3/\text{kg}) = 0.008741 \text{ m}^3$$

$$= (0.008741 \text{ m}^3) \left(\frac{35.315 \text{ ft}^3}{1 \text{ m}^3} \right) = \mathbf{0.3087 \text{ ft}^3}$$



4-102 Methane is heated in a rigid container. The final pressure of the methane is to be determined using the ideal gas equation and the Benedict-Webb-Rubin equation of state.

Analysis (a) From the ideal gas equation of state,

$$P_2 = P_1 \frac{T_2}{T_1} = (100 \text{ kPa}) \frac{673 \text{ K}}{293 \text{ K}} = \mathbf{229.7 \text{ kPa}}$$

The specific molar volume of the methane is

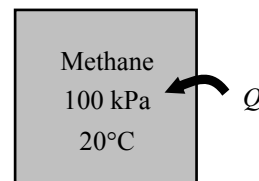
$$\bar{v}_1 = \bar{v}_2 = \frac{R_u T_1}{P_1} = \frac{(8.314 \text{ kPa} \cdot \text{m}^3/\text{kmol} \cdot \text{K})(293 \text{ K})}{100 \text{ kPa}} = 24.36 \text{ m}^3/\text{kmol}$$

(b) The specific molar volume of the methane is

$$\bar{v}_1 = \bar{v}_2 = \frac{R_u T_1}{P_1} = \frac{(8.314 \text{ kPa} \cdot \text{m}^3/\text{kmol} \cdot \text{K})(293 \text{ K})}{100 \text{ kPa}} = 24.36 \text{ m}^3/\text{kmol}$$

Using the coefficients of Table 4-4 for methane and the given data, the Benedict-Webb-Rubin equation of state for state 2 gives

$$\begin{aligned} P_2 &= \frac{R_u T_2}{\bar{v}_2} + \left(B_0 R_u T_2 - A_0 - \frac{C_0}{T_2} \right) \frac{1}{\bar{v}_2^2} + \frac{b R_u T_2 - a}{\bar{v}_2^3} + \frac{a \alpha}{\bar{v}_2^6} + \frac{c}{\bar{v}_2^3 T_2^2} \left(1 + \frac{\gamma}{\bar{v}_2^2} \right) \exp(-\gamma / \bar{v}_2^2) \\ &= \frac{(8.314)(673)}{24.36} + \left(0.04260 \times 8.314 \times 673 - 187.91 - \frac{2.286 \times 10^6}{673^2} \right) \frac{1}{24.36^2} + \frac{0.003380 \times 8.314 \times 673 - 5.00}{24.36^3} \\ &\quad + \frac{5.00 \times 1.244 \times 10^{-4}}{24.36^6} + \frac{2.578 \times 10^5}{24.36^3 (673)^2} \left(1 + \frac{0.0060}{24.36^2} \right) \exp(-0.0060 / 24.36^2) \\ &= \mathbf{229.8 \text{ kPa}} \end{aligned}$$



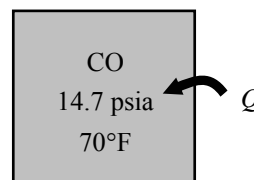
4-103E Carbon monoxide is heated in a rigid container. The final pressure of the CO is to be determined using the ideal gas equation and the Benedict-Webb-Rubin equation of state.

Properties The gas constant and molar mass of CO are (Table A-1)

$$R = 0.2968 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K}, \quad M = 28.011 \text{ kg/kmol}$$

Analysis (a) From the ideal gas equation of state,

$$P_2 = P_1 \frac{T_2}{T_1} = (14.7 \text{ psia}) \frac{1260 \text{ R}}{530 \text{ R}} = \mathbf{34.95 \text{ psia}}$$



The specific molar volume of the CO in SI units is

$$\bar{v}_1 = \bar{v}_2 = \frac{R_u T_1}{P_1} = \frac{(8.314 \text{ kPa}\cdot\text{m}^3/\text{kmol}\cdot\text{K})(294 \text{ K})}{101 \text{ kPa}} = 24.20 \text{ m}^3/\text{kmol}$$

(b) The specific molar volume of the CO in SI units is

$$\bar{v}_1 = \bar{v}_2 = \frac{R_u T_1}{P_1} = \frac{(8.314 \text{ kPa}\cdot\text{m}^3/\text{kmol}\cdot\text{K})(294 \text{ K})}{101 \text{ kPa}} = 24.20 \text{ m}^3/\text{kmol}$$

Using the coefficients of Table 4-4 for CO and the given data, the Benedict-Webb-Rubin equation of state for state 2 gives

$$\begin{aligned} P_2 &= \frac{R_u T_2}{\bar{v}_2} + \left(B_0 R_u T_2 - A_0 - \frac{C_0}{T_2^2} \right) \frac{1}{\bar{v}_2^2} + \frac{b R_u T_2 - a}{\bar{v}_2^3} + \frac{a \alpha}{\bar{v}_2^6} + \frac{c}{\bar{v}_2^3 T_2^2} \left(1 + \frac{\gamma}{\bar{v}_2^2} \right) \exp(-\gamma / \bar{v}_2^2) \\ &= \frac{(8.314)(700)}{24.20} + \left(0.05454 \times 8.314 \times 700 - 135.87 - \frac{8.673 \times 10^5}{700^2} \right) \frac{1}{24.20^2} + \frac{0.002632 \times 8.314 \times 700 - 3.71}{24.20^3} \\ &\quad + \frac{3.71 \times 1.350 \times 10^{-4}}{24.20^6} + \frac{1.054 \times 10^5}{24.20^3 (700)^2} \left(1 + \frac{0.0060}{24.20^2} \right) \exp(-0.0060 / 24.20^2) \\ &= 240.8 \text{ kPa} \end{aligned}$$

The pressure in English unit is

$$P_2 = (240.8 \text{ kPa}) \left(\frac{1 \text{ psia}}{6.8948 \text{ kPa}} \right) = \mathbf{34.92 \text{ psia}}$$

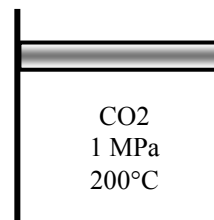
4-104 Carbon dioxide is compressed in a piston-cylinder device in a polytropic process. The final temperature is to be determined using the ideal gas and van der Waals equations.

Properties The gas constant, molar mass, critical pressure, and critical temperature of carbon dioxide are (Table A-1)

$$R = 0.1889 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K}, \quad M = 44.01 \text{ kg/kmol}, \quad T_{\text{cr}} = 304.2 \text{ K}, \quad P_{\text{cr}} = 7.39 \text{ MPa}$$

Analysis (a) The specific volume at the initial state is

$$\nu_1 = \frac{RT_1}{P_1} = \frac{(0.1889 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(473 \text{ K})}{1000 \text{ kPa}} = 0.08935 \text{ m}^3/\text{kg}$$



According to process specification,

$$\nu_2 = \nu_1 \left(\frac{P_1}{P_2} \right)^{1/n} = (0.08935 \text{ m}^3/\text{kg}) \left(\frac{1000 \text{ kPa}}{3000 \text{ kPa}} \right)^{1/1.2} = 0.03577 \text{ m}^3/\text{kg}$$

The final temperature is then

$$T_2 = \frac{P_2 \nu_2}{R} = \frac{(3000 \text{ kPa})(0.03577 \text{ m}^3/\text{kg})}{0.1889 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K}} = \mathbf{568 \text{ K}}$$

(b) The van der Waals constants for carbon dioxide are determined from

$$a = \frac{27R^2 T_{\text{cr}}^2}{64P_{\text{cr}}} = \frac{(27)(0.1889 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})^2 (304.2 \text{ K})^2}{(64)(7390 \text{ kPa})} = 0.1885 \text{ m}^6 \cdot \text{kPa}/\text{kg}^2$$

$$b = \frac{RT_{\text{cr}}}{8P_{\text{cr}}} = \frac{(0.1889 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(304.2 \text{ K})}{8 \times 7390 \text{ kPa}} = 0.0009720 \text{ m}^3/\text{kg}$$

Applying the van der Waals equation to the initial state,

$$\left(P + \frac{a}{\nu^2} \right) (\nu - b) = RT$$

$$\left(1000 + \frac{0.1885}{\nu^2} \right) (\nu - 0.0009720) = (0.1889)(473)$$

Solving this equation by trial-error or by EES gives

$$\nu_1 = 0.08821 \text{ m}^3/\text{kg}$$

According to process specification,

$$\nu_2 = \nu_1 \left(\frac{P_1}{P_2} \right)^{1/n} = (0.08821 \text{ m}^3/\text{kg}) \left(\frac{1000 \text{ kPa}}{3000 \text{ kPa}} \right)^{1/1.2} = 0.03531 \text{ m}^3/\text{kg}$$

Applying the van der Waals equation to the final state,

$$\left(P + \frac{a}{\nu^2} \right) (\nu - b) = RT$$

$$\left(3000 + \frac{0.1885}{0.03531^2} \right) (0.03531 - 0.0009720) = (0.1889)T$$

Solving for the final temperature gives

$$T_2 = \mathbf{573 \text{ K}}$$

4-105E The temperature of R-134a in a tank at a specified state is to be determined using the ideal gas relation, the van der Waals equation, and the refrigerant tables.

Properties The gas constant, critical pressure, and critical temperature of R-134a are (Table A-1E)

$$R = 0.1052 \text{ psia}\cdot\text{ft}^3/\text{lbm}\cdot\text{R}, \quad T_{cr} = 673.6 \text{ R}, \quad P_{cr} = 588.7 \text{ psia}$$

Analysis (a) From the ideal gas equation of state,

$$T = \frac{P\nu}{R} = \frac{(100 \text{ psia})(0.54022 \text{ ft}^3/\text{lbm})}{0.1052 \text{ psia}\cdot\text{ft}^3/\text{lbm}\cdot\text{R}} = \mathbf{513.5 \text{ R}}$$

(b) The van der Waals constants for the refrigerant are determined from

$$a = \frac{27R^2T_{cr}^2}{64P_{cr}} = \frac{(27)(0.1052 \text{ psia}\cdot\text{ft}^3/\text{lbm}\cdot\text{R})^2(673.6 \text{ R})^2}{(64)(588.7 \text{ psia})} = 3.591 \text{ ft}^6\cdot\text{psia}/\text{lbm}^2$$

$$b = \frac{RT_{cr}}{8P_{cr}} = \frac{(0.1052 \text{ psia}\cdot\text{ft}^3/\text{lbm}\cdot\text{R})(673.6 \text{ R})}{8 \times 588.7 \text{ psia}} = 0.0150 \text{ ft}^3/\text{lbm}$$

$$\text{Then, } T = \frac{1}{R} \left(P + \frac{a}{\nu^2} \right) (\nu - b) = \frac{1}{0.1052} \left(100 + \frac{3.591}{(0.54022)^2} \right) (0.54022 - 0.0150) = \mathbf{560.7 \text{ R}}$$

(c) From the superheated refrigerant table (Table A-13E),

$$\left. \begin{array}{l} P = 100 \text{ psia} \\ \nu = 0.54022 \text{ ft}^3/\text{lbm} \end{array} \right\} T = \mathbf{120^\circ\text{F}} \quad (580\text{R})$$

4-106 CD EES The pressure of nitrogen in a tank at a specified state is to be determined using the ideal gas relation and the Beattie-Bridgeman equation. The error involved in each case is to be determined.

Properties The gas constant and molar mass of nitrogen are (Table A-1)

$$R = 0.2968 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K} \quad \text{and} \quad M = 28.013 \text{ kg/kmol}$$

Analysis (a) From the ideal gas equation of state,

$$P = \frac{RT}{\nu} = \frac{(0.2968 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(150 \text{ K})}{0.041884 \text{ m}^3/\text{kg}} = \mathbf{1063 \text{ kPa}} \quad (6.3\% \text{ error})$$

N_2 $0.041884 \text{ m}^3/\text{kg}$ 150 K

(b) The constants in the Beattie-Bridgeman equation are

$$A = A_o \left(1 - \frac{a}{\bar{\nu}} \right) = 136.2315 \left(1 - \frac{0.02617}{1.1733} \right) = 133.193$$

$$B = B_o \left(1 - \frac{b}{\bar{\nu}} \right) = 0.05046 \left(1 - \frac{-0.00691}{1.1733} \right) = 0.05076$$

$$c = 4.2 \times 10^4 \text{ m}^3 \cdot \text{K}^3/\text{kmol}$$

since $\bar{\nu} = M\nu = (28.013 \text{ kg/kmol})(0.041884 \text{ m}^3/\text{kg}) = 1.1733 \text{ m}^3/\text{kmol}$.

Substituting,

$$P = \frac{R_u T}{\bar{\nu}^2} \left(1 - \frac{c}{\bar{\nu} T^3} \right) (\bar{\nu} + B) - \frac{A}{\bar{\nu}^2} = \frac{8.314 \times 150}{(1.1733)^2} \left(1 - \frac{4.2 \times 10^4}{1.1733 \times 150^3} \right) (1.1733 + 0.05076) - \frac{133.193}{(1.1733)^2}$$

$$= \mathbf{1000.4 \text{ kPa}} \quad (\text{negligible error})$$

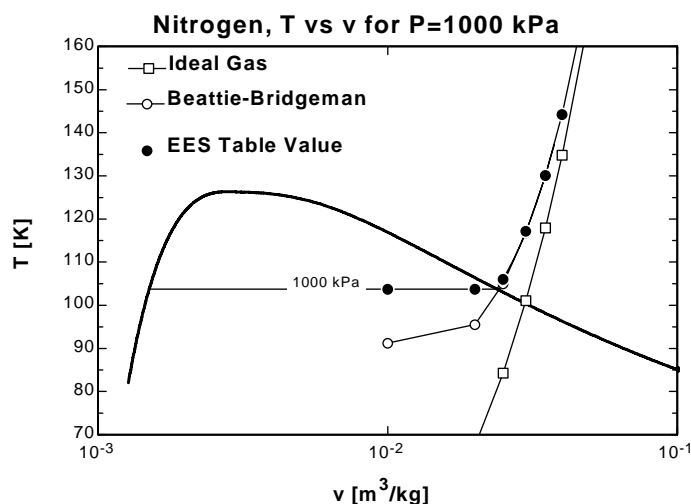
4-107 EES Problem 4-106 is reconsidered. Using EES (or other) software, the pressure results of the ideal gas and Beattie-Bridgeman equations with nitrogen data supplied by EES are to be compared. The temperature is to be plotted versus specific volume for a pressure of 1000 kPa with respect to the saturated liquid and saturated vapor lines of nitrogen over the range of $110 \text{ K} < T < 150 \text{ K}$.

Analysis The problem is solved using EES, and the solution is given below.

```
Function BeattBridg(T,v,M,R_u)
v_bar=v*M "Conversion from m^3/kg to m^3/kmol"
"The constants for the Beattie-Bridgeman equation of state are found in text"
Ao=136.2315; aa=0.02617; Bo=0.05046; bb=-0.00691; cc=4.20*1E4
B=Bo*(1-bb/v_bar)
A=Ao*(1-aa/v_bar)
"The Beattie-Bridgeman equation of state is"
BeattBridg:=R_u*T/(v_bar**2)*(1-cc/(v_bar*T**3))*(v_bar+B)-A/v_bar**2
End

T=150 [K]
v=0.041884 [m^3/kg]
P_exper=1000 [kPa]
T_table=T; T_BB=T;T_idealgas=T
P_table=PRESSURE(Nitrogen,T=T_table,v=v) "EES data for nitrogen as a real gas"
{T_table=temperature(Nitrogen, P=P_table,v=v)}
M=MOLARMASS(Nitrogen)
R_u=8.314 [kJ/kmol-K] "Universal gas constant"
R=R_u/M "Particular gas constant"
P_idealgas=R*T_idealgas/v "Ideal gas equation"
P_BB=BeattBridg(T_BB,v,M,R_u) "Beattie-Bridgeman equation of state Function"
```

P_{BB} [kPa]	P_{table} [kPa]	$P_{idealgas}$ [kPa]	v [m ³ /kg]	T_{BB} [K]	$T_{ideal\ gas}$ [K]	T_{table} [K]
1000	1000	1000	0.01	91.23	33.69	103.8
1000	1000	1000	0.02	95.52	67.39	103.8
1000	1000	1000	0.025	105	84.23	106.1
1000	1000	1000	0.03	116.8	101.1	117.2
1000	1000	1000	0.035	130.1	117.9	130.1
1000	1000	1000	0.04	144.4	134.8	144.3
1000	1000	1000	0.05	174.6	168.5	174.5



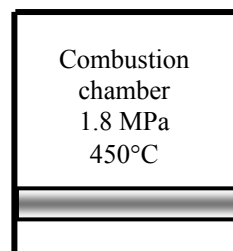
Review Problems

4-108 The cylinder conditions before the heat addition process is specified. The pressure after the heat addition process is to be determined.

Assumptions 1 The contents of cylinder are approximated by the air properties. **2** Air is an ideal gas.

Analysis The final pressure may be determined from the ideal gas relation

$$P_2 = \frac{T_2}{T_1} P_1 = \left(\frac{1300 + 273 \text{ K}}{450 + 273 \text{ K}} \right) (1800 \text{ kPa}) = \mathbf{3916 \text{ kPa}}$$



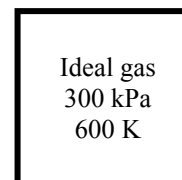
4-109 A rigid tank contains an ideal gas at a specified state. The final temperature is to be determined for two different processes.

Analysis (a) The first case is a constant volume process. When half of the gas is withdrawn from the tank, the final temperature may be determined from the ideal gas relation as

$$T_2 = \frac{m_1}{m_2} \frac{P_2}{P_1} T_1 = (2) \left(\frac{100 \text{ kPa}}{300 \text{ kPa}} \right) (600 \text{ K}) = \mathbf{400 \text{ K}}$$

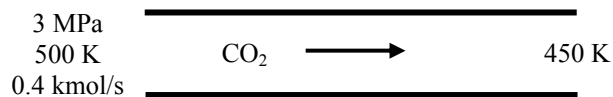
(b) The second case is a constant volume and constant mass process. The ideal gas relation for this case yields

$$P_2 = \frac{T_2}{T_1} P_1 = \left(\frac{400 \text{ K}}{600 \text{ K}} \right) (300 \text{ kPa}) = \mathbf{200 \text{ kPa}}$$



4-110 Carbon dioxide flows through a pipe at a given state. The volume and mass flow rates and the density of CO₂ at the given state and the volume flow rate at the exit of the pipe are to be determined.

Analysis (a) The volume and mass flow rates may be determined from ideal gas relation as



$$\dot{V}_1 = \frac{\dot{N}R_u T_1}{P} = \frac{(0.4 \text{ kmol/s})(8.314 \text{ kPa}\cdot\text{m}^3/\text{kmol}\cdot\text{K})(500 \text{ K})}{3000 \text{ kPa}} = \mathbf{0.5543 \text{ m}^3/\text{s}}$$

$$\dot{m}_1 = \frac{P_1 \dot{V}_1}{RT_1} = \frac{(3000 \text{ kPa})(0.5543 \text{ m}^3/\text{s})}{(0.1889 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(500 \text{ K})} = \mathbf{17.60 \text{ kg/s}}$$

The density is

$$\rho_1 = \frac{\dot{m}_1}{\dot{V}_1} = \frac{(17.60 \text{ kg/s})}{(0.5543 \text{ m}^3/\text{s})} = \mathbf{31.76 \text{ kg/m}^3}$$

(b) The volume flow rate at the exit is

$$\dot{V}_2 = \frac{\dot{N}R_u T_2}{P} = \frac{(0.4 \text{ kmol/s})(8.314 \text{ kPa}\cdot\text{m}^3/\text{kmol}\cdot\text{K})(450 \text{ K})}{3000 \text{ kPa}} = \mathbf{0.4988 \text{ m}^3/\text{s}}$$

4-111 The cylinder conditions before the heat addition process is specified. The temperature after the heat addition process is to be determined.

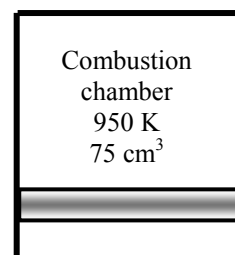
Assumptions 1 The contents of cylinder is approximated by the air properties. **2** Air is an ideal gas.

Analysis The ratio of the initial to the final mass is

$$\frac{m_1}{m_2} = \frac{AF}{AF+1} = \frac{22}{22+1} = \frac{22}{23}$$

The final temperature may be determined from ideal gas relation

$$T_2 = \frac{m_1}{m_2} \frac{V_2}{V_1} T_1 = \left(\frac{22}{23}\right) \left(\frac{150 \text{ cm}^3}{75 \text{ cm}^3}\right) (950 \text{ K}) = \mathbf{1817 \text{ K}}$$



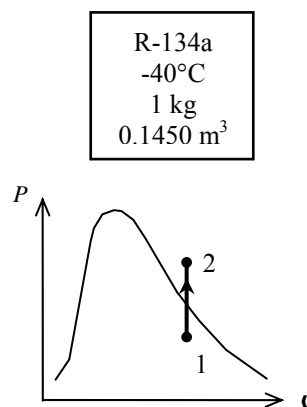
4-112 A rigid container that is filled with R-134a is heated. The initial pressure and the final temperature are to be determined.

Analysis The initial specific volume is $0.1450 \text{ m}^3/\text{kg}$. Using this with the initial temperature reveals that the initial state is a mixture. The initial pressure is then the saturation pressure,

$$\left. \begin{array}{l} T_1 = -40^\circ\text{C} \\ \nu_1 = 0.1450 \text{ m}^3/\text{kg} \end{array} \right\} P_1 = P_{\text{sat}@-40^\circ\text{C}} = \mathbf{51.25 \text{ kPa}} \quad (\text{Table A - 11})$$

This is a constant volume cooling process ($\nu = \nu/m = \text{constant}$). The final state is superheated vapor and the final temperature is then

$$\left. \begin{array}{l} P_2 = 200 \text{ kPa} \\ \nu_2 = \nu_1 = 0.1450 \text{ m}^3/\text{kg} \end{array} \right\} T_2 = \mathbf{90^\circ\text{C}} \quad (\text{Table A - 13})$$



4-113E A piston-cylinder device that is filled with water is cooled. The final pressure and volume of the water are to be determined.

Analysis The initial specific volume is

$$\nu_1 = \frac{V_1}{m} = \frac{2.649 \text{ ft}^3}{1 \text{ lbm}} = 2.649 \text{ ft}^3/\text{lbm}$$

This is a constant-pressure process. The initial state is determined to be superheated vapor and thus the pressure is determined to be

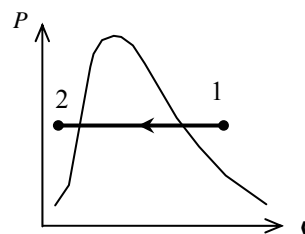
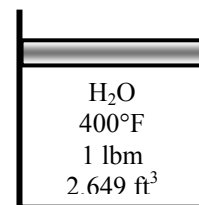
$$\left. \begin{array}{l} T_1 = 400^\circ\text{F} \\ \nu_1 = 2.649 \text{ ft}^3/\text{lbm} \end{array} \right\} P_1 = P_2 = \mathbf{180 \text{ psia}} \quad (\text{Table A - 6E})$$

The saturation temperature at 180 psia is 373.1°F . Since the final temperature is less than this temperature, the final state is compressed liquid. Using the incompressible liquid approximation,

$$\nu_2 = \nu_f @ 100^\circ\text{F} = 0.01613 \text{ ft}^3/\text{lbm} \quad (\text{Table A - 4E})$$

The final volume is then

$$V_2 = m\nu_2 = (1 \text{ lbm})(0.01613 \text{ ft}^3/\text{lbm}) = \mathbf{0.01613 \text{ ft}^3}$$



4-114 The volume of chamber 1 of the two-piston cylinder shown in the figure is to be determined.

Assumptions At specified conditions, helium behaves as an ideal gas.

Properties The gas constant of helium is $R = 2.0769 \text{ kJ/kg}\cdot\text{K}$ (Table A-1).

Analysis Since the water vapor in chamber 2 is condensing, the pressure in this chamber is the saturation pressure,

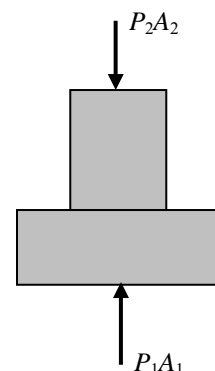
$$P_2 = P_{\text{sat}@200^\circ\text{C}} = 1555 \text{ kPa} \quad (\text{Table A-4})$$

Summing the forces acting on the piston in the vertical direction gives

$$P_1 = P_2 \frac{A_2}{A_1} = P_2 \left(\frac{D_2}{D_1} \right)^2 = (1555 \text{ kPa}) \left(\frac{4}{10} \right)^2 = 248.8 \text{ kPa}$$

According to the ideal gas equation of state,

$$V_1 = \frac{mRT}{P_1} = \frac{(1 \text{ kg})(2.0769 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(200 + 273 \text{ K})}{248.8 \text{ kPa}} = \mathbf{3.95 \text{ m}^3}$$



4-115 A propane tank contains 5 L of liquid propane at the ambient temperature. Now a leak develops at the top of the tank and propane starts to leak out. The temperature of propane when the pressure drops to 1 atm and the amount of heat transferred to the tank by the time the entire propane in the tank is vaporized are to be determined.

Properties The properties of propane at 1 atm are $T_{\text{sat}} = -42.1^\circ\text{C}$, $\rho = 581 \text{ kg/m}^3$, and $h_{fg} = 427.8 \text{ kJ/kg}$ (Table A-3).

Analysis The temperature of propane when the pressure drops to 1 atm is simply the saturation pressure at that temperature,

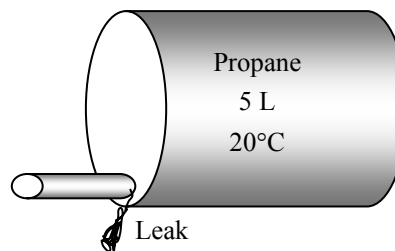
$$T = T_{\text{sat}@1 \text{ atm}} = \mathbf{-42.1^\circ\text{C}}$$

The initial mass of liquid propane is

$$m = \rho V = (581 \text{ kg/m}^3)(0.005 \text{ m}^3) = 2.905 \text{ kg}$$

The amount of heat absorbed is simply the total heat of vaporization,

$$Q_{\text{absorbed}} = mh_{fg} = (2.905 \text{ kg})(427.8 \text{ kJ/kg}) = \mathbf{1243 \text{ kJ}}$$



4-116 An isobutane tank contains 5 L of liquid isobutane at the ambient temperature. Now a leak develops at the top of the tank and isobutane starts to leak out. The temperature of isobutane when the pressure drops to 1 atm and the amount of heat transferred to the tank by the time the entire isobutane in the tank is vaporized are to be determined.

Properties The properties of isobutane at 1 atm are $T_{\text{sat}} = -11.7^\circ\text{C}$, $\rho = 593.8 \text{ kg/m}^3$, and $h_{\text{fg}} = 367.1 \text{ kJ/kg}$ (Table A-3).

Analysis The temperature of isobutane when the pressure drops to 1 atm is simply the saturation pressure at that temperature,

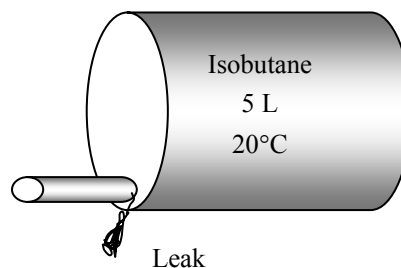
$$T = T_{\text{sat}@1 \text{ atm}} = -11.7^\circ\text{C}$$

The initial mass of liquid isobutane is

$$m = \rho V = (593.8 \text{ kg/m}^3)(0.005 \text{ m}^3) = 2.969 \text{ kg}$$

The amount of heat absorbed is simply the total heat of vaporization,

$$Q_{\text{absorbed}} = mh_{\text{fg}} = (2.969 \text{ kg})(367.1 \text{ kJ/kg}) = \mathbf{1090 \text{ kJ}}$$



4-117 A tank contains helium at a specified state. Heat is transferred to helium until it reaches a specified temperature. The final gage pressure of the helium is to be determined.

Assumptions 1 Helium is an ideal gas.

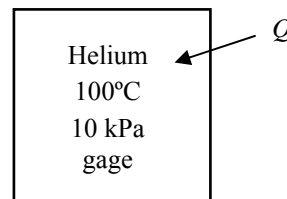
Properties The local atmospheric pressure is given to be 100 kPa.

Analysis Noting that the specific volume of helium in the tank remains constant, from ideal gas relation, we have

$$P_2 = P_1 \frac{T_2}{T_1} = (10 + 100 \text{ kPa}) \frac{(300 + 273)\text{K}}{(100 + 273)\text{K}} = 169.0 \text{ kPa}$$

Then the gage pressure becomes

$$P_{\text{gage},2} = P_2 - P_{\text{atm}} = 169.0 - 100 = \mathbf{69.0 \text{ kPa}}$$



4-118 ... 4-119 Design and Essay Problems

