

Chapter 3

PROPERTIES OF PURE SUBSTANCES

Pure Substances, Phase Change Processes, Property Diagrams

3-1C Yes. Because it has the same chemical composition throughout.

3-2C A liquid that is about to vaporize is saturated liquid; otherwise it is compressed liquid.

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

3-4C No.

3-5C No.

3-6C Yes. The saturation temperature of a pure substance depends on pressure. The higher the pressure, the higher the saturation or boiling temperature.

3-7C The temperature will also increase since the boiling or saturation temperature of a pure substance depends on pressure.

3-8C Because one cannot be varied while holding the other constant. In other words, when one changes, so does the other one.

3-9C 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.

3-10C Yes.

3-11C 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.

3-12C 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

3-13C A given volume of water will boil at a higher temperature in a **tall and narrow pot** since the pressure at the bottom (and thus the corresponding saturation pressure) will be higher in that case.

3-14C 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.

3-15C 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 can will most likely settle down instead of rising in a cooler environment

3-16C 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.

3-17C Yes. Otherwise we can create energy by alternately vaporizing and condensing a substance.

3-18C No. Because in the thermodynamic analysis we deal with the changes in properties; and the changes are independent of the selected reference state.

3-19C 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 $h_{fg} = h_g - h_f$.

3-20C Yes; the higher the temperature the lower the h_{fg} value.

3-21C Quality is the fraction of vapor in a saturated liquid-vapor mixture. It has no meaning in the superheated vapor region.

3-22C Completely vaporizing 1 kg of saturated liquid at 1 atm pressure since the higher the pressure, the lower the h_{fg} .

3-23C Yes. It decreases with increasing pressure and becomes zero at the critical pressure.

3-24C No. Quality is a mass ratio, and it is not identical to the volume ratio.

3-25C The compressed liquid can be approximated as a saturated liquid at the given temperature. Thus $V_{T,P} \cong V_{f@T}$.

3-26 [Also solved by EES on enclosed CD] Complete the following table for H_2O .

$T, ^\circ\text{C}$	P, kPa	$v, \text{m}^3/\text{kg}$	Phase description
50	12.349	4.16	Saturated mixture
120.23	200	0.8857	Saturated vapor
250	400	0.5951	Superheated vapor
110	600	0.001052	Compressed liquid

3-27 Problem 3-26 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.

\$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=xxx F2', 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, m^3/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)

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        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$,p=p,x=x)
        v=volume(Fluid$,p=p,x=x)
        u=IntEnergy(Fluid$,p=p,x=x)
    endif
Endif
If Prop1$='Enthalpy, kJ/kg' Then
    h=Value1

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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$,h=h,x=x)
endif
endif
If Prop1$='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)
    
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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

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value2=101.3}

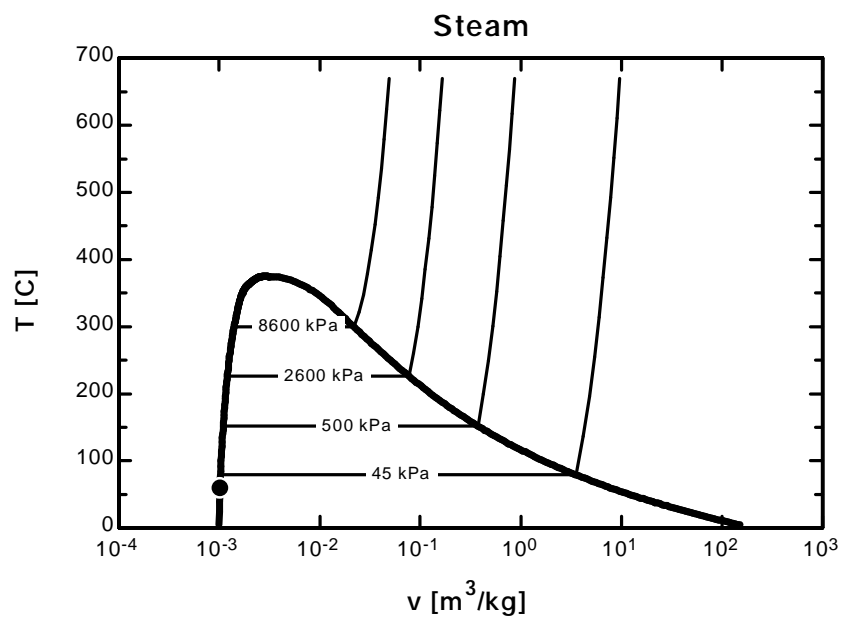
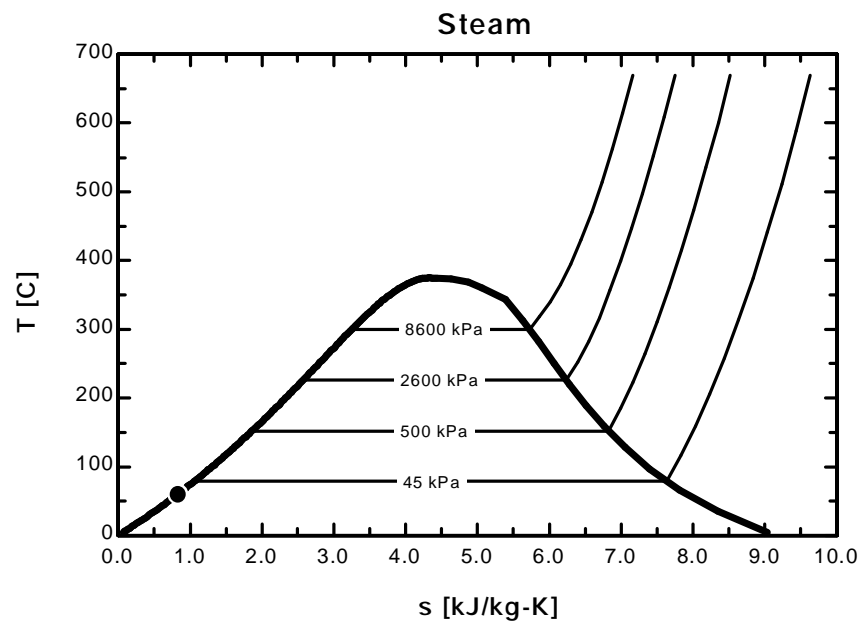
Call Find(Fluid\$,Prop1\$,Prop2\$,Value1,Value2:T,p,h,s,v,u,x,State\$)

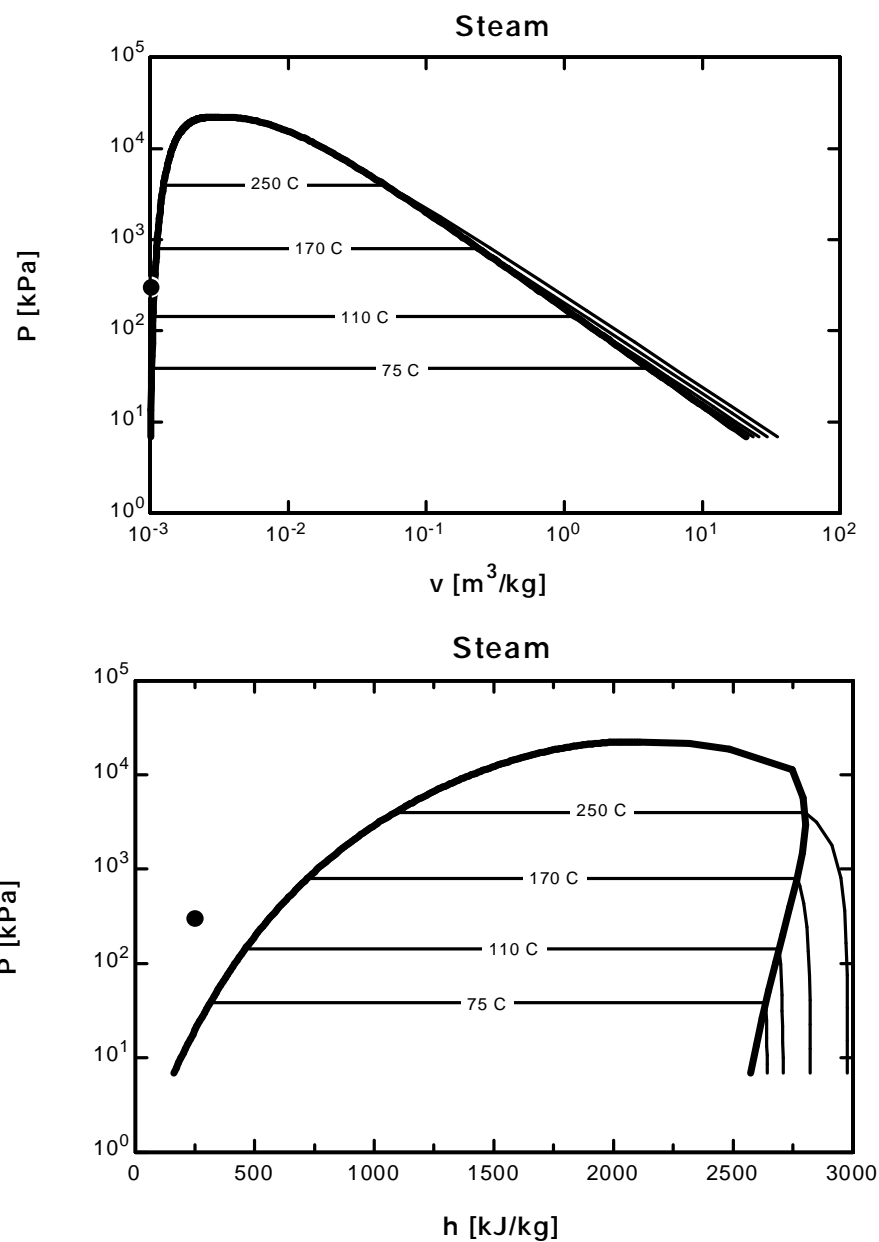
T[1]=T ; p[1]=p ; h[1]=h ; s[1]=s ; v[1]=v ; u[1]=u ; x[1]=x

"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	400	7.378	250	2726	0.5951	100





3-28E Complete the following table for H_2O .

T, °F	P, psia	u , Btu / lbm	Phase description
300	66.98	782	Saturated mixture
267.26	40	236.03	Saturated liquid
500	120	1174.2	Superheated vapor
400	400	374.27	Compressed liquid

3-29E Problem 3-28E 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.

\$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, F' Then

 T=Value1

 If Prop2\$='Temperature, F' then Call Error('Both properties cannot be Temperature, T=xxx F2', T)

 if Prop2\$='Pressure, psia' 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, Btu/lbm' 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, Btu/lbm-R' 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, ft^3/lbm' 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, Btu/lbm' 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)

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        u=IntEnergy(Fluid$,T=T,x=x)
    endif
Endif
If Prop1$='Pressure, psia' Then
    p=Value1
    If Prop2$='Pressure, psia' then Call Error('Both properties cannot be Pressure, p=xxxF2',p)
    if Prop2$='Temperature, F' 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, Btu/lbm' 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, Btu/lbm-R' 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, ft^3/lbm' 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, Btu/lbm' 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$,p=p,x=x)
        v=volume(Fluid$,p=p,x=x)
        u=IntEnergy(Fluid$,p=p,x=x)
    endif
Endif
If Prop1$='Enthalpy, Btu/lbm' Then
    h=Value1

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If Prop2$='Enthalpy, Btu/lbm' then Call Error('Both properties cannot be Enthalpy,
h=xxxF2',h)
if Prop2$='Pressure, psia' 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, F' 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, Btu/lbm-R' 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, ft^3/lbm' 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, Btu/lbm' 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$,h=h,x=x)
endif
endif
If Prop1$='Entropy, Btu/lbm-R' Then
    s=Value1
    If Prop2$='Entropy, Btu/lbm-R' then Call Error('Both properties cannot be Entrolpy,
h=xxxF2',s)
    if Prop2$='Pressure, psia' then
        p=value2

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    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, F' 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, Btu/lbm' 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, ft^3/lbm' 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, Btu/lbm' 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, F'

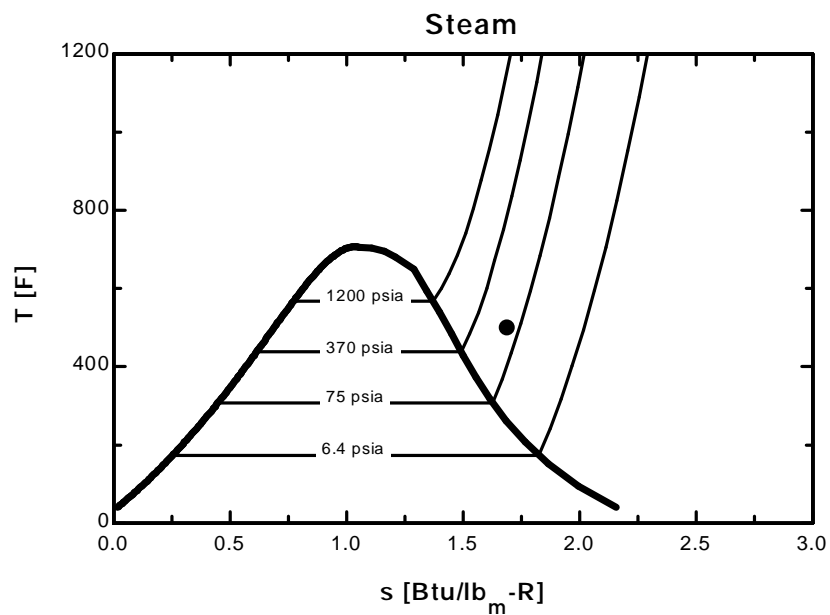
```
Prop2$='Pressure, psia'
Value1=230
value2=14.7}
```

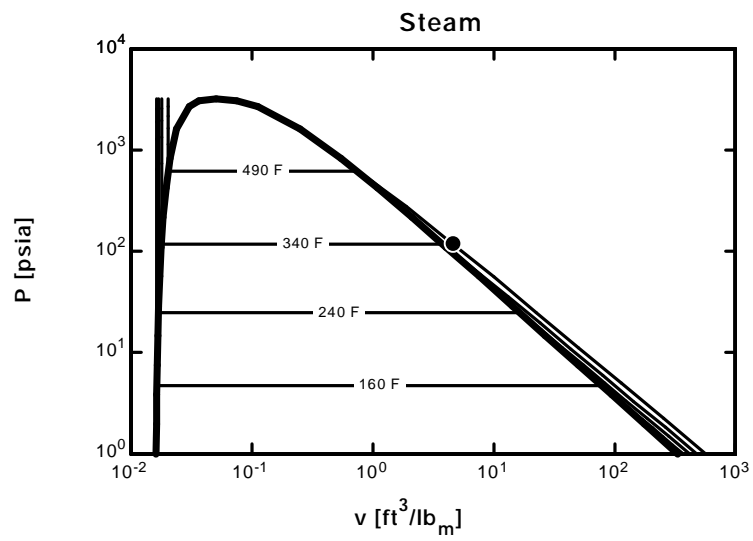
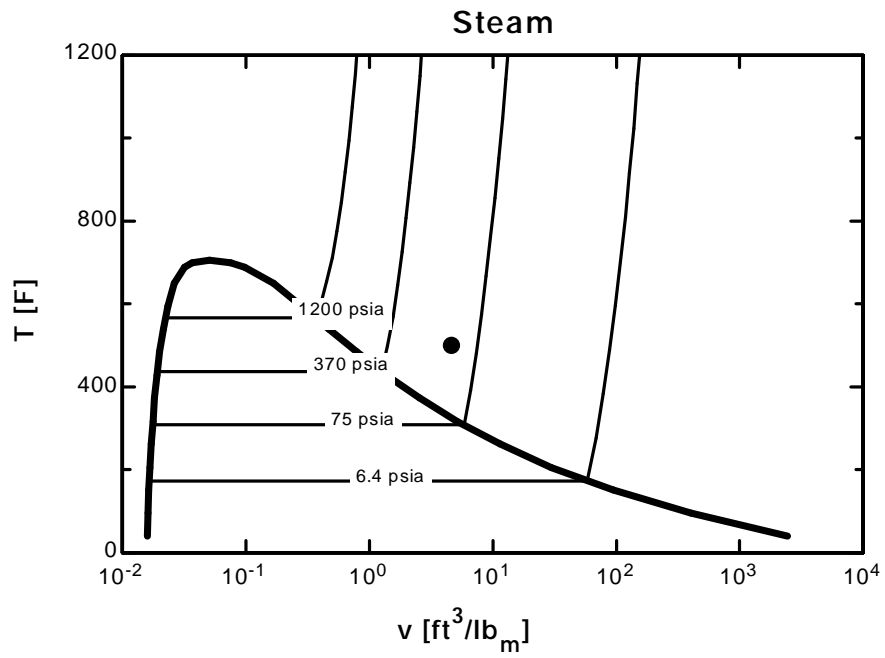
```
Call Find(Fluid$,Prop1$,Prop2$,Value1,Value2:T,p,h,s,v,u,x,State$)
```

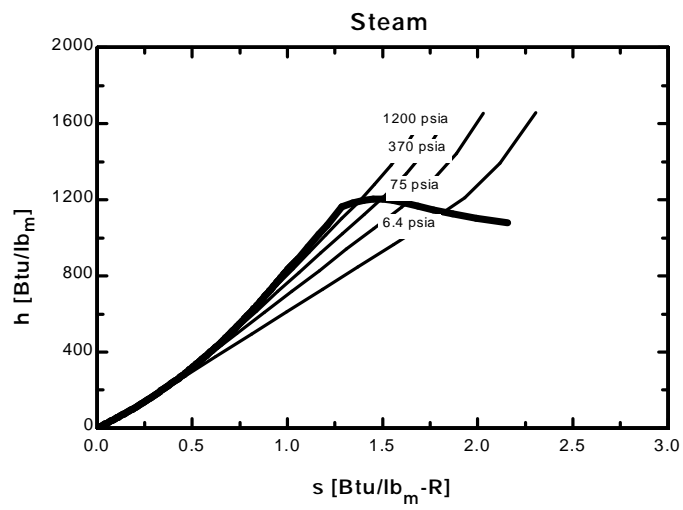
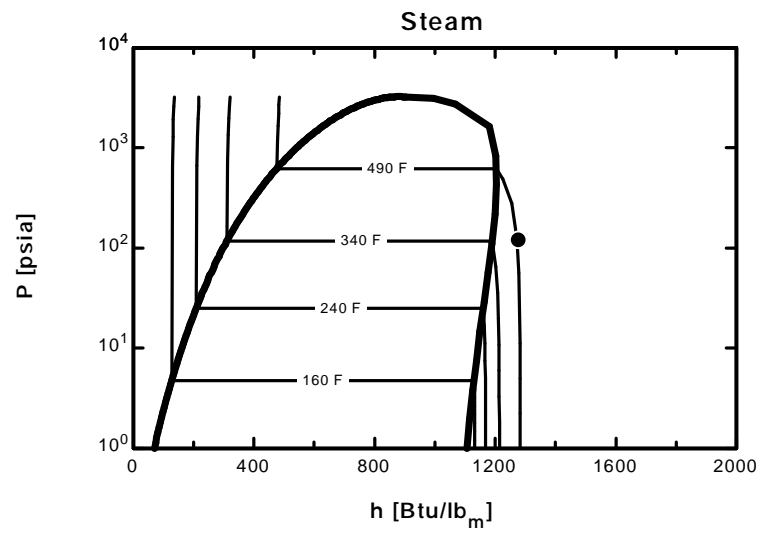
```
T[1]=T ; p[1]=p ; h[1]=h ; s[1]=s ; v[1]=v ; u[1]=u ; x[1]=x
"Array variables were used so the states can be plotted on property plots."
```

ARRAYS TABLE

h Btu/lb m	P psi a	s Btu/lbm R	T F	u Btu/lb m	v ft ³ /lb m	x
1277	120	1.686	500	1174	4.632	100







3-30 Complete the following table for H_2O .

T, °C	P, kPa	h , kJ / kg	x	Phase description
120.23	200	2046.0	0.7	<i>Saturated mixture</i>
140	361.3	1800	0.56	<i>Saturated mixture</i>
177.69	950	753.02	0.0	<i>Saturated liquid</i>
80	500	334.91	- - -	<i>Compressed liquid</i>
350	800	3161.7	- - -	<i>Superheated vapor</i>

3-31 Complete the following table for Refrigerant-134a.

T, °C	P, kPa	v , m ³ / kg	Phase description
-8	500	0.0007569	<i>Compressed liquid</i>
30	770.06	0.022	<i>Saturated mixture</i>
2.48	320	0.0632	Saturated vapor
100	600	0.04790	<i>Superheated vapor</i>

3-32 Complete the following table for Refrigerant-134a.

T, °C	P, kPa	u , kJ / kg	Phase description
20	571.6	95	<i>Saturated mixture</i>
-12	185.4	34.25	Saturated liquid
86.88	400	300	<i>Superheated vapor</i>
8	600	60.43	<i>Compressed liquid</i>

3-33E Complete the following table for Refrigerant-134a.

T, °F	P, psia	h , Btu / lbm	x	Phase description
65.93	80	78	0.581	<i>Saturated mixture</i>
15	29.756	68.83	0.6	<i>Saturated mixture</i>
10	70	14.66	- - -	<i>Compressed liquid</i>
160	180	128.77	- - -	<i>Superheated vapor</i>
110	161.04	115.96	1.0	<i>Saturated vapor</i>

3-34 Complete the following table for H_2O .

T, °C	P, kPa	v , m ³ / kg	Phase description
140	361.3	0.48	<i>Saturated mixture</i>
170.43	800	0.001115	Saturated liquid
25	750	0.001003	<i>Compressed liquid</i>
500	2709	0.130	<i>Superheated vapor</i>

3-35 Complete the following table for H_2O .

T, °C	P, kPa	u , kJ / kg	Phase description
143.63	400	1825	Saturated mixture
220	2318	2602.4	Saturated vapor
190	2000	806.19	Compressed liquid
466.7	4000	3040	Superheated vapor

3-36E The temperature in a pressure cooker during cooking at sea level is measured to be 250°F. The absolute pressure inside the cooker and the effect of elevation on the answer are to be determined.

Assumptions Properties of pure water can be used to approximate the properties of juicy water in the cooker.

Properties The saturation pressure of water at 250°F is 29.82 psia (Table A-5E). The standard atmospheric pressure at sea level is 1 atm = 14.7 psia.

Analysis The absolute pressure in the cooker is simply the saturation pressure at the cooking temperature,

$$P_{\text{abs}} = P_{\text{sat}@250^\circ\text{F}} = \mathbf{29.82 \text{ psia}}$$

It is equivalent to

$$P_{\text{abs}} = 29.82 \text{ psia} \left(\frac{1 \text{ atm}}{14.7 \text{ psia}} \right) = \mathbf{2.03 \text{ atm}}$$

H ₂ O 250°F

The elevation has **no effect** on the absolute pressure inside when the temperature is maintained constant at 250°F.

3-37E 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 11.529 and 14.698 psia, respectively (Table A-5E). 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

$$\frac{\Delta T}{\Delta P} = \frac{(212 - 200)^\circ\text{F}}{(14.698 - 11.529) \text{ psia}} = 3.787^\circ\text{F/psia}$$

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

$$\Delta T_{\text{boiling}} = (3.787^\circ\text{F/psia})\Delta P = (3.787^\circ\text{F/psia})(0.147 \text{ psia}) = \mathbf{0.56^\circ\text{F}}$$

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

P±0.3 inHg

3-38 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.

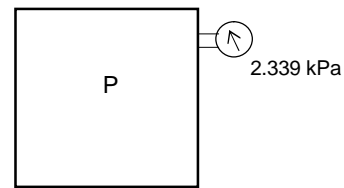
Properties The saturation pressure of water at 20°C is 2.339 kPa (Table A-4).

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

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

or,

$$\begin{aligned} F &= A(P_{atm} - P) = (\pi D^2 / 4)(P_{atm} - P) \\ &= \frac{\pi(0.3 \text{ m})^2}{4}(101,325 - 2339) \text{ Pa} \\ &= 6997 \text{ m}^2 \text{ Pa} = 6997 \text{ N} \quad (\text{since } 1 \text{ Pa} = 1 \text{ N/m}^2) \end{aligned}$$



$P_{atm} = 1 \text{ atm mmHg}$

The weight of the pan and its contents is

$$W = mg = (8 \text{ kg})(9.8 \text{ m/s}^2) = 78 \text{ N}$$

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.

3-39 Water is boiled at sea level (1 atm pressure) in a pan placed on top of a 3-kW electric burner that transfers 60% of the heat generated to the water. The rate of evaporation of water is to be determined.

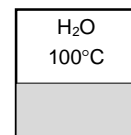
Properties The properties of water at 1 atm and thus at the saturation temperature of 100°C are $h_{fg} = 2257 \text{ kJ/kg}$ (Table A-4).

Analysis The net rate of heat transfer to the water is

$$\dot{Q} = 0.60 \times 3 \text{ kW} = 1.8 \text{ kW}$$

Noting that it takes 2257 kJ of energy to vaporize 1 kg of saturated liquid water, the rate of evaporation of water is determined to be

$$\dot{m}_{\text{evaporation}} = \frac{\dot{Q}}{h_{fg}} = \frac{1.8 \text{ kJ/s}}{2257 \text{ kJ/kg}} = 0.80 \times 10^{-3} \text{ kg/s} = 2.87 \text{ kg/h}$$



3-40 Water is boiled at 1500 m (84.5 kPa pressure) in a pan placed on top of a 3-kW electric burner that transfers 60% of the heat generated to the water. The rate of evaporation of water is to be determined.

Properties The properties of water at 84.5 kPa and thus at the saturation temperature of 95°C are $h_{fg} = 2270.2$ kJ/kg (Table A-4).

Analysis The net rate of heat transfer to the water is

$$\dot{Q} = 0.60 \times 3 \text{ kW} = 1.8 \text{ kW}$$

Noting that it takes 2270.2 kJ of energy to vaporize 1 kg of saturated liquid water, the rate of evaporation of water is determined to be

$$\dot{m}_{\text{evaporation}} = \frac{\dot{Q}}{h_{fg}} = \frac{1.8 \text{ kJ/s}}{2270.2 \text{ kJ/kg}} = 0.79 \times 10^{-3} \text{ kg/s} = 2.85 \text{ kg/h}$$

H ₂ O
95°C

3-41 Water is boiled at 1 atm pressure in a pan placed on an electric burner. The water level drops by 10 cm in 30 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 $h_{fg} = 2257$ kJ/kg and $\nu_f = 0.001044$ m³/kg (Table A-4).

Analysis The rate of evaporation of water is

$$m_{\text{evap}} = \frac{V_{\text{evap}}}{\nu_f} = \frac{(\pi D^2 / 4) L}{\nu_f} = \frac{[\pi(0.2 \text{ m})^2 / 4](0.10 \text{ m})}{0.001044} = 3.009 \text{ kg}$$

$$\dot{m}_{\text{evap}} = \frac{m_{\text{evap}}}{\Delta t} = \frac{3.009 \text{ kg}}{30 \times 60 \text{ s}} = 0.00167 \text{ kg/s}$$

Then the rate of heat transfer to water becomes

$$\dot{Q} = \dot{m}_{\text{evap}} h_{fg} = (0.00167 \text{ kg/s})(2257 \text{ kJ/kg}) = 3.77 \text{ kW}$$

H ₂ O
100°C

3-42 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 30 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 $T_{\text{sat}} = 93.2^\circ\text{C}$, $h_{\text{fg}} = 2275 \text{ kJ/kg}$ and $\nu_f = 0.001038 \text{ m}^3/\text{kg}$ (Table A-5).

Analysis The rate of evaporation of water is

$$m_{\text{evap}} = \frac{V_{\text{evap}}}{\nu_f} = \frac{(\pi D^2 / 4) L}{\nu_f} = \frac{[\pi(0.2 \text{ m})^2 / 4](0.10 \text{ m})}{0.001038} = 3.027 \text{ kg}$$

$$\dot{m}_{\text{evap}} = \frac{m_{\text{evap}}}{\Delta t} = \frac{3.027 \text{ kg}}{30 \times 60 \text{ s}} = 0.00168 \text{ kg/s}$$

H ₂ O
79.5
kPa

Then the rate of heat transfer to water becomes

$$\dot{Q} = \dot{m}_{\text{evap}} h_{\text{fg}} = (0.00168 \text{ kg/s})(2275 \text{ kJ/kg}) = \mathbf{3.82 \text{ kW}}$$

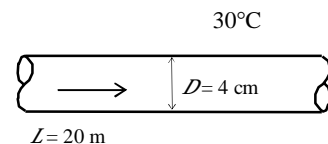
3-43 Saturated steam at $T_{\text{sat}} = 30^\circ\text{C}$ condenses on the outer surface of a cooling tube at a rate of 45 kg/h. The rate of heat transfer from the steam to the cooling water is to be determined.

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 $h_{\text{fg}} = 2431 \text{ kJ/kg}$.

Analysis Noting that 2431 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

$$\dot{Q} = \dot{m}_{\text{evap}} h_{\text{fg}} = (45 \text{ kg/h})(2431 \text{ kJ/kg}) = 109,395 \text{ kJ/h} = \mathbf{30.4 \text{ kW}}$$



3-44 The average atmospheric pressure in Denver is 83.4 kPa. The boiling temperature of water in Denver is to be determined.

Analysis The boiling temperature of water in Denver is the saturation temperature corresponding to the atmospheric pressure in Denver, which is 83.4 kPa:

$$T = T_{\text{sat@83.4 kPa}} = \mathbf{94.4^\circ\text{C}}$$

3-45 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 :

$$P = P_{\text{sat}@98^\circ\text{C}} = 94.63 \text{ kPa}$$

The pressure difference between the bottoms of two pans is

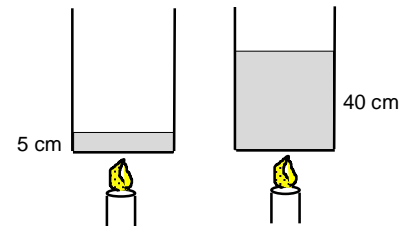
$$\Delta P = \rho gh = (1000 \text{ kg/m}^3)(9.8 \text{ m/s}^2)(0.35 \text{ m}) \left(\frac{1 \text{ kPa}}{1000 \text{ kg/m} \cdot \text{s}^2} \right) = 3.43 \text{ kPa}$$

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

$$P = 94.63 + 3.43 = 98.06 \text{ kPa}$$

Then the boiling temperature becomes

$$T_{\text{boiling}} = T_{\text{sat}@98.06 \text{ kPa}} = \mathbf{99.0^\circ\text{C}}$$



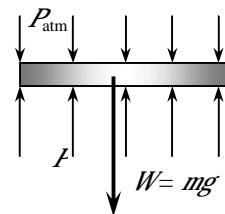
3-46 A cooking pan is filled with water and covered with a 4-kg lid. The boiling temperature of water is to be determined.

Analysis The pressure in the pan is determined from a force balance on the lid,

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

or,

$$\begin{aligned} P &= P_{\text{atm}} + \frac{mg}{A} \\ &= (101 \text{ kPa}) + \frac{(4 \text{ kg})(9.807 \text{ m/s}^2)}{\pi(0.1 \text{ m})^2} \left(\frac{1 \text{ kPa}}{1000 \text{ kg/m} \cdot \text{s}^2} \right) \\ &= 102.25 \text{ kPa} \end{aligned}$$



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

$$T = T_{\text{sat}@102.25 \text{ kPa}} = \mathbf{100.2^\circ\text{C}}$$

3-47 Problem 3-46 is reconsidered. Using EES (or other) software, the effect of the mass of the lid on the boiling temperature of water in the pan is to be investigated. The mass is to vary from 1 kg to 10 kg, and the boiling temperature is to be plotted against the mass of the lid.

"Given data"
 {P_atm=101"[kPa]}"
 D_lid=20"[cm]"
 {m_lid=4"[kg]}"

"Solution"

"From Problem 1-84, atmospheric pressure in kPa varies with altitude in km by the approximate function:"

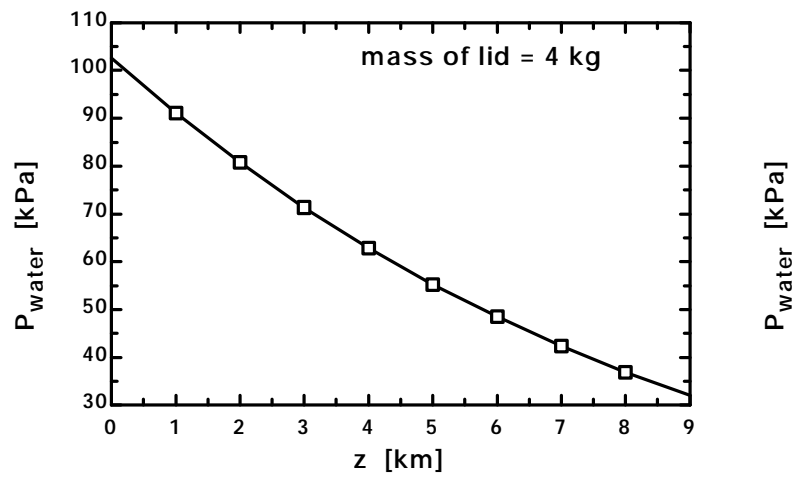
P_atm=101.325*(1-0.02256*z)^5.256"[kPa]"

"From Problem 1-9, third edition, the local acceleration of gravity at 45 degrees latitude as a function of altitude in m is given by:"

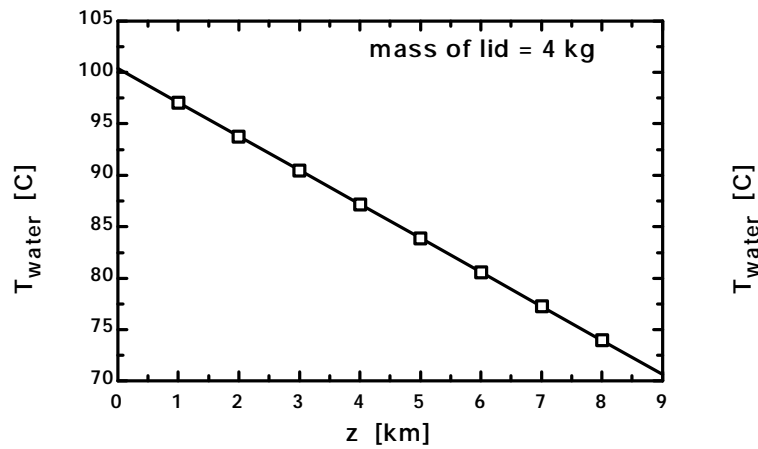
g=9.807+3.32*10⁻⁶*z*convert(km,m)"[m/s^2]"
 "At sea level:"
 z=0"[km]"

A_lid=pi*D_lid^2/4*convert(cm^2,m^2)"[m^2]"
 W_lid=m_lid*g*convert(kg*m/s^2,N)"[N]"
 P_lid=W_lid/A_lid*convert(N/m^2,kPa)"[kPa]"
 P_water=P_lid+P_atm"[kPa]"
 T_water=temperature(steam,P=P_water,x=0)"[C]"

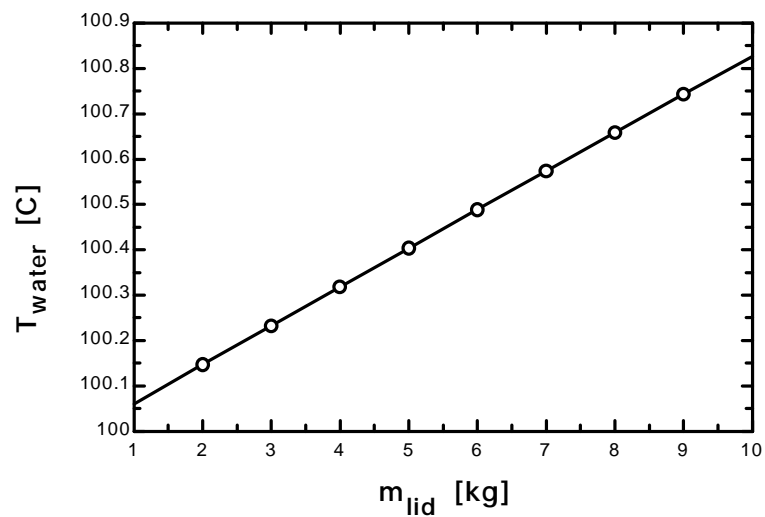
m _{lid} [kg]	T _{water} [C]
1	100.1
2	100.1
3	100.2
4	100.3
5	100.4
6	100.5
7	100.6
8	100.7
9	100.7
10	100.8



Effect of altitude on boiling pressure of water in pan with lid



Effect of altitude on boiling temperature of water in pan with lid



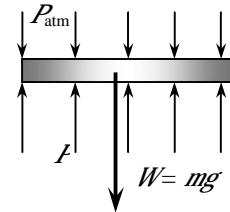
3-48 A vertical piston-cylinder device is filled with water and covered with a 20-kg piston that serves as the lid. The boiling temperature of water is to be determined. ✓

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

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

or,

$$\begin{aligned} P &= P_{atm} + \frac{mg}{A} \\ &= (100 \text{ kPa}) + \frac{(20 \text{ kg})(9.807 \text{ m/s}^2)}{0.01 \text{ m}^2} \left(\frac{1 \text{ kPa}}{1000 \text{ kg/m} \cdot \text{s}^2} \right) \\ &= 119.61 \text{ kPa} \end{aligned}$$



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

$$T = T_{sat @ 119.61 \text{ kPa}} = \mathbf{104.6^\circ \text{C}}$$

3-49 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 - v diagram is to be drawn.

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

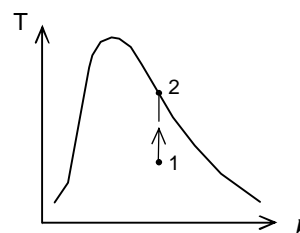
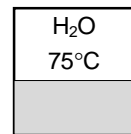
$$v = \frac{V}{m} = \frac{2.5 \text{ m}^3}{5 \text{ kg}} = 0.5 \text{ m}^3/\text{kg}$$

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

$$v_2 = v_g = 0.5 \text{ m}^3/\text{kg}$$

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

$$T = T_{sat @ v_g = 0.5 \text{ m}^3/\text{kg}} = \mathbf{140.7^\circ \text{C}}$$



3-50 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).

$$\left. \begin{array}{l} P = 900 \text{ kPa} \\ T = 80^\circ \text{C} \end{array} \right\} \begin{array}{l} u = 288.87 \text{ kJ/kg} \\ v = 0.02861 \text{ m}^3/\text{kg} \end{array}$$

R-134a
2 kg
900 kPa
80°C

Analysis The total volume and internal energy are determined from

$$V = mv = (2 \text{ kg})(0.02861 \text{ m}^3/\text{kg}) = \mathbf{0.05722 \text{ m}^3}$$

$$U = mu = (2 \text{ kg})(288.87 \text{ kJ/kg}) = \mathbf{577.74 \text{ kJ}}$$

3-51E A rigid tank contains water at a specified pressure. The temperature, total enthalpy, and the mass of each phase are to be determined.

Analysis(a) The specific volume of the water is

$$v = \frac{V}{m} = \frac{5 \text{ ft}^3}{5 \text{ lbm}} = 1.0 \text{ ft}^3/\text{lbm}$$

At 20 psia, $v_f = 0.01683 \text{ ft}^3/\text{lbm}$ and $v_g = 20.09 \text{ ft}^3/\text{lbm}$. Thus the tank contains saturated liquid-vapor mixture since $v_f < v < v_g$, and the temperature must be the saturation temperature at the specified pressure,

$$T = T_{\text{sat@20 psia}} = \mathbf{227.96^\circ \text{F}}$$

(b) The quality of the water and its total enthalpy are determined from

$$x = \frac{v - v_f}{v_{fg}} = \frac{1.0 - 0.01683}{20.09 - 0.01683} = 0.0490$$

$$h = h_f + xh_{fg} = 196.26 + 0.049 \times 960.1 = 243.3 \text{ Btu/lbm}$$

$$H = mh = (5 \text{ lbm})(243.3 \text{ Btu/lbm}) = \mathbf{1216.5 \text{ Btu}}$$

H ₂ O
5 lbm
20 psia

(c) The mass of each phase is determined from

$$m_g = xm_t = 0.049 \times 5 = \mathbf{0.245 \text{ lbm}}$$

$$m_f = m_t - m_g = 5 - 0.245 = \mathbf{4.755 \text{ lbm}}$$

3-52 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

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

At -20°C , $v_f = 0.0007361 \text{ m}^3/\text{kg}$ and $v_g = 0.1464 \text{ m}^3/\text{kg}$. Thus the tank contains saturated liquid-vapor mixture since $v_f < v < v_g$, and the pressure must be the saturation pressure at the specified temperature,

$$P = P_{\text{sat @ } -20^\circ\text{C}} = \mathbf{132.99 \text{ kPa}}$$

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

$$x = \frac{v - v_f}{v_{fg}} = \frac{0.05 - 0.0007361}{0.1464 - 0.0007361} = 0.338$$

$$u = u_f + xu_{fg} = 24.17 + 0.338 \times (215.84 - 24.17) = 88.95 \text{ kJ/kg}$$

$$U = mu = (10 \text{ kg})(88.95 \text{ kJ/kg}) = \mathbf{889.5 \text{ kJ}}$$

R-134a
10 kg
 -20°C

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

$$m_f = (1 - x)m = (1 - 0.338) \times 10 = 6.62 \text{ kg}$$

$$V_f = m_f v_f = (6.62 \text{ kg})(0.0007361 \text{ m}^3/\text{kg}) = \mathbf{0.00487 \text{ m}^3}$$

3-53 [Also solved by EES on enclosed CD] 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,

$$T = T_{\text{sat @ } 800 \text{ kPa}} = \mathbf{170.43^\circ\text{C}} \quad (\text{Table A-5})$$

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

$$m_f = \frac{V_f}{v_f} = \frac{0.1 \text{ m}^3}{0.001115 \text{ m}^3/\text{kg}} = 89.69 \text{ kg}$$

$$m_g = \frac{V_g}{v_g} = \frac{0.9 \text{ m}^3}{0.2404 \text{ m}^3/\text{kg}} = 3.74 \text{ kg}$$

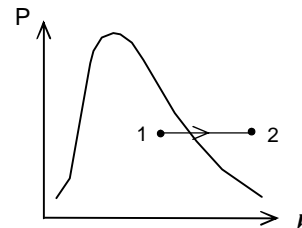
$$m_t = m_f + m_g = 89.69 + 3.74 = \mathbf{93.43 \text{ kg}}$$

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

$$\left. \begin{array}{l} P_2 = 800 \text{ kPa} \\ T_2 = 350^\circ\text{C} \end{array} \right\} v_2 = 0.3544 \text{ m}^3/\text{kg} \quad (\text{Table A-6})$$

Then,

$$V_2 = m v_2 = (93.43 \text{ kg})(0.3544 \text{ m}^3/\text{kg}) = \mathbf{33.1 \text{ m}^3}$$

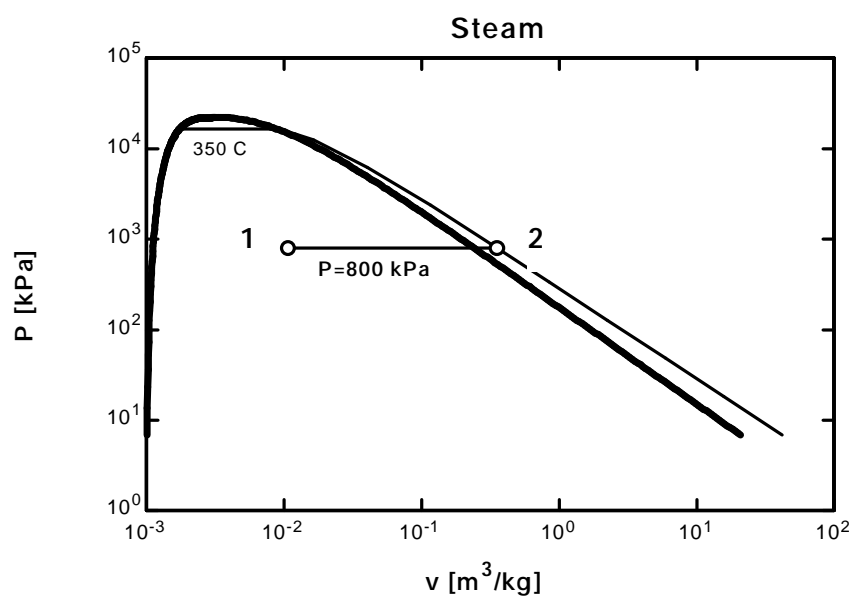


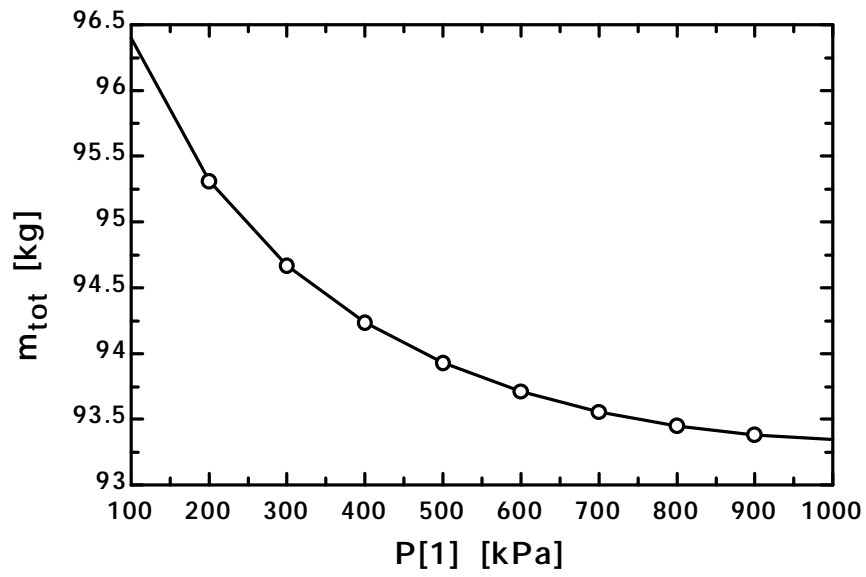
3-54 Problem 3-53 is reconsidered. The effect of pressure on the total mass of water in the tank as the pressure varies from 0.1 MPa to 1 MPa is to be investigated. The total mass of water is to be plotted against pressure, and results are to be discussed.

```

P[1]=800"kJPa"
P[2]=P[1]
T[2]=350"C"
V_f1 = 0.1"m^3"
V_g1=0.9"m^3"
spvsat_f1=volume(Steam, P=P[1],x=0)"sat. liq. specific volume, m^3/kg"
spvsat_g1=volume(Steam,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"kg"
V[1]=V_f1+V_g1"m^3"
spvol[1]=V[1]/m_tot"specific volume1, m^3"
T[1]=temperature(Steam,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, P=P[2], T=T[2])"specific volume2, m^3/kg"
V[2]=m_tot*spvol[2]"m^3"
    
```

m_{tot} [kg]	P_1 [kPa]
96.4	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
93.35	1000





3-55E 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 ($v = V/m = \text{constant}$), and the initial specific volume is determined to be

$$\left. \begin{array}{l} P_1 = 180 \text{ psia} \\ T_1 = 500^\circ \text{F} \end{array} \right\} v_1 = 3.042 \text{ ft}^3/\text{lbm} \quad (\text{Table A-6E})$$

At 250°F, $v_f = 0.017001 \text{ ft}^3/\text{lbm}$ and $v_g = 13.826 \text{ ft}^3/\text{lbm}$. Thus at the final state, the tank will contain saturated liquid-vapor mixture since $v_f < v < v_g$, and the final pressure must be the saturation pressure at the final temperature,

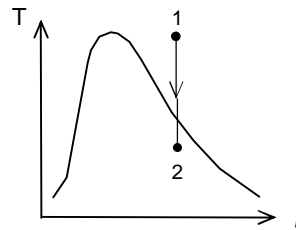
$$P = P_{\text{sat}@250^\circ \text{F}} = \mathbf{29.82 \text{ psia}}$$

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

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{3.042 - 0.017001}{13.826 - 0.017001} = \mathbf{0.219}$$

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

$$h = h_f + xh_{fg} = 218.59 + 0.219 \times 945.6 = \mathbf{425.7 \text{ Btu/lbm}}$$



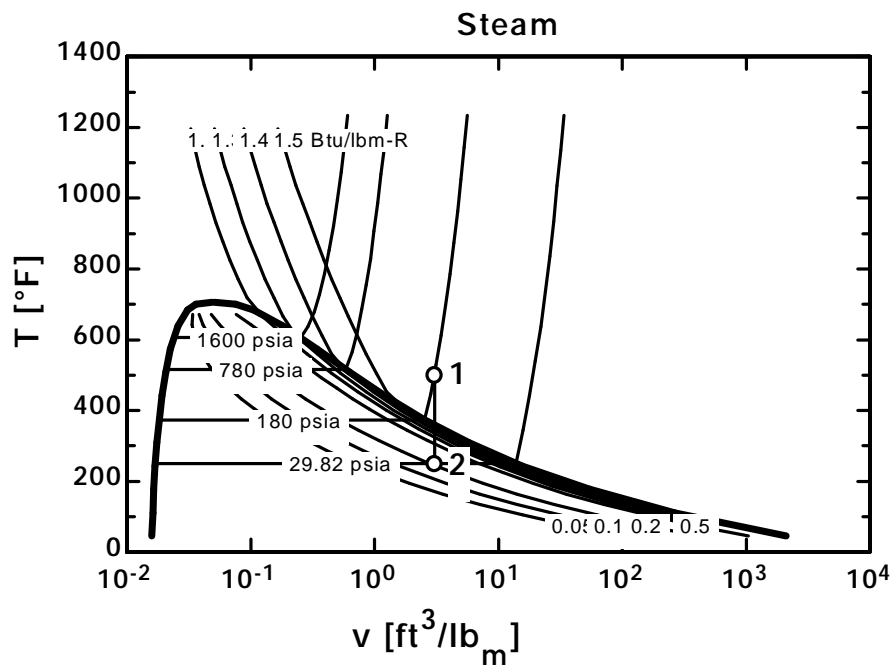
H ₂ O
180 psia
500 °F

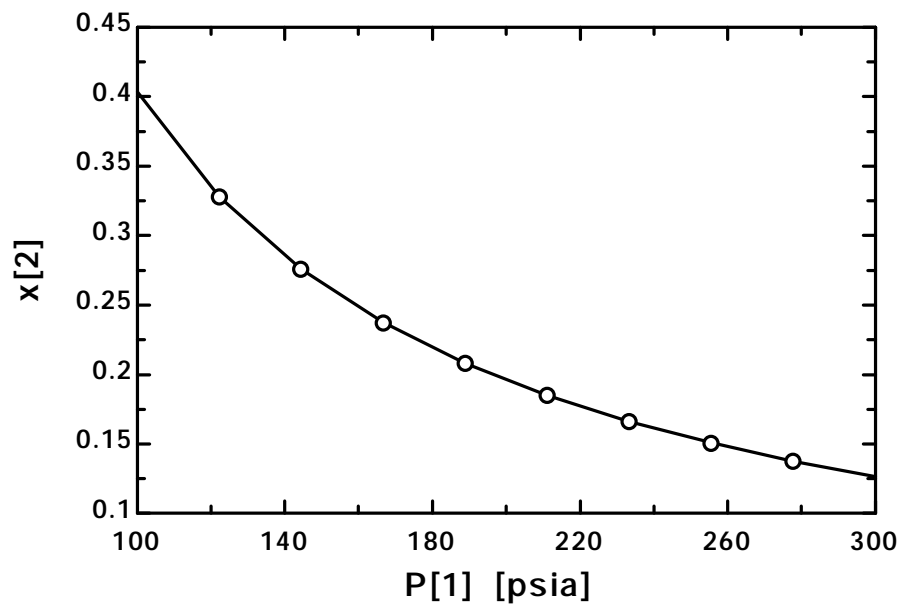
3-56E Problem 3-55E is reconsidered. The effect of initial pressure on the quality of water at the final state as the pressure varies from 100 psi to 300 psi is to be investigated. The quality is to be plotted against initial pressure, and the results are to be discussed.

```

T[1]=500"[F]"
P[1]=180"[psia]"
T[2]=250"[F]"
v[1]=volume(steam,T=T[1],P=P[1])"[ft^3/lbm]"
v[2]=v[1]"[ft^3/lbm]"
P[2]=pressure(steam,T=T[2],v=v[2])"[psia]"
h[2]=enthalpy(steam,T=T[2],v=v[2])"[Btu/lbm]"
x[2]=quality(steam,T=T[2],v=v[2])
    
```

P_1 [psia]	x_2
100	0.4032
122.2	0.3279
144.4	0.2757
166.7	0.2374
188.9	0.2081
211.1	0.185
233.3	0.1663
255.6	0.1508
277.8	0.1377
300	0.1266





3-57 A piston-cylinder device that is initially filled with water is heated at constant pressure until all the liquid has vaporized. The mass of water, the final temperature, and the total enthalpy change are to be determined, and the T - v diagram is to be drawn.

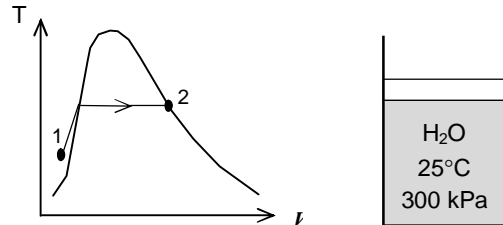
Analysis Initially the cylinder contains compressed liquid (since $P > P_{\text{atm @ } 25^\circ\text{C}}$) that can be approximated as a saturated liquid at the specified temperature,

$$v_1 \cong v_{f@25^\circ\text{C}} = 0.001003 \text{ m}^3/\text{kg}$$

$$h_1 \cong h_{f@25^\circ\text{C}} = 104.89 \text{ kJ/kg}$$

(a) The mass is determined from

$$m = \frac{V_1}{v_1} = \frac{0.050 \text{ m}^3}{0.001003 \text{ m}^3/\text{kg}} = \mathbf{49.85 \text{ kg}}$$



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

$$T = T_{\text{sat@ } 300 \text{ kPa}} = \mathbf{133.55^\circ\text{C}}$$

(c) The final enthalpy is $h_2 = h_g @ 300 \text{ kPa} = 2725.3 \text{ kJ/kg}$. Thus,

$$\Delta H = m(h_2 - h_1) = (49.85 \text{ kg})(2725.3 - 104.89) \text{ kJ/kg} = \mathbf{130,627 \text{ kJ}}$$

3-58 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,

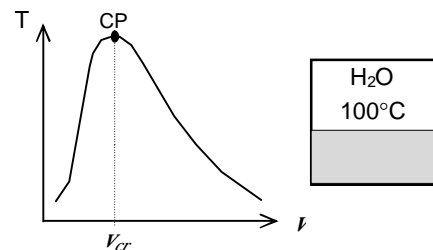
$$v_1 = v_2 = v_{\text{cr}} = 0.003155 \text{ m}^3/\text{kg} \quad (\text{last row of Table A-4})$$

The total mass is

$$m = \frac{V}{v} = \frac{0.5 \text{ m}^3}{0.003155 \text{ m}^3/\text{kg}} = 158.48 \text{ kg}$$

At 100°C , $v_f = 0.001044 \text{ m}^3/\text{kg}$ and $v_g = 1.6729 \text{ m}^3/\text{kg}$.
Then the quality of water at the initial state is

$$x_1 = \frac{v_1 - v_f}{v_{fg}} = \frac{0.003155 - 0.001044}{1.6729 - 0.001044} = 0.001263$$



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

$$m_f = (1 - x_1)m = (1 - 0.001263)(158.48) = \mathbf{158.28 \text{ kg}}$$

$$V_f = m_f v_f = (158.28 \text{ kg})(0.001044 \text{ m}^3/\text{kg}) = \mathbf{0.165 \text{ m}^3}$$

3-59 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,

$$\begin{aligned} T = 100^\circ\text{C} \Rightarrow \quad \nu &\cong \nu_{f@100^\circ\text{C}} = 0.001044 \text{ m}^3/\text{kg} && (0.76\% \text{ error}) \\ u &\cong u_{f@100^\circ\text{C}} = 418.94 \text{ kJ/kg} && (1.01\% \text{ error}) \\ h &\cong h_{f@100^\circ\text{C}} = 419.04 \text{ kJ/kg} && (2.61\% \text{ error}) \end{aligned}$$

From compressed liquid table (Table A-7),

$$\left. \begin{aligned} P &= 15 \text{ MPa} \\ T &= 100^\circ\text{C} \end{aligned} \right\} \begin{aligned} \nu &= 0.0010361 \text{ m}^3/\text{kg} \\ u &= 414.74 \text{ kJ/kg} \\ h &= 430.28 \text{ kJ/kg} \end{aligned}$$

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

3-60 Problem 3-59 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.

```
T = 100"[C]"
P = 15000"[kPa]"
v = VOLUME(Steam,T=T,P=P)"[m^3/kg]"
u = INTENERGY(Steam,T=T,P=P)"[kJ/kg]"
h = ENTHALPY(Steam,T=T,P=P)"[kJ/kg]"
v_app = VOLUME(Steam,T=T,x=0)"[m^3/kg]"
u_app = INTENERGY(Steam,T=T,x=0)"[kJ/kg]"
h_app_1 = ENTHALPY(Steam,T=T,x=0)"[kJ/kg]"
h_app_2 = ENTHALPY(Steam,T=T,x=0)+v_app*(P-pressure(Steam,T=T,x=0))"[kJ/kg]"
```

SOLUTION

Variables in Main

```
h=430.3 [kJ/kg]
h_app_1=419.1 [kJ/kg]
h_app_2=434.6 [kJ/kg]
P=15000 [kPa]
T=100 [C]
u=414.7 [kJ/kg]
u_app=419 [kJ/kg]
v=0.001036 [m^3/kg]
v_app=0.001043 [m^3/kg]
```

3-61E A rigid tank contains saturated liquid-vapor mixture of R-134a. The quality and total mass of the refrigerant are to be determined.

Analysis At 30 psia, $v_f = 0.01209 \text{ ft}^3/\text{lbm}$ and $v_g = 1.5408 \text{ ft}^3/\text{lbm}$. The volume occupied by the liquid and the vapor phases are

$$V_f = 1.5 \text{ ft}^3 \quad \text{and} \quad V_g = 13.5 \text{ ft}^3$$

Thus the mass of each phase is

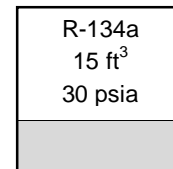
$$m_f = \frac{V_f}{v_f} = \frac{1.5 \text{ ft}^3}{0.01209 \text{ ft}^3/\text{lbm}} = 124.1 \text{ lbm}$$

$$m_g = \frac{V_g}{v_g} = \frac{13.5 \text{ ft}^3}{1.5408 \text{ ft}^3/\text{lbm}} = 8.76 \text{ lbm}$$

Then the total mass and the quality of the refrigerant are

$$m_t = m_f + m_g = 124.1 + 8.76 = \mathbf{132.86 \text{ lbm}}$$

$$x = \frac{m_g}{m_t} = \frac{8.76}{132.86} = \mathbf{0.0659}$$



3-62 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,

$$T = T_{\text{sat@1 MPa}} = \mathbf{179.91^\circ \text{C}}$$

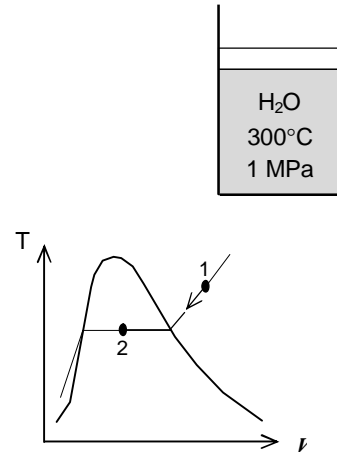
(c) The quality at the final state is specified to be $x_2 = 0.5$. The specific volumes at the initial and the final states are

$$\left. \begin{array}{l} P_1 = 1.0 \text{ MPa} \\ T_1 = 300^\circ \text{C} \end{array} \right\} v_1 = 0.2579 \text{ m}^3/\text{kg}$$

$$\left. \begin{array}{l} P_2 = 1.0 \text{ MPa} \\ x_2 = 0.5 \end{array} \right\} \begin{aligned} v_2 &= v_f + x_2 v_{fg} \\ &= 0.001127 + 0.5 \times (0.19444 - 0.001127) \\ &= 0.0978 \text{ m}^3/\text{kg} \end{aligned}$$

Thus,

$$\Delta V = m(v_2 - v_1) = (0.8 \text{ kg})(0.0978 - 0.2579) \text{ m}^3/\text{kg} = \mathbf{-0.128 \text{ m}^3}$$



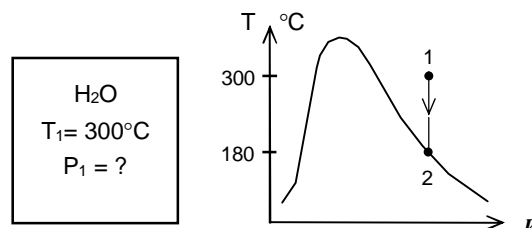
3-63 The water in a rigid tank is cooled until the vapor starts condensing. The initial pressure in the tank is to be determined.

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

$$v_1 = v_2 = v_{g@180^\circ \text{C}} = 0.19405 \text{ m}^3/\text{kg}$$

since the vapor starts condensing at 180°C . Then from Table A-6,

$$\left. \begin{array}{l} T_1 = 300^\circ \text{C} \\ v_1 = 0.19405 \text{ m}^3/\text{kg} \end{array} \right\} P_1 = \mathbf{1.325 \text{ MPa}}$$



Ideal Gas

3-64C 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.

3-65C 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.

3-66C 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.

3-67C 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.

3-68 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 kg/kmol (Table A-1).

Analysis The volume of the sphere is

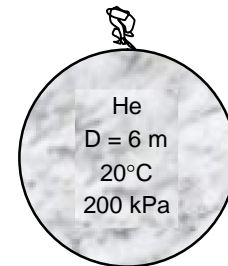
$$V = \frac{4}{3} \pi r^3 = \frac{4}{3} \pi (3 \text{ m})^3 = 113.1 \text{ m}^3$$

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

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



3-69 Problem 3-68 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) 100kPa 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.

"Given Data"

{D=6"[m]"}

{P=200"[kPa]"}

T=20"[C]"

P=100"[kPa]"

R_u=8.314"[kJ/kmol*K]"

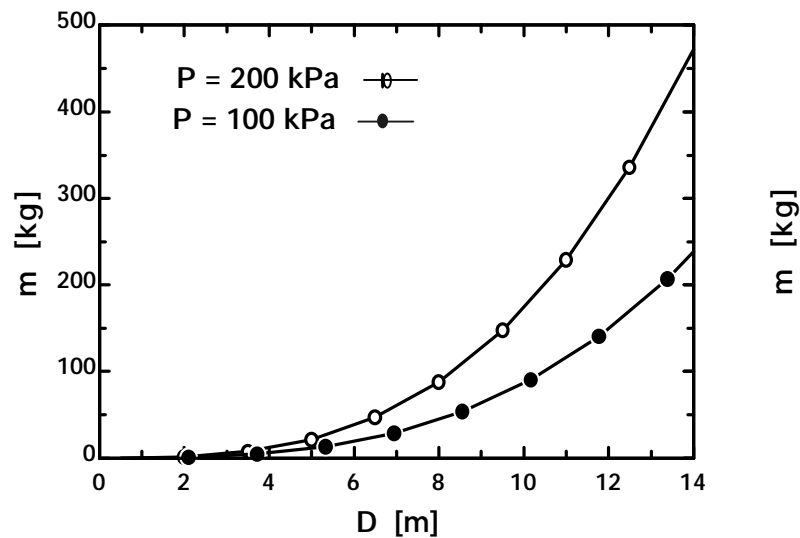
"Solution"

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

$V = 4 \cdot \pi \cdot (D/2)^3 / 3$ "[m^3]"

$m = N \cdot \text{MOLARMASS}(\text{Helium})$ "[kg]"

D [m]	m [kg]
0.5	0.01075
2.111	0.8095
3.722	4.437
5.333	13.05
6.944	28.81
8.556	53.88
10.17	90.41
11.78	140.6
13.39	206.5
15	290.4



Mass of Helium in Balloon as function of Diameter

3-70 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).

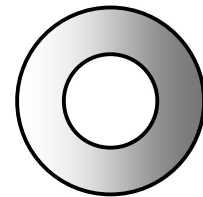
Analysis Initially, the absolute pressure in the tire is

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

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

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

Tire
25°C



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

$$m_1 = \frac{P_1 V}{R T_1} = \frac{(310 \text{ kPa})(0.025 \text{ m}^3)}{(0.287 \text{ kPa}\cdot\text{m}^3 / \text{kg}\cdot\text{K})(298 \text{ K})} = 0.0906 \text{ kg}$$

$$m_2 = \frac{P_2 V}{R T_2} = \frac{(336 \text{ kPa})(0.025 \text{ m}^3)}{(0.287 \text{ kPa}\cdot\text{m}^3 / \text{kg}\cdot\text{K})(323 \text{ K})} = 0.0836 \text{ kg}$$

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

3-71E An automobile tire is under inflated with air. The amount of air that needs to be added to the tire to raise its pressure to the recommended value is to be determined.

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

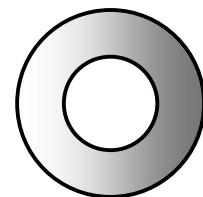
Properties The gas constant of air is $R = 0.3704 \text{ psia}\cdot\text{ft}^3/\text{lbm}\cdot\text{R}$ (Table A-1E).

Analysis The initial and final absolute pressures in the tire are

$$P_1 = P_{g1} + P_{atm} = 20 + 14.6 = 34.6 \text{ psia}$$

$$P_2 = P_{g2} + P_{atm} = 30 + 14.6 = 44.6 \text{ psia}$$

Tire
0.53 ft³
90°F



Treating air as an ideal gas, the initial mass in the tire is

$$m_1 = \frac{P_1 V}{R T_1} = \frac{(34.6 \text{ psia})(0.53 \text{ ft}^3)}{(0.3704 \text{ psia}\cdot\text{ft}^3 / \text{lbm}\cdot\text{R})(550 \text{ R})} = 0.0900 \text{ lbm}$$

Noting that the temperature and the volume of the tire remain constant, the final mass in the tire becomes

$$m_2 = \frac{P_2 V}{R T_2} = \frac{(44.6 \text{ psia})(0.53 \text{ ft}^3)}{(0.3704 \text{ psia}\cdot\text{ft}^3 / \text{lbm}\cdot\text{R})(550 \text{ R})} = 0.1160 \text{ lbm}$$

Thus the amount of air that needs to be added is

$$\Delta m = m_2 - m_1 = 0.1160 - 0.0900 = \mathbf{0.0260 \text{ lbm}}$$

3-72 The pressure and temperature of oxygen gas in a storage tank are given. The mass of oxygen in the tank is to be determined.

Assumptions At specified conditions, oxygen behaves as an ideal gas

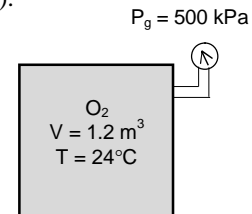
Properties The gas constant of oxygen is $R = 0.2598 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K}$ (Table A-1).

Analysis The absolute pressure of O_2 is

$$P = P_g + P_{\text{atm}} = 500 + 97 = 597 \text{ kPa}$$

Treating O_2 as an ideal gas, the mass of O_2 in tank is determined to be

$$m = \frac{PV}{RT} = \frac{(597 \text{ kPa})(1.2 \text{ m}^3)}{(0.2598 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K})(297 \text{ K})} = \mathbf{9.28 \text{ kg}}$$



3-73E A rigid tank contains slightly pressurized air. The amount of air that needs to be added to the tank to raise its pressure and temperature to the recommended values is to be determined. ✓

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

Properties The gas constant of air is $R = 0.3704 \text{ psia} \cdot \text{ft}^3 / \text{lbm} \cdot \text{R}$ (Table A-1E).

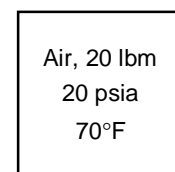
Analysis Treating air as an ideal gas, the initial volume and the final mass in the tank are determined to be

$$V = \frac{m_1 RT_1}{P_1} = \frac{(20 \text{ lbm})(0.3704 \text{ psia} \cdot \text{ft}^3 / \text{lbm} \cdot \text{R})(530 \text{ R})}{20 \text{ psia}} = 196.3 \text{ ft}^3$$

$$m_2 = \frac{P_2 V}{RT_2} = \frac{(35 \text{ psia})(196.3 \text{ ft}^3)}{(0.3704 \text{ psia} \cdot \text{ft}^3 / \text{lbm} \cdot \text{R})(550 \text{ R})} = 33.73 \text{ lbm}$$

Thus the amount of air added is

$$\Delta m = m_2 - m_1 = 33.73 - 20.0 = \mathbf{13.73 \text{ lbm}}$$



3-74 A rigid tank contains air at a specified state. The gage pressure of the gas in the tank is to be determined..

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

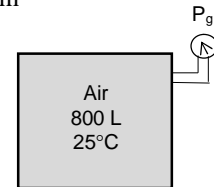
Properties The gas constant of air is $R = 0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K}$ (Table A-1).

Analysis Treating air as an ideal gas, the absolute pressure in the tank is determined from

$$P_2 = \frac{mRT}{V} = \frac{(10 \text{ kg})(0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(298 \text{ K})}{0.8 \text{ m}^3} = 1069.1 \text{ kPa}$$

Thus the gage pressure is

$$P_g = P - P_{\text{atm}} = 1069.1 - 97 = \mathbf{972.1 \text{ kPa}}$$



3-75 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

$$V_B = \left(\frac{m_B RT_B}{P_B} \right)_B = \frac{(5 \text{ kg})(0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(308 \text{ K})}{200 \text{ kPa}} = \mathbf{2.21 \text{ m}^3}$$

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

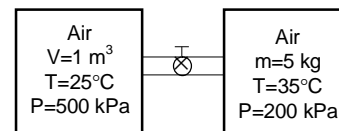
Thus,

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

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

Then the final equilibrium pressure becomes

$$P_2 = \frac{mRT_2}{V} = \frac{(10.846 \text{ kg})(0.287 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(293 \text{ K})}{3.21 \text{ m}^3} = \mathbf{284.1 \text{ kPa}}$$



Compressibility Factor

3-76C It represents the deviation from ideal gas behavior. The further away it is from 1, the more the gas deviates from ideal gas behavior.

3-77C All gases have the same compressibility factor Z at the same reduced temperature and pressure.

3-78C 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.

3-79 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,

$$R = 0.4615 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K}, \quad T_{cr} = 647.3 \text{ K}, \quad P_{cr} = 22.09 \text{ MPa}$$

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

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

(b) From the compressibility chart (Fig. A-30),

$$\left. \begin{aligned} P_R &= \frac{P}{P_{cr}} = \frac{10 \text{ MPa}}{22.09 \text{ MPa}} = 0.453 \\ T_R &= \frac{T}{T_{cr}} = \frac{673 \text{ K}}{647.3 \text{ K}} = 1.04 \end{aligned} \right\} Z = 0.84$$

H ₂ O
10 MPa
400°C

Thus,

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

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

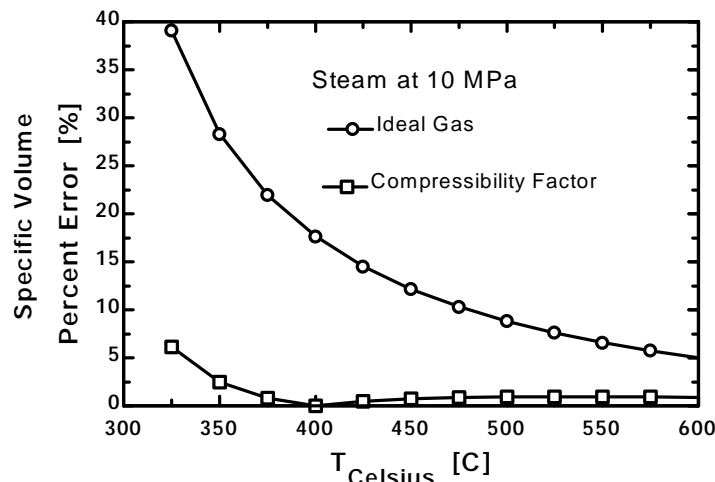
$$\left. \begin{aligned} P &= 10 \text{ MPa} \\ T &= 400^\circ \text{C} \end{aligned} \right\} \nu = \mathbf{0.02641 \text{ m}^3/\text{kg}}$$

3-80 Problem 3-79 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.

```
P=10*convert(MPa,kPa)"[kPa]"
{T_Celsius= 400"[C]"}
T=T_Celsius+273"[K]"
T_critical=T_CRIT(Steam)
P_critical=P_CRIT(Steam)
{v=Vol/m"[m3/kg]"}
P_table=P; P_comp=P;P_idealgas=P
T_table=T; T_comp=T;T_idealgas=T

v_table=volume(Steam,P=P_table,T=T_table)"[m^3/kg]"EES data for steam as a real gas"
{P_table=pressure(Steam, T=T_table,v=v)}
{T_sat=temperature(Steam,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"[kPa]"      "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*100
Error_comp=Abs(v_table-v_comp)/v_table*100
```

Error _{comp} [%]	Error _{ideal gas} [%]	T _{Celsius} [C]
6.183	39.12	325
2.511	28.34	350
0.8332	21.95	375
0.03603	17.65	400
0.5098	14.54	425
0.7686	12.18	450
0.9027	10.33	475
0.9613	8.84	500
0.9731	7.624	525
0.9554	6.614	550
0.9191	5.765	575
0.8714	5.044	600



3-81 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,

$$R = 0.08149 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K}, \quad T_{cr} = 374.25 \text{ K}, \quad P_{cr} = 4.067 \text{ MPa}$$

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

$$\nu = \frac{RT}{P} = \frac{(0.08149 \text{ kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})(413 \text{ K})}{1,400 \text{ kPa}} = \mathbf{0.02404 \text{ m}^3/\text{kg}} \quad (9.8\% \text{ error})$$

(b) From the compressibility chart (Fig. A-30),

$$\left. \begin{aligned} P_R = \frac{P}{P_{cr}} &= \frac{1.4 \text{ MPa}}{4.067 \text{ MPa}} = 0.344 \\ T_R = \frac{T}{T_{cr}} &= \frac{413 \text{ K}}{374.25 \text{ K}} = 1.104 \end{aligned} \right\} Z = 0.91$$

R-134a
1.4 MPa
140°C

Thus,

$$\nu = (Z)(\nu_{ideal}) = (0.91)(0.02404 \text{ m}^3/\text{kg}) = \mathbf{0.02188 \text{ m}^3/\text{kg}} \quad (0.05\% \text{ error})$$

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

$$\left. \begin{aligned} P &= 1.4 \text{ MPa} \\ T &= 140^\circ \text{C} \end{aligned} \right\} \nu = \mathbf{0.02189 \text{ m}^3/\text{kg}}$$

3-82 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,

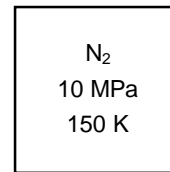
$$R = 0.2968 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K}, \quad T_{cr} = 126.2 \text{ K}, \quad P_{cr} = 3.39 \text{ MPa}$$

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

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

(b) From the compressibility chart (Fig. A-30),

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



Thus,

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

3-83 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,

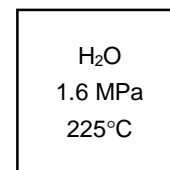
$$R = 0.4615 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K}, \quad T_{cr} = 647.3 \text{ K}, \quad P_{cr} = 22.09 \text{ MPa}$$

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

$$v = \frac{RT}{P} = \frac{(0.4615 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K})(498 \text{ K})}{1,600 \text{ kPa}} = \mathbf{0.14364 \text{ m}^3 / \text{kg}} \quad (8.1\% \text{ error})$$

(b) From the compressibility chart (Fig. A-30),

$$\left. \begin{aligned} P_R &= \frac{P}{P_{cr}} = \frac{1.6 \text{ MPa}}{22.09 \text{ MPa}} = 0.072 \\ T_R &= \frac{T}{T_{cr}} = \frac{498 \text{ K}}{647.3 \text{ K}} = 0.769 \end{aligned} \right\} Z = 0.935$$



Thus,

$$v = (Z)(v_{ideal}) = (0.935)(0.14364 \text{ m}^3 / \text{kg}) = \mathbf{0.13430 \text{ m}^3 / \text{kg}} \quad (1.1\% \text{ error})$$

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

$$\left. \begin{aligned} P &= 1.6 \text{ MPa} \\ T &= 225^\circ \text{C} \end{aligned} \right\} v = \mathbf{0.13287 \text{ m}^3 / \text{kg}}$$

3-84E The temperature of R-134a is to be determined using the ideal gas relation, the compressibility chart, and the R-134a tables.

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

$$R = 0.10517 \text{ psia} \cdot \text{ft}^3 / \text{lbm} \cdot \text{R}, \quad T_{cr} = 673.65 \text{ R}, \quad P_{cr} = 590 \text{ psia}$$

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

$$T = \frac{P\nu}{R} = \frac{(400 \text{ psia})(0.1386 \text{ ft}^3 / \text{lbm})}{(0.10517 \text{ psia} \cdot \text{ft}^3 / \text{lbm} \cdot \text{R})} = \mathbf{527.2 \text{ R}}$$

(b) From the compressibility chart (Fig. A-30a),

$$\left. \begin{aligned} P_R &= \frac{P}{P_{cr}} = \frac{400 \text{ psia}}{590 \text{ psia}} = 0.678 \\ \nu_R &= \frac{\nu_{\text{actual}}}{RT_{cr}/P_{cr}} = \frac{(0.1386 \text{ ft}^3 / \text{lbm})(590 \text{ psia})}{(0.10517 \text{ psia} \cdot \text{ft}^3 / \text{lbm} \cdot \text{R})(673.65 \text{ R})} = 1.15 \end{aligned} \right\} T_R = 1.03$$

Thus,

$$T = T_R T_{cr} = 1.03 \times 673.65 = \mathbf{693.9 \text{ R}}$$

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

$$\left. \begin{aligned} P &= 400 \text{ psia} \\ \nu &= 0.1386 \text{ ft}^3 / \text{lbm} \end{aligned} \right\} T = \mathbf{240^\circ \text{F} (700 \text{ R})}$$

3-85 The pressure of R-134a is to be determined using the ideal gas relation, the compressibility chart, and the R-134a tables.

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

$$R = 0.08149 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K}, \quad T_{cr} = 374.25 \text{ K}, \quad P_{cr} = 4.067 \text{ MPa}$$

Analysis The specific volume of the refrigerant is

$$v = \frac{V}{m} = \frac{0.01677 \text{ m}^3}{1 \text{ kg}} = 0.01677 \text{ m}^3 / \text{kg}$$

R-134a
0.01677
m ³ /kg
110°C

(a) From the ideal gas equation of state,

$$P = \frac{RT}{v} = \frac{(0.08149 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K})(383 \text{ K})}{0.01677 \text{ m}^3 / \text{kg}} = \mathbf{1861 \text{ kPa}}$$

(b) From the compressibility chart (Fig. A-30),

$$\left. \begin{aligned} T_R = \frac{T}{T_{cr}} &= \frac{383 \text{ K}}{374.25 \text{ K}} = 1.023 \\ v_R = \frac{v_{\text{actual}}}{RT_{cr}/P_{cr}} &= \frac{(0.01677 \text{ m}^3 / \text{kg})(4067 \text{ kPa})}{(0.08149 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K})(374.25 \text{ K})} = 2.24 \end{aligned} \right\} P_R = 0.39$$

Thus,

$$P = P_R P_{cr} = 0.39 \times 4067 = \mathbf{1586 \text{ kPa}}$$

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

$$\left. \begin{aligned} T &= 110^\circ \text{C} \\ v &= 0.01677 \text{ m}^3 / \text{kg} \end{aligned} \right\} \mathbf{P = 1600 \text{ kPa}}$$

3-86 Somebody claims that oxygen gas at a specified state can be treated as an ideal gas with an error less than 10%. The validity of this claim is to be determined.

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

$$T_{cr} = 154.8 \text{ K} \quad \text{and} \quad P_{cr} = 5.08 \text{ MPa}$$

Analysis From the compressibility chart (Fig. A-30),

$$\left. \begin{aligned} P_R = \frac{P}{P_{cr}} &= \frac{3 \text{ MPa}}{5.08 \text{ MPa}} = 0.591 \\ T_R = \frac{T}{T_{cr}} &= \frac{160 \text{ K}}{154.8 \text{ K}} = 1.034 \end{aligned} \right\} Z = 0.79$$

O ₂
3 MPa
160 K

Then the error involved can be determined from

$$\text{Error} = \frac{v - v_{\text{ideal}}}{v} = 1 - \frac{1}{Z} = 1 - \frac{1}{0.79} = -26.6\%$$

Thus the claim is **false**.

3-87 The % error involved in treating CO₂ at a specified state as an ideal gas is to be determined.

Properties The critical pressure, and the critical temperature of CO₂ are, from Table A-1,

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

Analysis From the compressibility chart (Fig. A-30),

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

<p>CO₂ 3 MPa 10°C</p>

Then the error involved in treating CO₂ as an ideal gas is

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

3-88 The % error involved in treating CO₂ at a specified state as an ideal gas is to be determined.

Properties The critical pressure, and the critical temperature of CO₂ are, from Table A-1,

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

Analysis From the compressibility chart (Fig. A-30),

$$\left. \begin{aligned} P_R = \frac{P}{P_{cr}} = \frac{5 \text{ MPa}}{7.39 \text{ MPa}} = 0.677 \\ T_R = \frac{T}{T_{cr}} = \frac{350 \text{ K}}{304.2 \text{ K}} = 1.15 \end{aligned} \right\} Z = 0.84$$

<p>CO₂ 5 MPa 350 K</p>

Then the error involved in treating CO₂ as an ideal gas is

$$\text{Error} = \frac{V - V_{\text{ideal}}}{V} = 1 - \frac{1}{Z} = 1 - \frac{1}{0.84} = -0.190 \text{ or } \mathbf{19.0\%}$$

Other Equations of State

3-89C 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.

3-90 The pressure of nitrogen in a tank at a specified state is to be determined using the ideal gas, van der Waals, and Beattie-Bridgeman equations. The error involved in each case is to be determined.

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

$$R = 0.2968 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K}, \quad M = 28.013 \text{ kg/kmol}, \quad T_{cr} = 126.2 \text{ K}, \quad P_{cr} = 3.39 \text{ MPa}$$

Analysis The specific volume of nitrogen is

$$v = \frac{V}{m} = \frac{3.27 \text{ m}^3}{100 \text{ kg}} = 0.0327 \text{ m}^3 / \text{kg}$$

N_2 $0.0327 \text{ m}^3 / \text{kg}$ 225 K

(a) From the ideal gas equation of state,

$$P = \frac{RT}{v} = \frac{(0.2968 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K})(225 \text{ K})}{0.0327 \text{ m}^3 / \text{kg}} = \mathbf{2042 \text{ kPa}} \quad (2.1\% \text{ error})$$

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

$$a = \frac{27 R^2 T_{cr}^2}{64 P_{cr}} = \frac{(27)(0.2968 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K})^2 (126.2 \text{ K})^2}{(64)(3390 \text{ kPa})} = 0.175 \text{ m}^6 \cdot \text{kPa} / \text{kg}^2$$

$$b = \frac{RT_{cr}}{8 P_{cr}} = \frac{(0.2968 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K})(126.2 \text{ K})}{8 \times 3390 \text{ kPa}} = 0.00138 \text{ m}^3 / \text{kg}$$

Then,

$$P = \frac{RT}{v-b} - \frac{a}{v^2} = \frac{0.2968 \times 225}{0.0327 - 0.00138} - \frac{0.175}{(0.0327)^2} = \mathbf{1969 \text{ kPa}} \quad (1.6\% \text{ error})$$

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

$$A = A_o \left(1 - \frac{a}{v} \right) = 136.2315 \left(1 - \frac{0.02617}{0.9160} \right) = 132.339$$

$$B = B_o \left(1 - \frac{b}{v} \right) = 0.05046 \left(1 - \frac{-0.00691}{0.9160} \right) = 0.05084$$

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

since $\bar{v} = Mv = (28.013 \text{ kg/kmol})(0.0327 \text{ m}^3 / \text{kg}) = 0.9160 \text{ m}^3 / \text{kmol}$. Substituting,

$$P = \frac{R_u T}{\bar{v}^2} \left(1 - \frac{c}{\bar{v} T^3} \right) \left(\bar{v} + B \right) - \frac{A}{\bar{v}^2}$$

$$= \frac{8.314 \times 225}{(0.9160)^2} \left(1 - \frac{4.2 \times 10^4}{0.9160 \times 225^3} \right) (0.9160 + 0.05084) - \frac{132.339}{(0.9160)^2} = \mathbf{1989 \text{ kPa}} \quad (0.6\% \text{ error})$$

3-91 The temperature of steam in a tank at a specified state is to be determined using the ideal gas relation, van der Waals equation, and the steam tables.

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

$$R = 0.4615 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K}, \quad T_{cr} = 647.3 \text{ K}, \quad P_{cr} = 22.09 \text{ MPa}$$

Analysis The specific volume of steam is

$$v = \frac{V}{m} = \frac{1 \text{ m}^3}{2.841 \text{ kg}} = 0.3520 \text{ m}^3 / \text{kg}$$

H ₂ O
1 m ³
2.841 kg
0.6 MPa

(a) From the ideal gas equation of state,

$$T = \frac{Pv}{R} = \frac{(600 \text{ kPa})(0.352 \text{ m}^3 / \text{kg})}{0.4615 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K}} = \mathbf{457.6 \text{ K}}$$

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

$$a = \frac{27 R^2 T_{cr}^2}{64 P_{cr}} = \frac{(27)(0.4615 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K})^2 (647.3 \text{ K})^2}{(64)(22,090 \text{ kPa})} = 1.704 \text{ m}^6 \cdot \text{kPa} / \text{kg}^2$$

$$b = \frac{RT_{cr}}{8 P_{cr}} = \frac{(0.4615 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K})(647.3 \text{ K})}{8 \times 22,090 \text{ kPa}} = 0.00169 \text{ m}^3 / \text{kg}$$

Then,

$$T = \frac{1}{R} \left(P + \frac{a}{v^2} \right) (v - b) = \frac{1}{0.4615} \left(600 + \frac{1.704}{(0.3520)^2} \right) (0.352 - 0.00169) = \mathbf{465.9 \text{ K}}$$

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

$$\left. \begin{array}{l} P = 0.6 \text{ MPa} \\ v = 0.352 \text{ m}^3 / \text{kg} \end{array} \right\} T = \mathbf{200^\circ \text{C}} \quad (= 473 \text{ K})$$

3-92 Problem 3-91 is reconsidered. The problem is to be solved using EES (or other) software. The temperature of water is to be compared for the three cases at constant specific volume over the pressure range of 0.1 MPa to 1 MPa in 0.1 MPa increments. The %error involved in the ideal gas approximation is to be plotted against pressure.

Function vanderWaals(T,v,M,R_u,T_cr,P_cr)

v_bar=v*M "Conversion from m³/kg to m³/kmol"

"The constants for the van der Waals equation of state are given by equation 2-24"

a=27*R_u^2*T_cr^2/(64*P_cr)

b=R_u*T_cr/(8*P_cr)

"The van der Waals equation of state gives the pressure as"

vanderWaals:=R_u*T/(v_bar-b)-a/v_bar**2

End

m=2.841"[kg]"

Vol=1"[m^3]"

{P=6*convert(MPa,kPa)"[kPa]"}

T_cr=T_CRIT(Steam)

P_cr=P_CRIT(Steam)

v=Vol/m"[m3/kg]"

P_table=P; P_vdW=P;P_idealgas=P

T_table=temperature(Steam,P=P_table,v=v)"[K]" "EES data for steam as a real gas"

{P_table=pressure(Steam, T=T_table,v=v)}

{T_sat=temperature(Steam,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=R*T_idealgas/v"[kPa]" "Ideal gas equation"

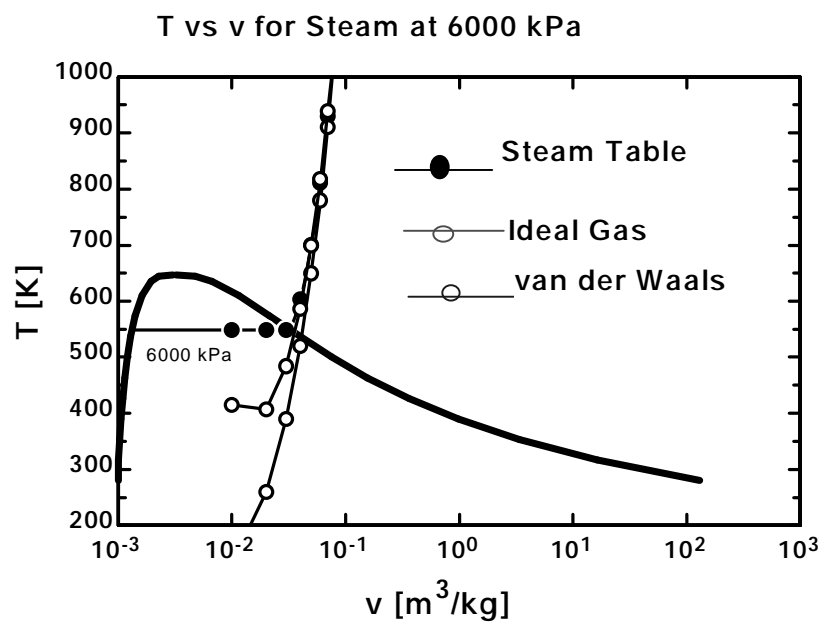
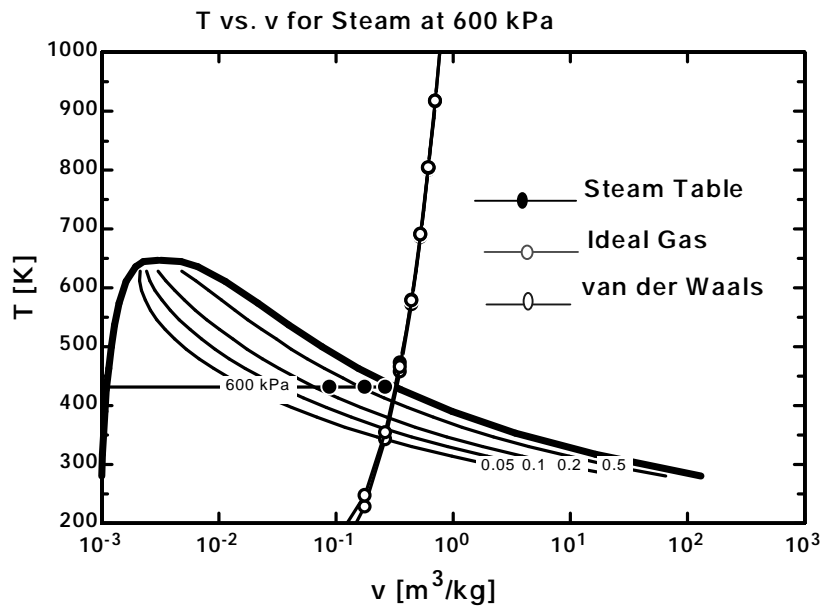
"The value of P_vdW is found from van der Waals equation of state Function"

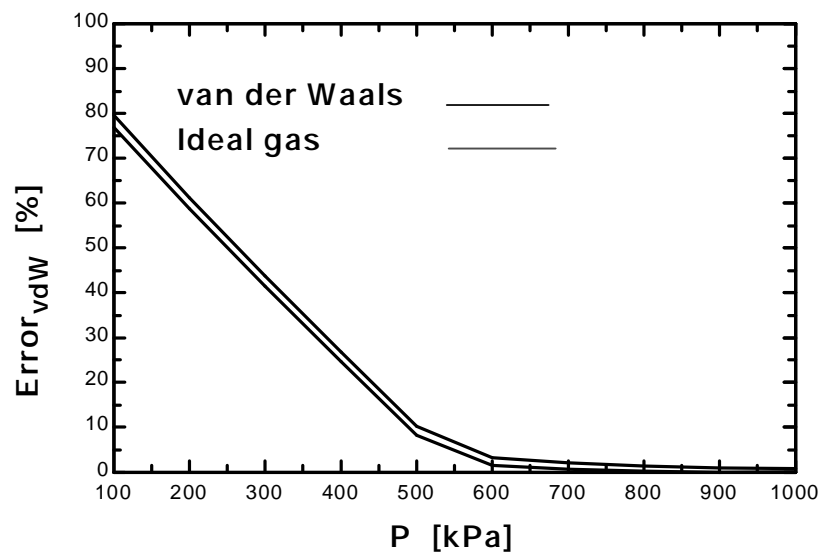
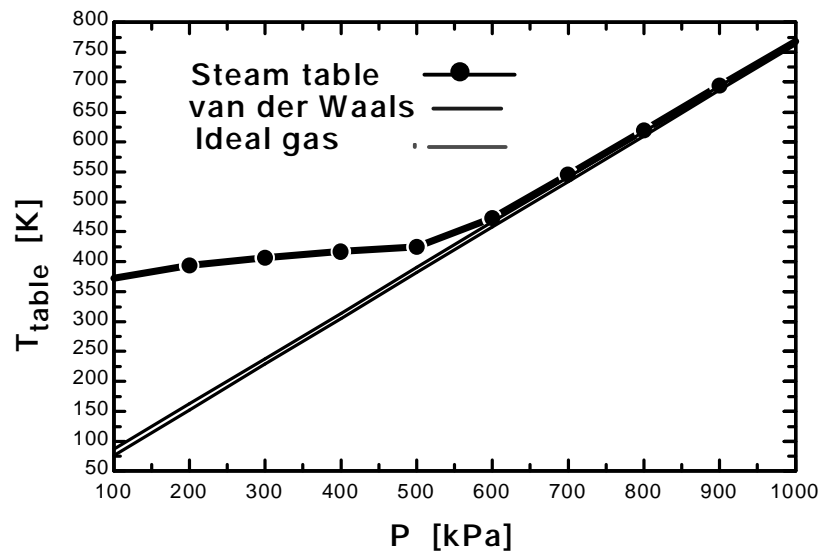
P_vdW=vanderWaals(T_vdW,v,MM,R_u,T_cr,P_cr)"[kPa]"

Error_idealgas=Abs(T_table-T_idealgas)/T_table*100"[%]"

Error_vdW=Abs(T_table-T_vdW)/T_table*100"[%]"

P [kPa]	T _{ideal gas} [K]	T _{table} [K]	T _{vdW} [K]	Error _{ideal gas} [K]
100	76.27	372.8	86.36	79.54
200	152.5	393.4	162.3	61.22
300	228.8	406.7	238.2	43.73
400	305.1	416.8	314.1	26.8
500	381.4	425	390	10.26
600	457.6	473.2	465.9	3.282
700	533.9	545.4	541.8	2.105
800	610.2	619.2	617.7	1.448
900	686.5	693.7	693.6	1.042
1000	762.7	768.7	769.5	0.7724





3-93E 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. \checkmark

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

$$R = 0.1052 \text{ psia} \cdot \text{ft}^3/\text{lbm} \cdot \text{R}, \quad T_{\text{cr}} = 673.65 \text{ R}, \quad P_{\text{cr}} = 590 \text{ psia}$$

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

$$T = \frac{Pv}{R} = \frac{(100 \text{ psia})(0.5388 \text{ ft}^3/\text{lbm})}{0.1052 \text{ psia} \cdot \text{ft}^3/\text{lbm} \cdot \text{R}} = \mathbf{512.2 \text{ R}}$$

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

$$a = \frac{27 R^2 T_{\text{cr}}^2}{64 P_{\text{cr}}} = \frac{(27)(0.1052 \text{ psia} \cdot \text{ft}^3/\text{lbm} \cdot \text{R})^2 (673.65 \text{ R})^2}{(64)(590 \text{ psia})} = 3.591 \text{ ft}^6 \cdot \text{psia}/\text{lbm}^2$$

$$b = \frac{RT_{\text{cr}}}{8 P_{\text{cr}}} = \frac{(0.1052 \text{ psia} \cdot \text{ft}^3/\text{lbm} \cdot \text{R})(673.65 \text{ R})}{8 \times 590 \text{ psia}} = 0.0150 \text{ ft}^3/\text{lbm}$$

Then,

$$T = \frac{1}{R} \left(P + \frac{a}{v^2} \right) (v - b) = \frac{1}{0.1052} \left(100 + \frac{3.591}{(0.5388)^2} \right) (0.5388 - 0.0150) = \mathbf{559.5 \text{ R}}$$

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

$$\left. \begin{array}{l} P = 100 \text{ psia} \\ v = 0.5388 \text{ ft}^3/\text{lbm} \end{array} \right\} T = \mathbf{120^\circ \text{F}} (580 \text{ R})$$

3-94 [Also solved by EES on enclosed CD] 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,

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

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

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

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

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

N ₂
0.041884
m ³ /kg
150 K

since $\bar{v} = Mv = (28.013 \text{ kg/kmol})(0.041884 \text{ m}^3 / \text{kg}) = 1.1733 \text{ m}^3 / \text{kmol}$. Substituting,

$$\begin{aligned} P &= \frac{R_u T}{\bar{v}^2} \left(1 - \frac{c}{\bar{v} T^3} \right) \left(\bar{v} + B \right) - \frac{A}{\bar{v}^2} \\ &= \frac{8.314 \times 150}{(1.1733)^2} \left(1 - \frac{4.2 \times 10^4}{1.1733 \times 150^3} \right) (1.1733 + 0.05076) - \frac{133.193}{(1.1733)^2} \\ &= \mathbf{1000.4 \text{ kPa}} \quad (\text{negligible error}) \end{aligned}$$

3-95 Problem 3-94 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 K < T < 150 K.

Function BeattBridg(T,v,M,R_u)

v_bar=v*M "Conversion from m³/kg to m³/kmol"

"The constants for the Beattie-Bridgeman equation of state are found in Table A-29"

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 "m³/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)

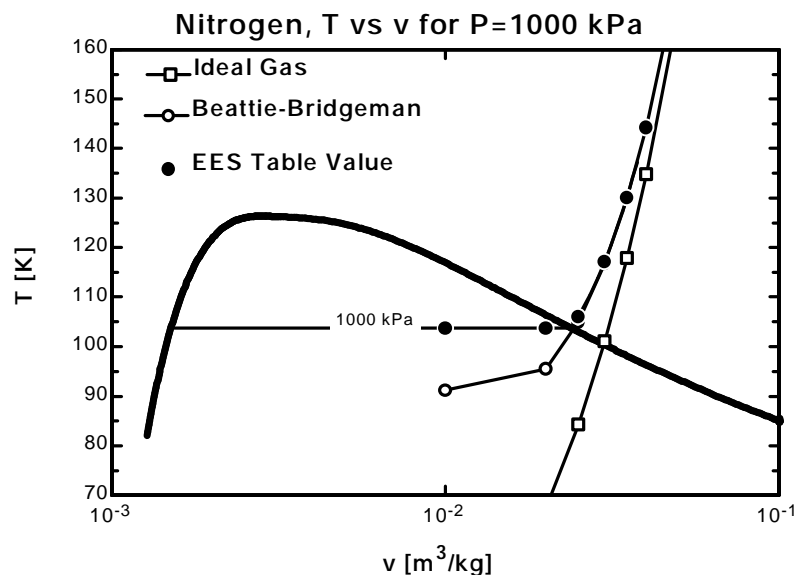
R_u=8.314 "kJ/kg-K" "Universal gas constant"

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



Specific Heats, Δu and Δh of Ideal Gases

3-96C It can be used for any kind of process of an ideal gas.

3-97C It can be used for any kind of process of an ideal gas.

3-98C The desired result is obtained by multiplying the first relation by the molar mass M

$$MC_p = MC_v + MR$$

or $C_p = C_v + R_u$

3-99C Very close, but no. Because the heat transfer during this process is $Q = mC_p\Delta T$, and C_p varies with temperature.

3-100C It can be either. The difference in temperature in both the K and °C scales is the same.

3-101C The energy required is $mC_p\Delta T$, which will be the same in both cases. This is because the C_p of an ideal gas does not vary with pressure.

3-102C The energy required is $mC_p\Delta T$, which will be the same in both cases. This is because the C_p of an ideal gas does not vary with volume.

3-103C For the constant pressure case. This is because the heat transfer to an ideal gas is $mC_p\Delta T$ at constant pressure, $mC_v\Delta T$ at constant volume, and C_p is always greater than C_v .

3-104 The enthalpy change of nitrogen gas during a heating process is to be determined using an empirical specific heat relation, constant specific heat at average temperature, and constant specific heat at room temperature.

Analysis (a) Using the empirical relation for $\bar{c}_p(T)$ from Table A-2c,

$$\bar{c}_p = a + bT + cT^2 + dT^3$$

where $a = 28.90$, $b = -0.1571 \times 10^{-2}$, $c = 0.8081 \times 10^{-5}$, and $d = -2.873 \times 10^{-9}$. Then,

$$\begin{aligned} \Delta \bar{h} &= \int_1^2 \bar{c}_p(T) dT = \int_1^2 [a + bT + cT^2 + dT^3] dT \\ &= a(T_2 - T_1) + \frac{b}{2}(T_2^2 - T_1^2) + \frac{c}{3}(T_2^3 - T_1^3) + \frac{d}{4}(T_2^4 - T_1^4) \\ &= 28.90(1000 - 600) - \frac{1}{2}(0.1571 \times 10^{-2})(1000^2 - 600^2) \\ &\quad + \frac{1}{3}(0.8081 \times 10^{-5})(1000^3 - 600^3) - \frac{1}{4}(2.873 \times 10^{-9})(1000^4 - 600^4) \\ &= 12,544 \text{ kJ/kmol} \\ \Delta h &= \frac{\Delta \bar{h}}{M} = \frac{12,544 \text{ kJ/kmol}}{28.013 \text{ kg/kmol}} = \mathbf{447.8 \text{ kJ/kg}} \quad (0.2\% \text{ error}) \end{aligned}$$

(b) Using the constant C_p value from Table A-2b at the average temperature of 800 K,

$$\begin{aligned} C_{p,ave} &= C_{p@800\text{K}} = 1.121 \text{ kJ/kg} \cdot \text{K} \\ \Delta h &= C_{p,ave}(T_2 - T_1) = (1.121 \text{ kJ/kg} \cdot \text{K})(1000 - 600) \text{ K} = \mathbf{448.4 \text{ kJ/kg}} \end{aligned}$$

(c) Using the constant C_p value from Table A-2a at room temperature,

$$\begin{aligned} C_{p,ave} &= C_{p@300\text{K}} = 1.039 \text{ kJ/kg} \cdot \text{K} \\ \Delta h &= C_{p,ave}(T_2 - T_1) = (1.039 \text{ kJ/kg} \cdot \text{K})(1000 - 600) \text{ K} = \mathbf{415.6 \text{ kJ/kg}} \end{aligned}$$

3-105E The enthalpy change of oxygen gas during a heating process is to be determined using an empirical specific heat relation, constant specific heat at average temperature, and constant specific heat at room temperature.

Analysis (a) Using the empirical relation for $\bar{c}_p(T)$ from Table A-2Ec,

$$\bar{c}_p = a + bT + cT^2 + dT^3$$

where $a = 6.085$, $b = 0.2017 \times 10^{-2}$, $c = -0.05275 \times 10^{-5}$, and $d = 0.05372 \times 10^{-9}$. Then,

$$\begin{aligned} \Delta \bar{h} &= \int_1^2 \bar{c}_p(T) dT = \int_1^2 [a + bT + cT^2 + dT^3] dT \\ &= a(T_2 - T_1) + \frac{b}{2}(T_2^2 - T_1^2) + \frac{c}{3}(T_2^3 - T_1^3) + \frac{d}{4}(T_2^4 - T_1^4) \\ &= 6.085(1500 - 800) + \frac{1}{2}(0.2017 \times 10^{-2})(1500^2 - 800^2) \\ &\quad - \frac{1}{3}(0.05275 \times 10^{-5})(1500^3 - 800^3) + \frac{1}{4}(0.05372 \times 10^{-9})(1500^4 - 800^4) \\ &= 5442.3 \text{ Btu/lbmol} \\ \Delta h &= \frac{\Delta \bar{h}}{M} = \frac{5442.3 \text{ Btu/lbmol}}{31.999 \text{ lbm/lbmol}} = \mathbf{170.1 \text{ Btu/lbm}} \end{aligned}$$

(b) Using the constant C_p value from Table A-2Eb at the average temperature of 1150 R,

$$\begin{aligned} C_{p,ave} &= C_{p@1150 \text{ R}} = 0.255 \text{ Btu/lbm} \cdot \text{R} \\ \Delta h &= C_{p,ave}(T_2 - T_1) = (0.255 \text{ Btu/lbm} \cdot \text{R})(1500 - 800) \text{ R} = \mathbf{178.5 \text{ Btu/lbm}} \end{aligned}$$

(c) Using the constant C_p value from Table A-2Ea at room temperature,

$$\begin{aligned} C_{p,ave} &= C_{p@537 \text{ R}} = 0.219 \text{ Btu/lbm} \cdot \text{R} \\ \Delta h &= C_{p,ave}(T_2 - T_1) = (0.219 \text{ Btu/lbm} \cdot \text{R})(1500 - 800) \text{ R} = \mathbf{153.3 \text{ Btu/lbm}} \end{aligned}$$

3-106 The internal energy change of hydrogen gas during a heating process is to be determined using an empirical specific heat relation, constant specific heat at average temperature, and constant specific heat at room temperature.

Analysis (a) Using the empirical relation for $\bar{C}_p(T)$ from Table A-2c and relating it to $\bar{C}_v(T)$,

$$\bar{C}_v(T) = \bar{C}_p - R_u = (a - R_u) + bT + cT^2 + dT^3$$

where $a = 29.11$, $b = -0.1916 \times 10^{-2}$, $c = 0.4003 \times 10^{-5}$, and $d = -0.8704 \times 10^{-9}$. Then,

$$\begin{aligned} \Delta \bar{u} &= \int_1^2 \bar{C}_v(T) dT = \int_1^2 [(a - R_u) + bT + cT^2 + dT^3] dT \\ &= (a - R_u)(T_2 - T_1) + \frac{1}{2}b(T_2^2 - T_1^2) + \frac{1}{3}c(T_2^3 - T_1^3) + \frac{1}{4}d(T_2^4 - T_1^4) \\ &= (29.11 - 8.314)(1000 - 400) - \frac{1}{2}(0.1961 \times 10^{-2})(1000^2 - 400^2) \\ &\quad + \frac{1}{3}(0.4003 \times 10^{-5})(1000^3 - 400^3) - \frac{1}{4}(0.8704 \times 10^{-9})(1000^4 - 400^4) \\ &= 12,691 \text{ kJ/kmol} \\ \Delta u &= \frac{\Delta \bar{u}}{M} = \frac{12,691 \text{ kJ/kmol}}{2.016 \text{ kg/kmol}} = \mathbf{6295.3 \text{ kJ/kg}} \end{aligned}$$

(b) Using a constant C_p value from Table A-2b at the average temperature of 700 K,

$$\begin{aligned} C_{v,ave} &= C_{v@700 \text{ K}} = 10.48 \text{ kJ/kg} \cdot \text{K} \\ \Delta u &= C_{v,ave}(T_2 - T_1) = (10.48 \text{ kJ/kg} \cdot \text{K})(1000 - 400)\text{K} = \mathbf{6288 \text{ kJ/kg}} \end{aligned}$$

(c) Using a constant C_p value from Table A-2a at room temperature,

$$\begin{aligned} C_{v,ave} &= C_{v@300 \text{ K}} = 10.183 \text{ kJ/kg} \cdot \text{K} \\ \Delta u &= C_{v,ave}(T_2 - T_1) = (10.183 \text{ kJ/kg} \cdot \text{K})(1000 - 400)\text{K} = \mathbf{6110 \text{ kJ/kg}} \end{aligned}$$

Review Problems

3-107 A smoking lounge that can accommodate 15 smokers is considered. The required minimum flow rate of air that needs to be supplied to the lounge and the diameter of the duct are to be determined.

Assumptions Infiltration of air into the smoking lounge is negligible.

Properties The minimum fresh air requirements for a smoking lounge is given to be 30 L/s per person.

Analysis The required minimum flow rate of air that needs to be supplied to the lounge is determined directly from

$$\begin{aligned}\dot{V}_{\text{air}} &= \dot{V}_{\text{air per person}} (\text{No. of persons}) \\ &= (30 \text{ L/s} \cdot \text{person})(15 \text{ persons}) = 450 \text{ L/s} = \mathbf{0.45 \text{ m}^3/\text{s}}\end{aligned}$$

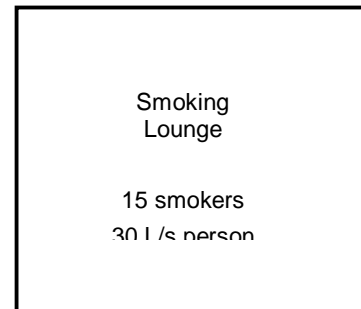
The volume flow rate of fresh air can be expressed as

$$\dot{V} = \mathbf{VA} = \mathbf{V(\pi D^2/4)}$$

Solving for the diameter D and substituting,

$$D = \sqrt{\frac{4\dot{V}}{\pi V}} = \sqrt{\frac{4(0.45 \text{ m}^3/\text{s})}{\pi(8 \text{ m/s})}} = \mathbf{0.268 \text{ m}}$$

Therefore, the diameter of the fresh air duct should be at least 26.8 cm if the velocity of air is not to exceed 8 m/s.



3-108 The minimum fresh air requirements of a residential building is specified to be 0.35 air changes per hour. The size of the fan that needs to be installed and the diameter of the duct are to be determined. ✓

Analysis The volume of the building and the required minimum volume flow rate of fresh air are

$$\begin{aligned}V_{\text{room}} &= (2.7 \text{ m})(200 \text{ m}^2) = 540 \text{ m}^3 \\ \dot{V} &= V_{\text{room}} \times \text{ACH} = (540 \text{ m}^3)(0.35/\text{h}) = 189 \text{ m}^3/\text{h} = 189,000 \text{ L/h} = \mathbf{3150 \text{ L/min}}\end{aligned}$$

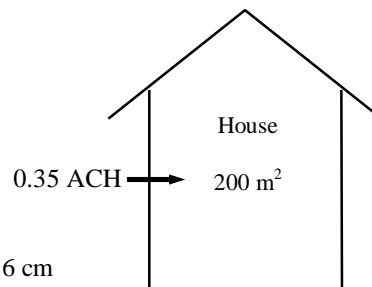
The volume flow rate of fresh air can be expressed as

$$\dot{V} = \mathbf{VA} = \mathbf{V(\pi D^2/4)}$$

Solving for the diameter D and substituting,

$$D = \sqrt{\frac{4\dot{V}}{\pi V}} = \sqrt{\frac{4(189/3600 \text{ m}^3/\text{s})}{\pi(6 \text{ m/s})}} = \mathbf{0.106 \text{ m}}$$

Therefore, the diameter of the fresh air duct should be at least 10.6 cm if the velocity of air is not to exceed 6 m/s.



3-109 The pressure in an automobile tire increases during a trip while its volume remains constant. The percent increase in the absolute temperature of the air in the tire is to be determined.

Assumptions **1** The volume of the tire remains constant. **2** Air is an ideal gas.

Properties The local atmospheric pressure is 90 kPa.

Analysis The absolute pressures in the tire before and after the trip are

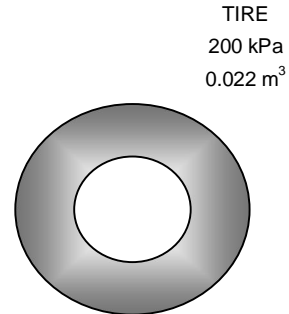
$$P_1 = P_{\text{gage},1} + P_{\text{atm}} = 200 + 90 = 290 \text{ kPa}$$

$$P_2 = P_{\text{gage},2} + P_{\text{atm}} = 220 + 90 = 310 \text{ kPa}$$

Noting that air is an ideal gas and the volume is constant, the ratio of absolute temperatures after and before the trip are

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \rightarrow \frac{T_2}{T_1} = \frac{P_2}{P_1} = \frac{310 \text{ kPa}}{290 \text{ kPa}} = 1.069$$

Therefore, the absolute temperature of air in the tire will increase by **6.9%** during this trip.



3-110 A hot air balloon with 3 people in its cage is hanging still in the air. The average temperature of the air in the balloon for two environment temperatures is to be determined.

Assumptions Air is an ideal gas.

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

Analysis The buoyancy force acting on the balloon is

$$V_{\text{balloon}} = 4\pi r^3 / 3 = 4\pi (10\text{m})^3 / 3 = 4189\text{m}^3$$

$$\rho_{\text{cool air}} = \frac{P}{RT} = \frac{90\text{kPa}}{(0.287\text{kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K})(288\text{K})} = 1.089\text{kg/m}^3$$

$$F_B = \rho_{\text{cool air}} g V_{\text{balloon}} = (1.089 \text{ kg/m}^3)(9.8 \text{ m/s}^2)(4189 \text{ m}^3) \left(\frac{1 \text{ N}}{1\text{kg} \cdot \text{m/s}^2} \right) = 44,700 \text{ N}$$

The vertical force balance on the balloon gives

$$F_B = W_{\text{hot air}} + W_{\text{cage}} + W_{\text{people}} = (m_{\text{hot air}} + m_{\text{cage}} + m_{\text{people}})g$$

Substituting,

$$44,700 \text{ N} = (m_{\text{hot air}} + 80 \text{ kg} + 195 \text{ kg})(9.8 \text{ m/s}^2) \left(\frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right)$$

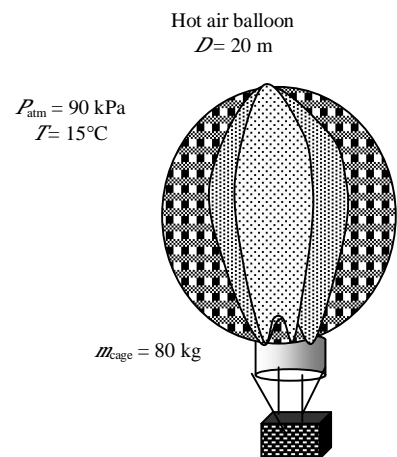
which gives

$$m_{\text{hot air}} = 4287 \text{ kg}$$

Therefore, the average temperature of the air in the balloon is

$$T = \frac{PV}{mR} = \frac{(90 \text{ kPa})(4189 \text{ m}^3)}{(4287 \text{ kg})(0.287 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K})} = \mathbf{306.5 \text{ K}}$$

Repeating the solution above for an atmospheric air temperature of 30°C gives **323.6 K** for the average air temperature in the balloon.



3-111 Problem 3-110 is to be reconsidered. The effect of the environment temperature on the average air temperature in the balloon when the balloon is suspended in the air is to be investigated as the environment temperature varies from -10°C to 30°C . The average air temperature in the balloon is to be plotted versus the environment temperature.

"Given Data:"

"atm---atmosphere about balloon"

"gas---heated air inside balloon"

$g=9.807\text{ [m/s}^2\text{]}$

$d_{\text{balloon}}=20\text{ [m]}$

$m_{\text{cage}}=80\text{ [kg]}$

$m_{\text{1person}}=65\text{ [kg]}$

$\text{NoPeople}=6$

$\{T_{\text{atm,Celsius}}=15\text{ [C]}\}$

$T_{\text{atm}}=T_{\text{atm,Celsius}}+273\text{ [K]}$

$P_{\text{atm}}=90\text{ [kPa]}$

$R=0.287\text{ [kJ/kg}\cdot\text{K]}$

$P_{\text{gas}}=P_{\text{atm}}\text{ [kPa]}$

$T_{\text{gas,Celsius}}=T_{\text{gas}}-273\text{ [C]}$

"Calculated values:"

$P_{\text{atm}}=\rho_{\text{atm}}R T_{\text{atm}}$ " ρ_{atm} = density of air outside balloon"

$P_{\text{gas}}=\rho_{\text{gas}}R T_{\text{gas}}$ " ρ_{gas} = density of gas inside balloon"

$r_{\text{balloon}}=d_{\text{balloon}}/2\text{ [m]}$

$V_{\text{balloon}}=4\pi r_{\text{balloon}}^3/3\text{ [m}^3\text{]}$

$m_{\text{people}}=\text{NoPeople}\cdot m_{\text{1person}}\text{ [kg]}$

$m_{\text{gas}}=\rho_{\text{gas}}V_{\text{balloon}}\text{ [kg]}$

$m_{\text{total}}=m_{\text{gas}}+m_{\text{people}}+m_{\text{cage}}\text{ [kg]}$

"The total weight of balloon, people, and cage is:"

$W_{\text{total}}=m_{\text{total}}\cdot g\text{ [N]}$

"The buoyancy force acting on the balloon, F_b , is equal to the weight of the air displaced by the balloon."

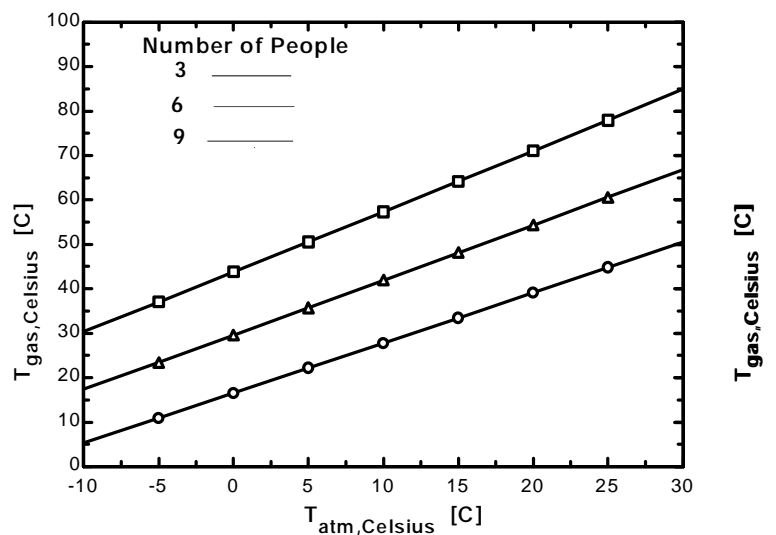
$F_b=\rho_{\text{atm}}V_{\text{balloon}}\cdot g\text{ [N]}$

"From the free body diagram of the balloon, the balancing vertical forces must equal the product of the total mass and the vertical acceleration:"

$F_b - W_{\text{total}}=m_{\text{total}}\cdot a_{\text{up}}$

$a_{\text{up}}=0\text{ [m/s}^2\text{]}$ "The balloon is hanging still in the air"

$T_{\text{atm,Celsius}}\text{ [C]}$	$T_{\text{gas,Celsius}}\text{ [C]}$
-10	17.32
-5	23.42
0	29.55
5	35.71
10	41.89
15	48.09
20	54.31
25	60.57
30	66.84



Chapter 3 *Properties of Pure Substances*

3-112 A hot air balloon with 2 people in its cage is about to take off. The average temperature of the air in the balloon for two environment temperatures is to be determined.

Assumptions Air is an ideal gas.

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

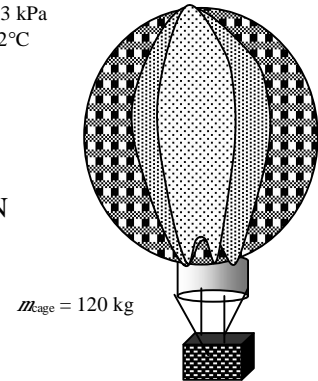
Analysis The buoyancy force acting on the balloon is

$$V_{\text{balloon}} = 4\pi r^3 / 3 = 4\pi (9 \text{ m})^3 / 3 = 3054 \text{ m}^3$$

$$\rho_{\text{coolair}} = \frac{P}{RT} = \frac{93 \text{ kPa}}{(0.287 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K})(285 \text{ K})} = 1.137 \text{ kg/m}^3$$

$$F_B = \rho_{\text{coolair}} g V_{\text{balloon}} = (1.137 \text{ kg/m}^3)(9.8 \text{ m/s}^2)(3054 \text{ m}^3) \left(\frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) = 34,029 \text{ N}$$

Hot air balloon
 $D = 18 \text{ m}$



The vertical force balance on the balloon gives

$$F_B = W_{\text{hotair}} + W_{\text{cage}} + W_{\text{people}} = (m_{\text{hotair}} + m_{\text{cage}} + m_{\text{people}})g$$

Substituting,

$$34,029 \text{ N} = (m_{\text{hotair}} + 120 \text{ kg} + 140 \text{ kg})(9.8 \text{ m/s}^2) \left(\frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right)$$

which gives

$$m_{\text{hot air}} = 3212 \text{ kg}$$

Therefore, the average temperature of the air in the balloon is

$$T = \frac{PV}{mR} = \frac{(93 \text{ kPa})(3054 \text{ m}^3)}{(3212 \text{ kg})(0.287 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K})} = \mathbf{308 \text{ K}}$$

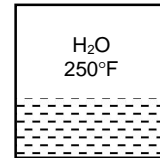
Repeating the solution above for an atmospheric air temperature of 25°C gives **323 K** for the average air temperature in the balloon.

Chapter 3 *Properties of Pure Substances*

3-113E Water in a pressure cooker boils at 260°F. The absolute pressure in the pressure cooker is to be determined.

Analysis The absolute pressure in the pressure cooker is the saturation pressure that corresponds to the boiling temperature,

$$P = P_{\text{sat @ 260°F}} = \mathbf{35.42 \text{ psia}}$$



3-114 The refrigerant in a rigid tank is allowed to cool. The pressure at which the refrigerant starts condensing is to be determined, and the process is to be shown on a P - v diagram.

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

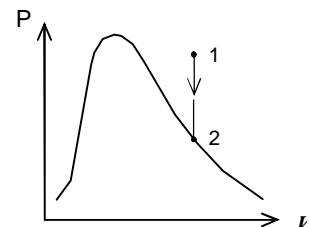
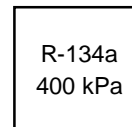
$$v = \frac{V}{m} = \frac{0.07 \text{ m}^3}{1 \text{ kg}} = 0.07 \text{ m}^3/\text{kg}$$

When the refrigerant starts condensing, the tank will contain saturated vapor only. Thus,

$$v_2 = v_g = 0.07 \text{ m}^3/\text{kg}$$

The pressure at this point is the pressure that corresponds to this v_g value,

$$P_2 = P_{\text{sat @ } v_g = 0.07 \text{ m}^3/\text{kg}} = \mathbf{0.29 \text{ MPa}}$$



3-115 The rigid tank contains saturated liquid-vapor mixture of water. The mixture is heated until it exists in a single phase. For a given tank volume, it is to be determined if the final phase is a liquid or a vapor.

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

$$v_2 = v_1$$

The critical specific volume of water is $0.003155 \text{ m}^3/\text{kg}$. Thus if the final specific volume is smaller than this value, the water will exist as a liquid, otherwise as a vapor.

H ₂ O
V = 4 L
m = 2 kg
T = 50°C

$$V = 4 \text{ L} \longrightarrow v = \frac{V}{m} = \frac{0.004 \text{ m}^3}{2 \text{ kg}} = 0.002 \text{ m}^3/\text{kg} < v_{cr} \quad \text{Thus, liquid.}$$

$$V = 400 \text{ L} \longrightarrow v = \frac{V}{m} = \frac{0.4 \text{ m}^3}{2 \text{ kg}} = 0.2 \text{ m}^3/\text{kg} > v_{cr} \quad \text{Thus, vapor.}$$

3-116 Superheated refrigerant-134a is cooled at constant pressure until it exists as a compressed liquid. The changes in total volume and internal energy are to be determined, and the process is to be shown on a T - v diagram.

Analysis The refrigerant is a superheated vapor at the initial state and a compressed liquid at the final state. From Tables A-13 and A-11,

$$\left. \begin{array}{l} P_1 = 0.8 \text{ MPa} \\ T_1 = 40^\circ \text{C} \end{array} \right\} \begin{array}{l} u_1 = 252.13 \text{ kJ/kg} \\ v_1 = 0.02691 \text{ m}^3/\text{kg} \end{array}$$

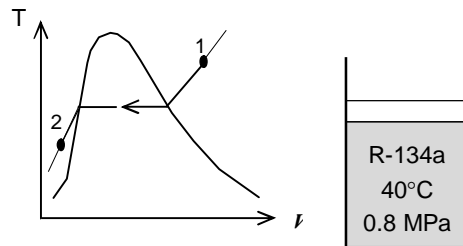
$$\left. \begin{array}{l} P_2 = 0.8 \text{ MPa} \\ T_2 = 20^\circ \text{C} \end{array} \right\} \begin{array}{l} u_2 \cong u_{f@20^\circ \text{C}} = 76.80 \text{ kJ/kg} \\ v_2 \cong v_{f@20^\circ \text{C}} = 0.0008157 \text{ m}^3/\text{kg} \end{array}$$

Thus,

$$\Delta V = m(v_2 - v_1) = (10 \text{ kg})(0.0008157 - 0.02691) \text{ m}^3/\text{kg} = -0.261 \text{ m}^3$$

and

$$\Delta U = m(u_2 - u_1) = (10 \text{ kg})(76.80 - 252.13) \text{ kJ/kg} = -1753.3 \text{ kJ}$$



3-117 Two rigid tanks that contain hydrogen at two different states are connected to each other. Now a valve is opened, and the two gases are allowed to mix while achieving thermal equilibrium with the surroundings. The final pressure in the tanks is to be determined.

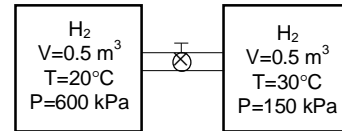
Analysis Let's call the first and the second tanks A and B. Treating H_2 as an ideal gas, the total volume and the total mass of H_2 are

$$V = V_A + V_B = 0.5 + 0.5 = 1.0 \text{ m}^3$$

$$m_A = \left(\frac{PV}{RT_1} \right)_A = \frac{(600 \text{ kPa})(0.5 \text{ m}^3)}{(4.124 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K})(293 \text{ K})} = 0.248 \text{ kg}$$

$$m_B = \left(\frac{PV}{RT_1} \right)_B = \frac{(150 \text{ kPa})(0.5 \text{ m}^3)}{(4.124 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K})(303 \text{ K})} = 0.060 \text{ kg}$$

$$m = m_A + m_B = 0.248 + 0.060 = 0.308 \text{ kg}$$



Then the final pressure can be determined from

$$P = \frac{mRT_2}{V} = \frac{(0.308 \text{ kg})(4.124 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K})(288 \text{ K})}{1.0 \text{ m}^3} = \mathbf{365.8 \text{ kPa}}$$

3-118 Problem 3-117 is reconsidered. The effect of the surroundings temperature on the final equilibrium pressure in the tanks is to be investigated as the surroundings temperature varies from -10°C to 30°C. The final pressure in the tanks is to be plotted versus the surroundings temperature, and the results are to be discussed.

"Given Data"

$$V_A = 0.5 \text{ [m}^3\text{]}$$

$$T_A = 20 \text{ [}^\circ\text{C}\text{]}$$

$$P_A = 600 \text{ [kPa]}$$

$$V_B = 0.5 \text{ [m}^3\text{]}$$

$$T_B = 30 \text{ [}^\circ\text{C}\text{]}$$

$$P_B = 150 \text{ [kPa]}$$

$$\{T_2 = 15 \text{ [}^\circ\text{C}\text{]}\}$$

"Solution"

$$R = 8.314 / \text{MOLARMASS}(\text{H}_2) \text{ [kJ/kg-K]}$$

$$V_{\text{total}} = V_A + V_B$$

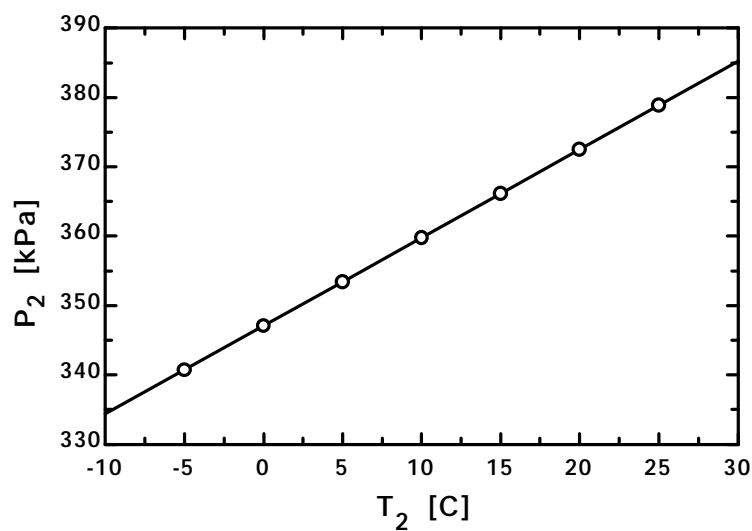
$$m_{\text{total}} = m_A + m_B$$

$$P_A V_A = m_A R (T_A + 273)$$

$$P_B V_B = m_B R (T_B + 273)$$

$$P_2 V_{\text{total}} = m_{\text{total}} R (T_2 + 273)$$

P_2 [kPa]	T_2 [C]
334.4	-10
340.7	-5
347.1	0
353.5	5
359.8	10
366.2	15
372.5	20
378.9	25
385.2	30

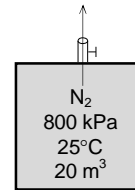


3-119 A large tank contains nitrogen at a specified temperature and pressure. Now some nitrogen is allowed to escape, and the temperature and pressure of nitrogen drop to new values. The amount of nitrogen that has escaped is to be determined.

Analysis Treating N_2 as an ideal gas, the initial and the final masses in the tank are determined to be

$$m_1 = \frac{P_1 V}{RT_1} = \frac{(800 \text{ kPa})(20 \text{ m}^3)}{(0.2968 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K})(298 \text{ K})} = 180.9 \text{ kg}$$

$$m_2 = \frac{P_2 V}{RT_2} = \frac{(600 \text{ kPa})(20 \text{ m}^3)}{(0.2968 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K})(293 \text{ K})} = 138.0 \text{ kg}$$



Thus the amount of N_2 that escaped is

$$\Delta m = m_1 - m_2 = 180.9 - 138.0 = \mathbf{42.9 \text{ kg}}$$

3-120 The temperature of steam in a tank at a specified state is to be determined using the ideal gas relation, the generalized chart, and the steam tables.

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

$$R = 0.4615 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K}, \quad T_{cr} = 647.3 \text{ K}, \quad P_{cr} = 22.09 \text{ MPa}$$

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

$$P = \frac{RT}{v} = \frac{(0.4615 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K})(673 \text{ K})}{0.02 \text{ m}^3 / \text{kg}} = \mathbf{15,529 \text{ kPa}}$$

(b) From the compressibility chart (Fig. A-30a),

$$\left. \begin{aligned} T_R &= \frac{T}{T_{cr}} = \frac{673 \text{ K}}{647.3 \text{ K}} = 1.040 \\ v_R &= \frac{v_{\text{actual}}}{RT_{cr}/P_{cr}} = \frac{(0.02 \text{ m}^3 / \text{kg})(22,090 \text{ kPa})}{(0.4615 \text{ kPa} \cdot \text{m}^3 / \text{kg} \cdot \text{K})(647.3 \text{ K})} = 1.48 \end{aligned} \right\} P_R = 0.57$$

H_2O $0.02 \text{ m}^3 / \text{kg}$ 400°C

Thus,

$$P = P_R P_{cr} = 0.57 \times 22,090 = \mathbf{12,591 \text{ kPa}}$$

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

$$\left. \begin{aligned} T &= 400^\circ\text{C} \\ v &= 0.02 \text{ m}^3 / \text{kg} \end{aligned} \right\} P = \mathbf{12,500 \text{ kPa}}$$

3-121 One section of a tank is filled with saturated liquid R-134a while the other side is evacuated. The partition is removed, and the temperature and pressure in the tank are measured. The volume of the tank is to be determined.

Analysis The mass of the refrigerant contained in the tank is

$$m = \frac{V}{v_1} = \frac{0.01 \text{ m}^3}{0.0008454 \text{ m}^3 / \text{kg}} = 11.83 \text{ kg}$$

since

$$v_1 = v_f @ 0.8 \text{ MPa} = 0.0008454 \text{ m}^3 / \text{kg}$$

At the final state (Table A-13),

$$\left. \begin{aligned} P_2 &= 200 \text{ kPa} \\ T_2 &= 25^\circ\text{C} \end{aligned} \right\} v_2 = 0.11625 \text{ m}^3 / \text{kg}$$

Thus,

$$V_{\text{tank}} = V_2 = mv_2 = (11.83 \text{ kg})(0.11625 \text{ m}^3 / \text{kg}) = \mathbf{1.375 \text{ m}^3}$$

R-134a P=0.8 MPa V=0.01 m ³	Evacuated
----------------------------------------------	-----------

3-122 Problem 3-121 is reconsidered. The effect of the initial pressure of refrigerant-134 on the volume of the tank is to be investigated as the initial pressure varies from 0.5 MPa to 1.5 MPa. The volume of the tank is to be plotted versus the initial pressure, and the results are to be discussed.

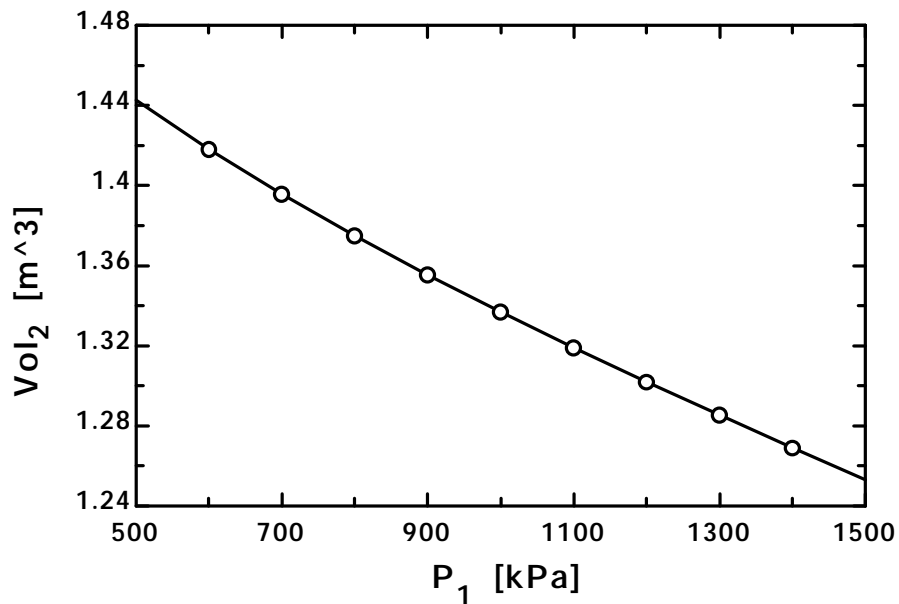
"Given Data"

$x_1=0.0$
 $\text{Vol}_1=0.01\text{[m}^3\text{]}$
 $P_1=800\text{[kPa]}$
 $T_2=25\text{[C]}$
 $P_2=200\text{[kPa]}$

"Solution"

$v_1=\text{volume}(\text{R134a}, P=P_1, x=x_1)$
 $\text{Vol}_1=m*v_1$
 $v_2=\text{volume}(\text{R134a}, P=P_2, T=T_2)$
 $\text{Vol}_2=m*v_2$

P_1 [kPa]	Vol_2 [m^3]	m [kg]
500	1.443	12.41
600	1.418	12.2
700	1.396	12.01
800	1.375	11.83
900	1.355	11.66
1000	1.337	11.5
1100	1.319	11.35
1200	1.302	11.2
1300	1.285	11.06
1400	1.269	10.92
1500	1.253	10.78



3-123 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 $h_{\text{fg}} = 427.8 \text{ kJ/kg}$ (Table A-3).

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

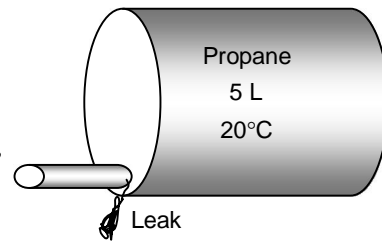
$$T = T_{\text{sat @ 1 atm}} = -42.1^\circ\text{C}$$

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,

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



3-124 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,

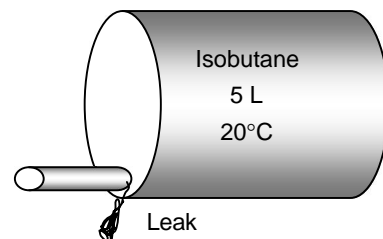
$$T = T_{\text{sat @ 1 atm}} = -11.7^\circ\text{C}$$

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,

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



3-125 ... 3-126 Design and Essay Problems

3-125 A claim that fruits and vegetables are cooled by 6°C for each percentage point of weight loss as moisture during vacuum cooling is to be evaluated.

Analysis Assuming the fruits and vegetables are cooled from 30°C and 0°C, the average heat of vaporization can be taken to be 2466 kJ/kg, which is the value at 15°C, and the specific heat of products can be taken to be 4 kJ/kg.°C. Then the vaporization of 0.01 kg water will lower the temperature of 1 kg of produce by $24.66/4 = 6^\circ\text{C}$. Therefore, the vacuum cooled products will lose 1 percent moisture for each 6°C drop in temperature. Thus the claim is **reasonable**.

3-126 It is helium.

h g