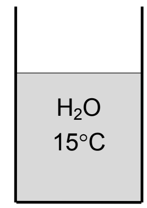
Special Topic: Vapor Pressure and Phase Equilibrium

3-102 A glass of water is left in a room. The vapor pressures at the free surface of the water and in the room far from the glass are to be determined.

Assumptions The water in the glass is at a uniform temperature.

Properties The saturation pressure of water is 2.339 kPa at 20°C, and 1.706 kPa at 15°C (Table A-4).

Analysis The vapor pressure at the water surface is the saturation pressure of water at the water temperature,



$$P_{v,\text{ water surface}} = P_{\text{sat @ }T_\text{water}} = P_{\text{sat@15°C}} = \mathbf{1.706\ kPa}$$

Noting that the air in the room is not saturated, the vapor pressure in the room far from the glass is

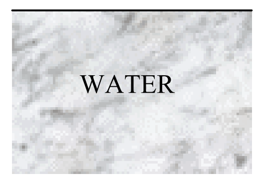
$$P_{v,\text{ air}} = \phi P_{\text{sat @ }T_\text{air}} = \phi P_{\text{sat@20°C}} = (0.6)(2.339\text{ kPa}) = \mathbf{1.404\ kPa}$$

3-103 The vapor pressure in the air at the beach when the air temperature is 30°C is claimed to be 5.2 kPa. The validity of this claim is to be evaluated.

Properties The saturation pressure of water at 30°C is 4.247 kPa (Table A-4).

Analysis The maximum vapor pressure in the air is the saturation pressure of water at the given temperature, which is

30°C



$$P_{v,\text{ max}} = P_{\text{sat @ }T_\text{air}} = P_{\text{sat@30°C}} = \mathbf{4.247\ kPa}$$

which is less than the claimed value of 5.2 kPa. Therefore, the claim is **false**.

3-104 The temperature and relative humidity of air over a swimming pool are given. The water temperature of the swimming pool when phase equilibrium conditions are established is to be determined.

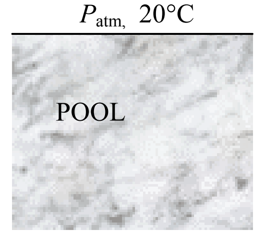
Assumptions The temperature and relative humidity of air over the pool remain constant.

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

Analysis The vapor pressure of air over the swimming pool is

$$P_{v,\text{ air}} = \phi P_{\text{sat @ }T_\text{air}} = \phi P_{\text{sat@20°C}} = (0.4)(2.339\text{ kPa}) = 0.9357\text{ kPa}$$

P_{atm}, 20°C



Phase equilibrium will be established when the vapor pressure at the water surface equals the vapor pressure of air far from the surface. Therefore,

$$P_{v,\text{ water surface}} = P_{v,\text{ air}} = 0.9357\text{ kPa}$$

and $$T_\text{water} = T_{\text{sat @ }P_v} = T_{\text{sat @ 0.9357 kPa}} = \mathbf{6.0°C}$$

Discussion Note that the water temperature drops to 6.0°C in an environment at 20°C when phase equilibrium is established.

3-105 Two rooms are identical except that they are maintained at different temperatures and relative humidities. The room that contains more moisture is to be determined.

Properties The saturation pressure of water is 2.339 kPa at 20°C, and 4.247 kPa at 30°C (Table A-4).

Analysis The vapor pressures in the two rooms are

Room 1: $$P_{v1} = \phi_1 P_{\text{sat}\,@\,T_1} = \phi_1 P_{\text{sat}@30°\text{C}} = (0.4)(4.247\ \text{kPa}) = \mathbf{1.699\ kPa}$$

Room 2: $$P_{v2} = \phi_2 P_{\text{sat}\,@\,T_2} = \phi_2 P_{\text{sat}@20°\text{C}} = (0.7)(2.339\ \text{kPa}) = \mathbf{1.637\ kPa}$$

Therefore, room 1 at 30°C and 40% relative humidity contains more moisture.

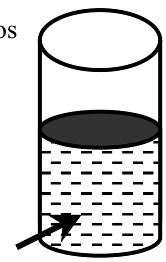
3-106E A thermos bottle half-filled with water is left open to air in a room at a specified temperature and pressure. The temperature of water when phase equilibrium is established is to be determined.

Assumptions The temperature and relative humidity of air over the bottle remain constant.

Properties The saturation pressure of water at 70°F is 0.3633 psia (Table A-4E).

Analysis The vapor pressure of air in the room is

$$P_{v,\,\text{air}} = \phi P_{\text{sat}\,@\,T_{\text{air}}} = \phi P_{\text{sat}@70°\text{F}} = (0.35)(0.3633\ \text{psia}) = 0.1272\ \text{psia}$$



Phase equilibrium will be established when the vapor pressure at the water surface equals the vapor pressure of air far from the surface. Therefore,

$$P_{v,\,\text{water surface}} = P_{v,\,\text{air}} = 0.1272\ \text{psia}$$

and

$$T_{\text{water}} = T_{\text{sat}\,@\,P_v} = T_{\text{sat}\,@\,0.1272\ \text{psia}} = \mathbf{41.1°F}$$

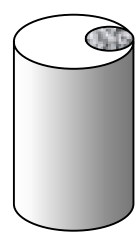
Discussion Note that the water temperature drops to 41°F in an environment at 70°F when phase equilibrium is established.

3-107 A person buys a supposedly cold drink in a hot and humid summer day, yet no condensation occurs on the drink. The claim that the temperature of the drink is below 10°C is to be evaluated.

Properties The saturation pressure of water at 35°C is 5.629 kPa (Table A-4).

Analysis The vapor pressure of air is

$$P_{v,\,\text{air}} = \phi P_{\text{sat}\,@\,T_{\text{air}}} = \phi P_{\text{sat}@35°\text{C}} = (0.7)(5.629\ \text{kPa}) = 3.940\ \text{kPa}$$



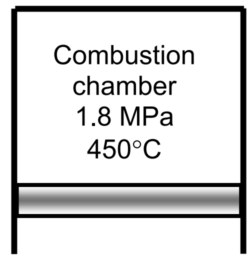
The saturation temperature corresponding to this pressure (called the dew-point temperature) is

$$T_{\text{sat}} = T_{\text{sat}\,@\,P_v} = T_{\text{sat}@3.940\ \text{kPa}} = \mathbf{28.7°C}$$

That is, the vapor in the air will condense at temperatures below 28.7°C. Noting that no condensation is observed on the can, the claim that the drink is at 10°C is **false**.

Review Problems

3-108 The cylinder conditions before the heat addition process is specified. The pressure after the heat addition process is to be determined.



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

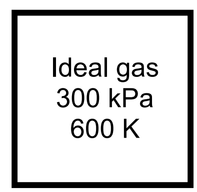
Analysis The final pressure may be determined from the ideal gas relation

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

3-109 A rigid tank contains an ideal gas at a specified state. The final temperature is to be determined for two different processes.

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

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

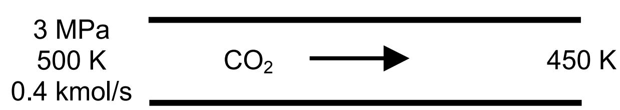


(*b*) The second case is a constant volume and constant mass process. The ideal gas relation for this case yields

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

3-110 Carbon dioxide flows through a pipe at a given state. The volume and mass flow rates and the density of CO_2 at the given state and the volume flow rate at the exit of the pipe are to be determined.

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



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

$$\dot{m}_1 = \frac{P_1 \dot{\mathbf{V}}_1}{R T_1} = \frac{(3000\text{ kPa})(0.5543\text{ m}^3/s)}{(0.1889\text{ kPa.m}^3\text{/kg.K})(500\text{ K})} = \mathbf{17.60\ kg/s}$$

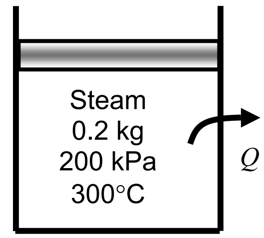
The density is

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

(b) The volume flow rate at the exit is

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

3-111 A piston-cylinder device contains steam at a specified state. Steam is cooled at constant pressure. The volume change is to be determined using compressibility factor.



Properties The gas constant, the critical pressure, and the critical temperature of steam are

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

Analysis The exact solution is given by the following:

$$\left.\begin{array}{l} P = 200\ \text{kPa} \\ T_1 = 300°\text{C} \end{array}\right\} v_1 = 1.31623\ \text{m}^3\text{/kg}$$

(Table A-6)

$$\left.\begin{array}{l} P = 200\ \text{kPa} \\ T_2 = 150°\text{C} \end{array}\right\} v_2 = 0.95986\ \text{m}^3\text{/kg}$$

$$\Delta V_{\text{exact}} = m(v_1 - v_2) = (0.2\ \text{kg})(1.31623 - 0.95986)\text{m}^3\text{/kg} = \mathbf{0.07128\ m^3}$$

Using compressibility chart (EES function for compressibility factor is used)

$$\left.\begin{array}{l} P_R = \dfrac{P_1}{P_{cr}} = \dfrac{0.2\ \text{MPa}}{22.06\ \text{MPa}} = 0.0091 \\ T_{R,1} = \dfrac{T_1}{T_{cr}} = \dfrac{300 + 273\ \text{K}}{647.1\ \text{K}} = 0.886 \end{array}\right\} Z_1 = 0.9956$$

$$\left.\begin{array}{l} P_R = \dfrac{P_2}{P_{cr}} = \dfrac{0.2\ \text{MPa}}{22.06\ \text{MPa}} = 0.0091 \\ T_{R,2} = \dfrac{T_2}{T_{cr}} = \dfrac{150 + 273\ \text{K}}{647.1\ \text{K}} = 0.65 \end{array}\right\} Z_2 = 0.9897$$

$$V_1 = \frac{Z_1 m R T_1}{P_1} = \frac{(0.9956)(0.2\ \text{kg})(0.4615\ \text{kPa}\cdot\text{m}^3\text{/kg}\cdot\text{K})(300 + 273\ \text{K})}{(200\ \text{kPa})} = 0.2633\ \text{m}^3$$

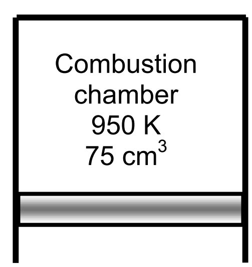
$$V_2 = \frac{Z_2 m R T_2}{P_2} = \frac{(0.9897)(0.2\ \text{kg})(0.4615\ \text{kPa}\cdot\text{m}^3\text{/kg}\cdot\text{K})(150 + 273\ \text{K})}{(200\ \text{kPa})} = 0.1932\ \text{m}^3$$

$$\Delta V_{\text{chart}} = V_1 - V_2 = 0.2633 - 0.1932 = \mathbf{0.07006\ m^3},\qquad \text{Error : } \mathbf{1.7\%}$$

3-112 The cylinder conditions before the heat addition process is specified. The temperature after the heat addition process is to be determined.

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

Analysis The ratio of the initial to the final mass is



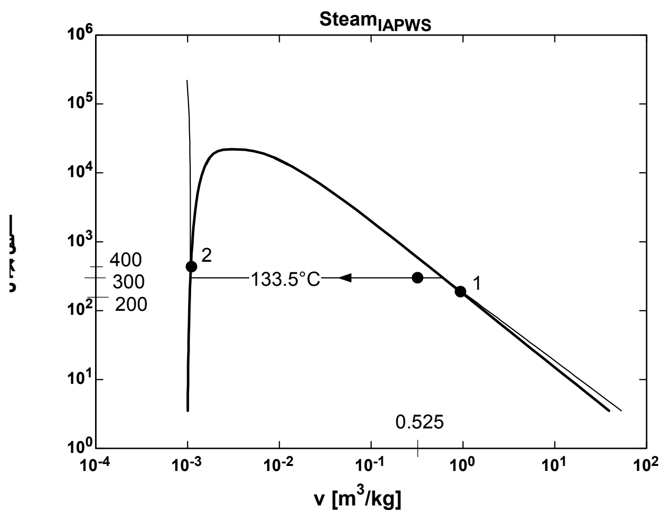
$$\frac{m_1}{m_2} = \frac{\text{AF}}{\text{AF} + 1} = \frac{22}{22 + 1} = \frac{22}{23}$$

The final temperature may be determined from ideal gas relation

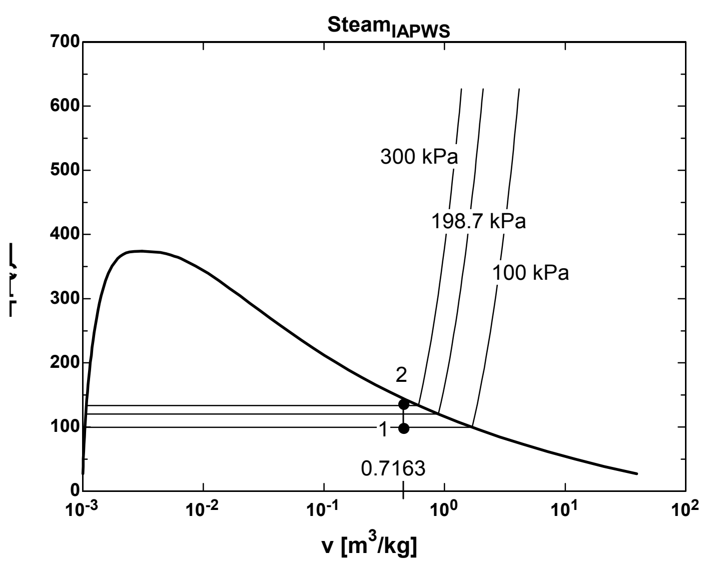
$$T_2 = \frac{m_1}{m_2}\frac{V_2}{V_1}T_1 = \left(\frac{22}{23}\right)\left(\frac{150\ \text{cm}^3}{75\ \text{cm}^3}\right)(950\ \text{K}) = \mathbf{1817\ K}$$

3-113

(*a*) On the P-v diagram, the constant temperature process through the state P= 300 kPa, v = 0.525 m^3/kg as pressure changes from P_1 = 200 kPa to P_2 = 400 kPa is to be sketched. The value of the temperature on the process curve on the P-v diagram is to be placed.



(*b*) On the T-v diagram the constant specific vol-ume process through the state T = 120°C, v = 0.7163 m^3/kg from P_1= 100 kPa to P_2 = 300 kPa is to be sketched.. For this data set, the temperature values at states 1 and 2 on its axis is to be placed. The value of the specific volume on its axis is also to be placed.



3-114 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.

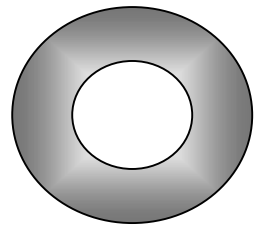
Assumptions **1** The volume of the tire remains constant. **2** Air is an ideal gas.

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

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

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

3-115 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 kPa.m^3/kg.K (Table A-1).

Analysis The buoyancy force acting on the balloon is

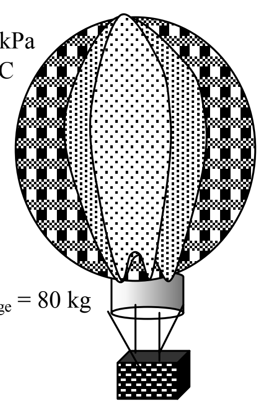
$$V_{\text{balloon}} = 4\pi r^3/3 = 4\pi(10\text{m})^3/3 = 4189\text{m}^3$$

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

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

The vertical force balance on the balloon gives

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



Substituting,

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

which gives

$$m_{\text{hotair}} = 4287 \text{ kg}$$

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

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

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

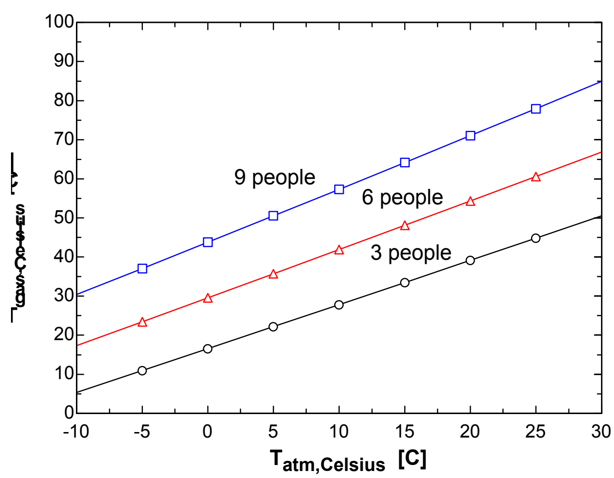
3-116 EES Problem 3-115 is to be reconsidered. The effect of the environment temperature on the average air temperature in the balloon when the balloon is suspended in the air is to be investigated as the environment temperature varies from -10°C to 30°C. The average air temperature in the balloon is to be plotted versus the environment temperature.

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

```
"Given Data:"
"atm---atmosphere about balloon"
"gas---heated air inside balloon"
g=9.807  [m/s^2]
d_balloon=20 [m]
m_cage = 80  [kg]
m_1person=65 [kg]
NoPeople = 6
{T_atm_Celsius = 15 [C]}
T_atm =T_atm_Celsius+273 "[K]"
P_atm = 90 [kPa]
R=0.287 [kJ/kg-K]
P_gas = P_atm
T_gas_Celsius=T_gas - 273 "[C]"

"Calculated values:"
P_atm= rho_atm*R*T_atm  "rho_atm = density of air outside balloon"
P_gas= rho_gas*R*T_gas  "rho_gas = density of gas inside balloon"
r_balloon=d_balloon/2
V_balloon=4*pi*r_balloon^3/3
m_people=NoPeople*m_1person
m_gas=rho_gas*V_balloon
m_total=m_gas+m_people+m_cage
"The total weight of balloon, people, and cage is:"
W_total=m_total*g
"The buoyancy force acting on the balloon, F_b, is equal to the weight of the air displaced by the
balloon."
F_b=rho_atm*V_balloon*g
"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_total=m_total*a_up
a_up = 0  "The balloon is hanging still in the air"
```

$T_{atm,Celcius}$ [C]	$T_{gas,Celcius}$ [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

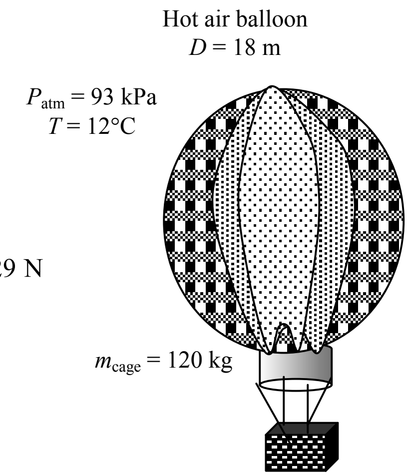


3-117 A hot air balloon with 2 people in its cage is about to take off. The average temperature of the air in the balloon for two environment temperatures is to be determined.

Assumptions Air is an ideal gas.

Properties The gas constant of air is R = 0.287 kPa.m^3/kg.K.

Analysis The buoyancy force acting on the balloon is



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

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

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

The vertical force balance on the balloon gives

$$\begin{aligned} F_B &= W_{hotair} + W_{cage} + W_{people} \\ &= (m_{hotair} + m_{cage} + m_{people})g \end{aligned}$$

Substituting,

$$34{,}029\text{ N} = (m_{hotair} + 120\text{ kg} + 140\text{ kg})(9.81\text{ m/s}^2)\left(\frac{1\text{ N}}{1\text{ kg}\cdot\text{m/s}^2}\right)$$

which gives

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

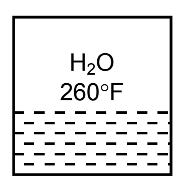
Therefore, the average temperature of the air in the balloon is

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

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

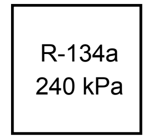
3-118E Water in a pressure cooker boils at 260°F. The absolute pressure in the pressure cooker is to be determined.

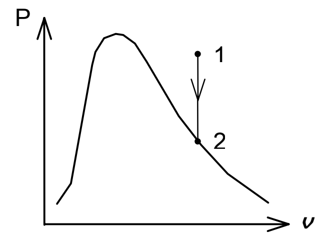
Analysis The absolute pressure in the pressure cooker is the saturation pressure that corresponds to the boiling temperature,



$$P = P_{sat@260^\circ F} = \mathbf{35.45\ psia}$$

3-119 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 ($v = V/m$ = constant), and the specific volume is determined to be

$$v = \frac{V}{m} = \frac{0.117 \text{ m}^3}{1 \text{ kg}} = 0.117 \text{ m}^3/\text{kg}$$

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

$$v_2 = v_g = 0.117 \text{ m}^3/\text{kg}$$

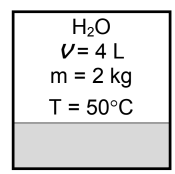
The pressure at this point is the pressure that corresponds to this v_g value,

$$P_2 = P_{\text{sat@}v_g = 0.117 \text{ m}^3/\text{kg}} = \mathbf{169 \text{ kPa}}$$

3-120 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 ($v = V/m$ = 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 0.003106 m^3/kg. Thus if the final specific volume is smaller than this value, the water will exist as a liquid, otherwise as a vapor.

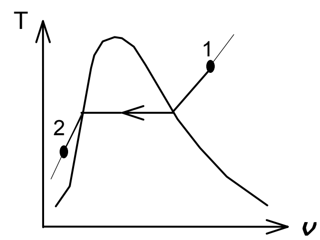
$$V = 4L \longrightarrow v = \frac{V}{m} = \frac{0.004 \text{ m}^3}{2 \text{ kg}} = 0.002 \text{ m}^3/\text{kg} < v_{\text{cr}} \quad \text{Thus, } \textbf{liquid}.$$

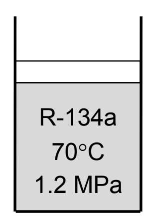
$$V = 400L \longrightarrow v = \frac{V}{m} = \frac{0.4 \text{ m}^3}{2 \text{ kg}} = 0.2 \text{ m}^3/\text{kg} > v_{\text{cr}}. \quad \text{Thus, } \textbf{vapor}.$$

3-121 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,

$$\left.\begin{array}{l} P_1 = 1.2 \text{ MPa} \\ T_1 = 70°\text{C} \end{array}\right\} \begin{array}{l} u_1 = 277.21 \text{ kJ/kg} \\ v_1 = 0.019502 \text{ m}^3/\text{kg} \end{array}$$





$$\left.\begin{array}{l} P_2 = 1.2 \text{ MPa} \\ T_2 = 20°\text{C} \end{array}\right\} \begin{array}{l} u_2 \cong u_{f @ 20°\text{C}} = 78.86 \text{ kJ/kg} \\ v_2 \cong v_{f @ 20°\text{C}} = 0.0008161 \text{ m}^3/\text{kg} \end{array}$$

Thus,

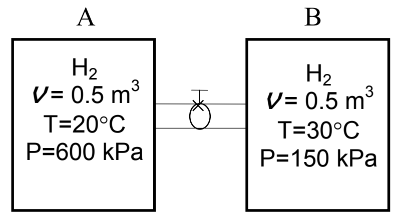
(*b*) $\Delta V = m(v_2 - v_1) = (10 \text{ kg})(0.0008161 - 0.019502) \text{ m}^3/\text{kg} = \mathbf{-0.187 \text{ m}^3}$

(*c*) $\Delta U = m(u_2 - u_1) = (10 \text{ kg})(78.86 - 277.21) \text{ kJ/kg} = \mathbf{-1984 \text{ kJ}}$

3-122 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.

Properties The gas constant for hydrogen is 4.124 kPa·m^3/kg·K (Table A-1).

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



$$\boldsymbol{V} = \boldsymbol{V}_A + \boldsymbol{V}_B = 0.5 + 0.5 = 1.0 \text{ m}^3$$

$$m_A = \left(\frac{P_1 \boldsymbol{V}}{RT_1}\right)_A = \frac{(600 \text{ kPa})(0.5 \text{ m}^3)}{(4.124 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(293 \text{ K})} = 0.248 \text{ kg}$$

$$m_B = \left(\frac{P_1 \boldsymbol{V}}{RT_1}\right)_B = \frac{(150 \text{ kPa})(0.5 \text{ m}^3)}{(4.124 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(303 \text{ K})} = 0.060 \text{ kg}$$

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

Then the final pressure can be determined from

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

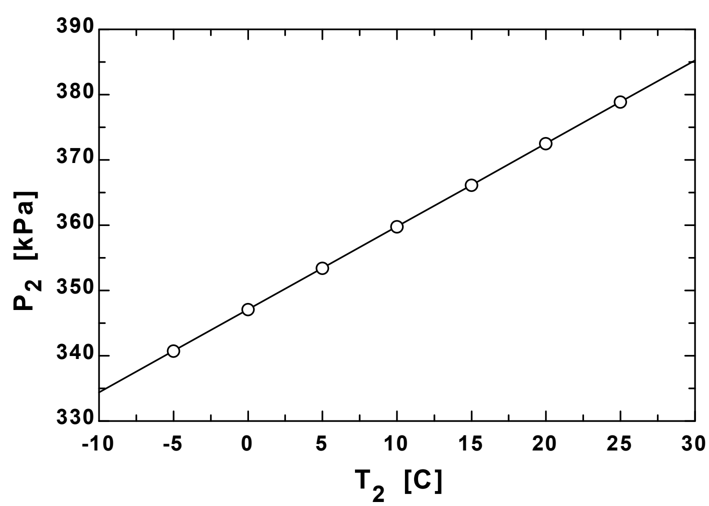
3-123 EES Problem 3-122 is reconsidered. The effect of the surroundings temperature on the final equilibrium pressure in the tanks is to be investigated. The final pressure in the tanks is to be plotted versus the surroundings temperature, and the results are to be discussed.

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

```
"Given Data"
V_A=0.5 [m^3]
T_A=20 [C]
P_A=600 [kPa]
V_B=0.5 [m^3]
T_B=30 [C]
P_B=150 [kPa]
{T_2=15 [C]}

"Solution"
R=R_u/MOLARMASS(H2)
R_u=8.314 [kJ/kmol-K]
V_total=V_A+V_B
m_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_total=m_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



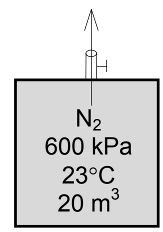
3-124 A large tank contains nitrogen at a specified temperature and pressure. Now some nitrogen is allowed to escape, and the temperature and pressure of nitrogen drop to new values. The amount of nitrogen that has escaped is to be determined.

Properties The gas constant for nitrogen is 0.2968 kPa·m^3/kg·K (Table A-1).

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

$$m_1 = \frac{P_1\boldsymbol{V}}{RT_1} = \frac{(600\text{ kPa})(20\text{ m}^3)}{(0.2968\text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(296\text{ K})} = 136.6\text{ kg}$$

$$m_2 = \frac{P_2\boldsymbol{V}}{RT_2} = \frac{(400\text{ kPa})(20\text{ m}^3)}{(0.2968\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(293\text{ K})} = 92.0\text{ kg}$$



Thus the amount of N_2 that escaped is

$$\Delta m = m_1 - m_2 = 136.6 - 92.0 = \mathbf{44.6\ kg}$$

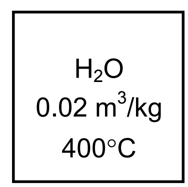
3-125 The temperature of steam in a tank at a specified state is to be determined using the ideal gas relation, the generalized chart, and the steam tables.

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

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

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

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



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

$$\left.\begin{aligned} T_R &= \frac{T}{T_{cr}} = \frac{673\text{ K}}{647.1\text{ K}} = 1.040 \\ \boldsymbol{v}_R &= \frac{\boldsymbol{v}_{actual}}{RT_{cr}/P_{cr}} = \frac{(0.02\text{ m}^3/\text{kg})(22{,}060\text{ kPa})}{(0.4615\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(647.1\text{ K})} = 1.48 \end{aligned}\right\} P_R = 0.57$$

Thus, $P = P_R P_{cr} = 0.57\times 22{,}060 = \mathbf{12{,}574\ kPa}$

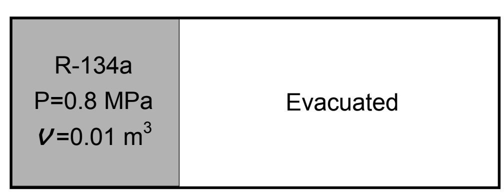
(*c*) From the superheated steam table,

$$\left.\begin{aligned} T &= 400°\text{C} \\ \boldsymbol{v} &= 0.02\text{ m}^3/\text{kg} \end{aligned}\right\} P = \mathbf{12{,}576\ kPa} \qquad \text{(from EES)}$$

3-126 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

$$m = \frac{\boldsymbol{V}_1}{\boldsymbol{v}_1} = \frac{0.01\text{ m}^3}{0.0008458\text{ m}^3/\text{kg}} = 11.82\text{ kg}$$



since $\boldsymbol{v}_1 = \boldsymbol{v}_{f@0.8\text{MPa}} = 0.0008458\text{ m}^3/\text{kg}$

At the final state (Table A-13),

$$\left.\begin{aligned} P_2 &= 400\text{ kPa} \\ T_2 &= 20°\text{C} \end{aligned}\right\} \boldsymbol{v}_2 = 0.05421\text{ m}^3/\text{kg}$$

Thus, $\boldsymbol{V}_{tank} = \boldsymbol{V}_2 = m\boldsymbol{v}_2 = (11.82\text{ kg})(0.05421\text{ m}^3/\text{kg}) = \mathbf{0.641\ m^3}$

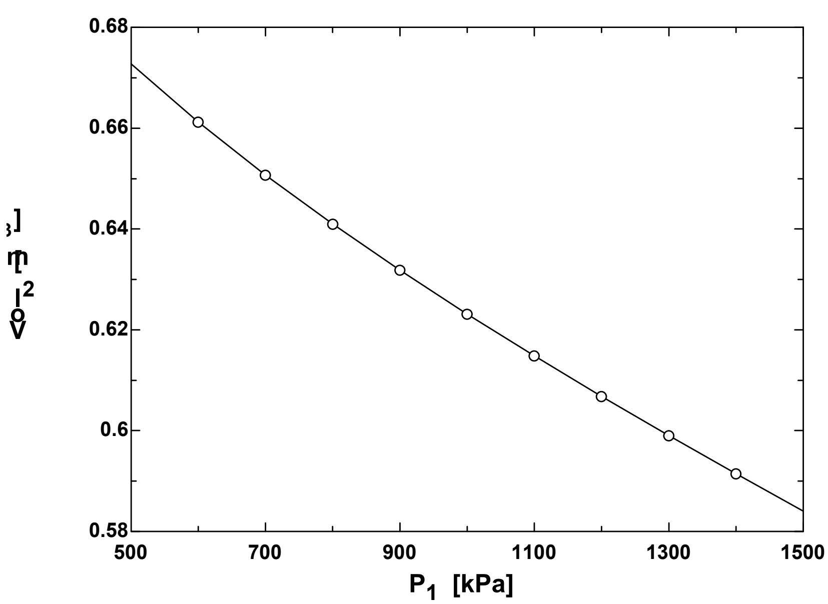
3-127 EES Problem 3-126 is reconsidered. The effect of the initial pressure of refrigerant-134 on the volume of the tank is to be investigated as the initial pressure varies from 0.5 MPa to 1.5 MPa. The volume of the tank is to be plotted versus the initial pressure, and the results are to be discussed.

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

```
"Given Data"
x_1=0.0
Vol_1=0.01[m^3]
P_1=800 [kPa]
T_2=20 [C]
P_2=400 [kPa]

"Solution"
v_1=volume(R134a,P=P_1,x=x_1)
Vol_1=m*v_1
v_2=volume(R134a,P=P_2,T=T_2)
Vol_2=m*v_2
```

P_1 [kPa]	Vol_2 [m^3]	m [kg]
500	0.6727	12.41
600	0.6612	12.2
700	0.6507	12
800	0.641	11.82
900	0.6318	11.65
1000	0.6231	11.49
1100	0.6148	11.34
1200	0.6068	11.19
1300	0.599	11.05
1400	0.5914	10.91
1500	0.584	10.77



3-128 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.

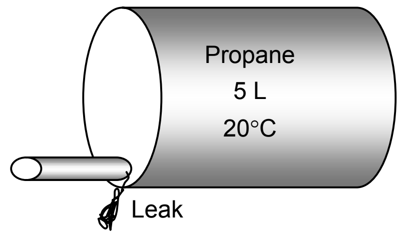
Properties The properties of propane at 1 atm are T_{sat} = -42.1°C, $\rho = 581\ \text{kg/m}^3$, and h_{fg} = 427.8 kJ/kg (Table A-3).

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

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

The initial mass of liquid propane is

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



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

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

3-129 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.

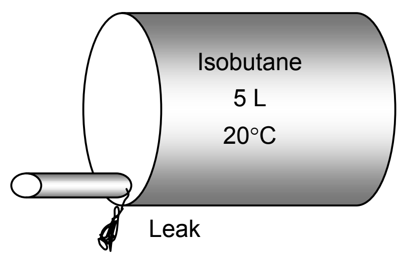
Properties The properties of isobutane at 1 atm are T_{sat} = -11.7°C, $\rho = 593.8\ \text{kg/m}^3$, and h_{fg} = 367.1 kJ/kg (Table A-3).

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

$$T = T_{\text{sat @1 atm}} = \mathbf{-11.7°C}$$

The initial mass of liquid isobutane is

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



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

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

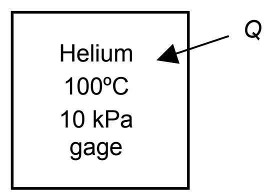
3-130 A tank contains helium at a specified state. Heat is transferred to helium until it reaches a specified temperature. The final gage pressure of the helium is to be determined.

Assumptions **1** Helium is an ideal gas.

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

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

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



Then the gage pressure becomes

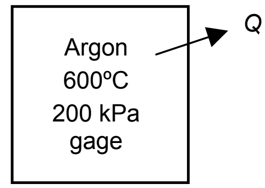
$$P_{\text{gage},2} = P_2 - P_{\text{atm}} = 169.0 - 100 = \mathbf{69.0\ kPa}$$

3-131 A tank contains argon at a specified state. Heat is transferred from argon until it reaches a specified temperature. The final gage pressure of the argon is to be determined.

Assumptions **1** Argon is an ideal gas.

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

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



$$P_2 = P_1 \frac{T_2}{T_1} = (200+100\text{ kPa})\frac{(300+273)\text{K}}{(600+273)\text{K}} = 196.9\text{ kPa}$$

Then the gage pressure becomes

$$P_{\text{gage},2} = P_2 - P_{\text{atm}} = 196.9 - 100 = \mathbf{96.9\ kPa}$$

3-132 *Complete the following table for H_2O*:

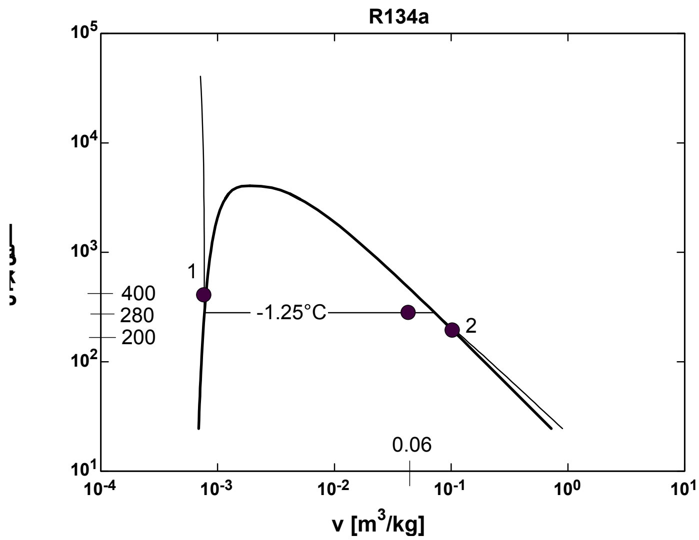
P, kPa	T, °C	v, m^3/kg	u, kJ/kg	Phase description
200	30	**0.001004**	125.71	Compressed liquid
270.3	130	-	-	Insufficient information
200	400	1.5493	**2967.2**	Superheated steam
300	**133.52**	0.500	**2196.4**	Saturated mixture, x=0.825
500	**473.1**	**0.6858**	3084	Superheated steam

3-133 *Complete the following table for R-134a*:

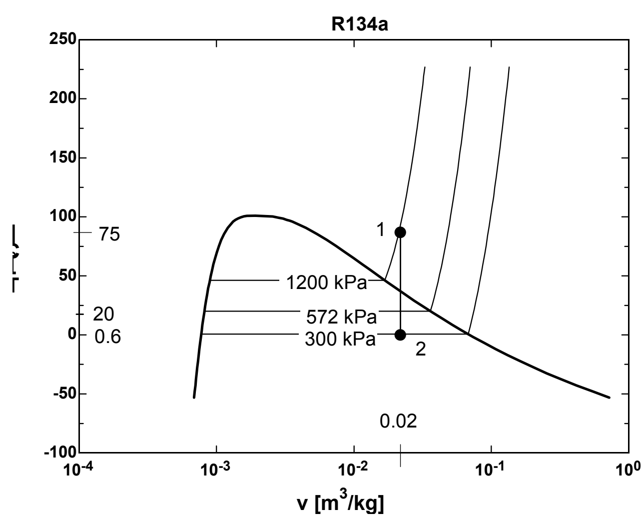
P, kPa	T, °C	v, m^3/kg	u, kJ/kg	Phase description
320	-12	**0.0007497**	**35.72**	Compressed liquid
1000	39.37	-	-	Insufficient information
140	40	0.17794	**263.79**	Superheated vapor
180	**-12.73**	0.0700	**153.66**	Saturated mixture, x=0.6315
200	**22.13**	**0.1152**	249	Superheated vapor

3-134

(*a*) On the P-v diagram the constant temperature process through the state P = 280 kPa, v = 0.06 m^3/kg as pressure changes from P_1 = 400 kPa to P_2 = 200 kPa is to be sketched. The value of the temperature on the process curve on the P-v diagram is to be placed.



(*b*) On the T-v diagram the constant specific volume process through the state T = 20°C, v = 0.02 m^3/kg from P_1 = 1200 kPa to P_2 = 300 kPa is to be sketched. For this data set the temperature values at states 1 and 2 on its axis is to be placed. The value of the specific volume on its axis is also to be placed.



Fundamentals of Engineering (FE) Exam Problems

3-135 A rigid tank contains 6 kg of an ideal gas at 3 atm and 40°C. Now a valve is opened, and half of mass of the gas is allowed to escape. If the final pressure in the tank is 2.2 atm, the final temperature in the tank is

(a) 186°C (b) 59°C (c) -43°C (d) 20°C (e) 230°C

Answer (a) 186°C

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
"When R=constant and V= constant, P1/P2=m1*T1/m2*T2"
m1=6 "kg"
P1=3 "atm"
P2=2.2 "atm"
T1=40+273 "K"
m2=0.5*m1 "kg"
P1/P2=m1*T1/(m2*T2)
T2_C=T2-273 "C"

"Some Wrong Solutions with Common Mistakes:"
P1/P2=m1*(T1-273)/(m2*W1_T2) "Using C instead of K"
P1/P2=m1*T1/(m1*(W2_T2+273)) "Disregarding the decrease in mass"
P1/P2=m1*T1/(m1*W3_T2) "Disregarding the decrease in mass, and not converting to deg. C"
W4_T2=(T1-273)/2 "Taking T2 to be half of T1 since half of the mass is discharged"
```

3-136 The pressure of an automobile tire is measured to be 190 kPa (gage) before a trip and 215 kPa (gage) after the trip at a location where the atmospheric pressure is 95 kPa. If the temperature of air in the tire before the trip is 25°C, the air temperature after the trip is

(a) 51.1°C (b) 64.2°C (c) 27.2°C (d) 28.3°C (e) 25.0°C

Answer (a) 51.1°C

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
"When R, V, and m are constant, P1/P2=T1/T2"
Patm=95
P1=190+Patm "kPa"
P2=215+Patm "kPa"
T1=25+273 "K"
P1/P2=T1/T2
T2_C=T2-273 "C"

"Some Wrong Solutions with Common Mistakes:"
P1/P2=(T1-273)/W1_T2 "Using C instead of K"
(P1-Patm)/(P2-Patm)=T1/(W2_T2+273) "Using gage pressure instead of absolute pressure"
(P1-Patm)/(P2-Patm)=(T1-273)/W3_T2 "Making both of the mistakes above"
W4_T2=T1-273 "Assuming the temperature to remain constant"
```

3-137 A 300-m^3 rigid tank is filled with saturated liquid-vapor mixture of water at 200 kPa. If 25% of the mass is liquid and the 75% of the mass is vapor, the total mass in the tank is
(a) 451 kg (b) 556 kg (c) 300 kg (d) 331 kg (e) 195 kg

Answer (a) 451 kg

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
V_tank=300 "m3"
P1=200 "kPa"
x=0.75
v_f=VOLUME(Steam_IAPWS, x=0,P=P1)
v_g=VOLUME(Steam_IAPWS, x=1,P=P1)
v=v_f+x*(v_g-v_f)
m=V_tank/v "kg"

"Some Wrong Solutions with Common Mistakes:"
R=0.4615 "kJ/kg.K"
T=TEMPERATURE(Steam_IAPWS,x=0,P=P1)
P1*V_tank=W1_m*R*(T+273) "Treating steam as ideal gas"
P1*V_tank=W2_m*R*T "Treating steam as ideal gas and using deg.C"
W3_m=V_tank "Taking the density to be 1 kg/m^3"
```

3-138 Water is boiled at 1 atm pressure in a coffee maker equipped with an immersion-type electric heating element. The coffee maker initially contains 1 kg of water. Once boiling started, it is observed that half of the water in the coffee maker evaporated in 18 minutes. If the heat loss from the coffee maker is negligible, the power rating of the heating element is
(a) 0.90 kW (b) 1.52 kW (c) 2.09 kW (d) 1.05 kW (e) 1.24 kW

Answer (d) 1.05 kW

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
m_1=1 "kg"
P=101.325 "kPa"
time=18*60 "s"
m_evap=0.5*m_1
Power*time=m_evap*h_fg "kJ"
h_f=ENTHALPY(Steam_IAPWS, x=0,P=P)
h_g=ENTHALPY(Steam_IAPWS, x=1,P=P)
h_fg=h_g-h_f

"Some Wrong Solutions with Common Mistakes:"
W1_Power*time=m_evap*h_g "Using h_g"
W2_Power*time/60=m_evap*h_g "Using minutes instead of seconds for time"
W3_Power=2*Power  "Assuming all the water evaporates"
```

3-139 A 1-m^3 rigid tank contains 10 kg of water (in any phase or phases) at 160°C. The pressure in the tank is

(a) 738 kPa (b) 618 kPa (c) 370 kPa (d) 2000 kPa (e) 1618 kPa

Answer (b) 618 kPa

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
V_tank=1 "m^3"
m=10 "kg"
v=V_tank/m
T=160 "C"
P=PRESSURE(Steam_IAPWS,v=v,T=T)

"Some Wrong Solutions with Common Mistakes:"
R=0.4615 "kJ/kg.K"
W1_P*V_tank=m*R*(T+273) "Treating steam as ideal gas"
W2_P*V_tank=m*R*T "Treating steam as ideal gas and using deg.C"
```

3-140 Water is boiling at 1 atm pressure in a stainless steel pan on an electric range. It is observed that 2 kg of liquid water evaporates in 30 minutes. The rate of heat transfer to the water is

(a) 2.51 kW (b) 2.32 kW (c) 2.97 kW (d) 0.47 kW (e) 3.12 kW

Answer (a) 2.51 kW

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
m_evap=2 "kg"
P=101.325 "kPa"
time=30*60 "s"
Q*time=m_evap*h_fg "kJ"
h_f=ENTHALPY(Steam_IAPWS, x=0,P=P)
h_g=ENTHALPY(Steam_IAPWS, x=1,P=P)
h_fg=h_g-h_f

"Some Wrong Solutions with Common Mistakes:"
W1_Q*time=m_evap*h_g "Using h_g"
W2_Q*time/60=m_evap*h_g "Using minutes instead of seconds for time"
W3_Q*time=m_evap*h_f "Using h_f"
```

3-141 Water is boiled in a pan on a stove at sea level. During 10 min of boiling, its is observed that 200 g of water has evaporated. Then the rate of heat transfer to the water is

(a) 0.84 kJ/min (b) 45.1 kJ/min (c) 41.8 kJ/min (d) 53.5 kJ/min (e) 225.7 kJ/min

Answer (b) 45.1 kJ/min

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
m_evap=0.2 "kg"
P=101.325 "kPa"
time=10 "min"
Q*time=m_evap*h_fg "kJ"
h_f=ENTHALPY(Steam_IAPWS, x=0,P=P)
h_g=ENTHALPY(Steam_IAPWS, x=1,P=P)
h_fg=h_g-h_f

"Some Wrong Solutions with Common Mistakes:"
W1_Q*time=m_evap*h_g "Using h_g"
W2_Q*time*60=m_evap*h_g "Using seconds instead of minutes for time"
W3_Q*time=m_evap*h_f "Using h_f"
```

3-142 A rigid 3-m^3 rigid vessel contains steam at 10 MPa and 500°C. The mass of the steam is

(a) 3.0 kg (b) 19 kg (c) 84 kg (d) 91 kg (e) 130 kg

Answer (d) 91 kg

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
V=3 "m^3"
m=V/v1 "m^3/kg"
P1=10000 "kPa"
T1=500 "C"
 v1=VOLUME(Steam_IAPWS,T=T1,P=P1)

"Some Wrong Solutions with Common Mistakes:"
R=0.4615 "kJ/kg.K"
P1*V=W1_m*R*(T1+273) "Treating steam as ideal gas"
P1*V=W2_m*R*T1 "Treating steam as ideal gas and using deg.C"
```

3-143 Consider a sealed can that is filled with refrigerant-134a. The contents of the can are at the room temperature of 25°C. Now a leak developes, and the pressure in the can drops to the local atmospheric pressure of 90 kPa. The temperature of the refrigerant in the can is expected to drop to (rounded to the nearest integer)

(a) 0°C (b) -29°C (c) -16°C (d) 5°C (e) 25°C

Answer (b) -29°C

Solution Solved by EES Software. Solutions can be verified by copying-and-pasting the following lines on a blank EES screen. (Similar problems and their solutions can be obtained easily by modifying numerical values).

```
T1=25 "C"
P2=90 "kPa"
T2=TEMPERATURE(R134a,x=0,P=P2)

"Some Wrong Solutions with Common Mistakes:"
W1_T2=T1 "Assuming temperature remains constant"
```

3-144 … 3-146 Design, Essay and Experiment Problems

3-144 It is helium.
