3–30 Complete this table for H_2O:

T, °C	P, kPa	h, kJ/kg	x	Phase description
	200		0.7	
140		1800		
	950		0.0	
80	500			
	800	3162.2		

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

3–26 Complete this table for H_2O:

T, °C	P, kPa	v, m^3/kg	Phase description
50		4.16	
	200		Saturated vapor
250	400		
110	600		

T, °C	P, kPa	v, m^3 / kg	Phase description
50	*12.352*	4.16	*Saturated mixture*
120.21	200	*0.8858*	Saturated vapor
250	400	*0.5952*	*Superheated vapor*
110	600	*0.001051*	*Compressed liquid*

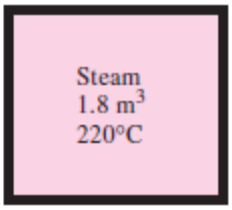
3–31 Complete this table for refrigerant-134a:

T, °C	P, kPa	v, m^3/kg	Phase description
−8	320		
30		0.015	
	180		Saturated vapor
80	600		

3-31 *Complete the following table for Refrigerant-134a:*

T, °C	P, kPa	v, m^3 / kg	Phase description
-8	320	*0.0007569*	*Compressed liquid*
30	*770.64*	0.015	*Saturated mixture*
-12.73	180	*0.11041*	Saturated vapor
80	600	*0.044710*	*Superheated vapor*

3–36 A 1.8-m^3 rigid tank contains steam at 220°C. One-third of the volume is in the liquid phase and the rest is in the vapor form. Determine (*a*) the pressure of the steam, (*b*) the quality of the saturated mixture, and (*c*) the density of the mixture.

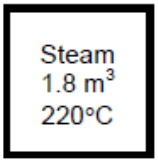


3-36 A rigid tank contains steam at a specified state. The pressure, quality, and density of steam are to be determined.

Properties At 220°C v_f = 0.001190 m^3/kg and v_g = 0.08609 m^3/kg (Table A-4).

Analysis (*a*) Two phases coexist in equilibrium, thus we have a saturated liquid-vapor mixture. The pressure of the steam is the saturation pressure at the given temperature. Then the pressure in the tank must be the saturation pressure at the specified temperature,

$$P = T_{\text{sat@220°C}} = \mathbf{2320\ kPa}$$



(*b*) The total mass and the quality are determined as

$$m_f = \frac{V_f}{v_f} = \frac{1/3 \times (1.8\ \text{m}^3)}{0.001190\ \text{m}^3/\text{kg}} = 504.2\ \text{kg}$$

$$m_g = \frac{V_g}{v_g} = \frac{2/3 \times (1.8\ \text{m}^3)}{0.08609\ \text{m}^3/\text{kg}} = 13.94\ \text{kg}$$

$$m_t = m_f + m_g = 504.2 + 13.94 = 518.1\ \text{kg}$$

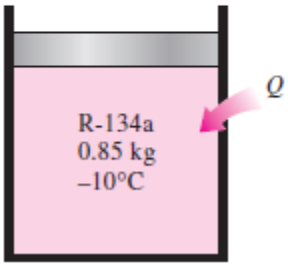
$$x = \frac{m_g}{m_t} = \frac{13.94}{518.1} = \mathbf{0.0269}$$

(*c*) The density is determined from

$$v = v_f + x(v_g - v_f) = 0.001190 + (0.0269)(0.08609) = 0.003474\ \text{m}^3/\text{kg}$$

$$\rho = \frac{1}{v} = \frac{1}{0.003474} = \mathbf{287.8\ kg/m^3}$$

3–37 A piston–cylinder device contains 0.85 kg of refrigerant-134a at −10°C. The piston that is free to move has a mass of 12 kg and a diameter of 25 cm. The local atmospheric pressure is 88 kPa. Now, heat is transferred to refrigerant-134a until the temperature is 15°C. Determine (*a*) the final pressure, (*b*) the change in the volume of the cylinder, and (*c*) the change in the enthalpy of the refrigerant-134a.



3-37 A piston-cylinder device contains R-134a at a specified state. Heat is transferred to R-134a. The final pressure, the volume change of the cylinder, and the enthalpy change are to be determined.

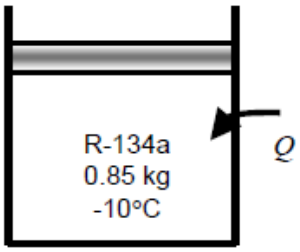
Analysis (a) The final pressure is equal to the initial pressure, which is determined from

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

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

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

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



The initial and the final volumes and the volume change are

$$V_1 = mv_1 = (0.85\text{ kg})(0.2302\text{ m}^3/\text{kg}) = 0.1957\text{ m}^3$$

$$V_2 = mv_2 = (0.85\text{ kg})(0.2544\text{ m}^3/\text{kg}) = 0.2162\text{ m}^3$$

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

(c) The total enthalpy change is determined from

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

3–41 Water is to be boiled at sea level in a 30-cm-diameter stainless steel pan placed on top of a 3–kW electric burner. If

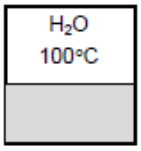
60 percent of the heat generated by the burner is transferred to the water during boiling, determine the rate of evaporation of water.

3-41 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} = 2256.4 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 2256.4 kJ of energy to vaporize 1 kg of saturated liquid water, the rate of evaporation of water is determined to be

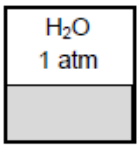
$$\dot{m}_{\text{evaporation}} = \frac{\dot{Q}}{h_{fg}} = \frac{1.8\,\text{kJ/s}}{2256.4\,\text{kJ/kg}} = 0.80 \times 10^{-3}\ \text{kg/s} = \mathbf{2.872\ kg/h}$$

3–43 Water is boiled at 1 atm pressure in a 25-cm-internal-diameter stainless steel pan on an electric range. If it is observed that the water level in the pan drops by 10 cm in 45 min, determine the rate of heat transfer to the pan.

3-43 Water is boiled at 1 atm pressure in a pan placed on an electric burner. The water level drops by 10 cm in 45 min during boiling. The rate of heat transfer to the water is to be determined.

Properties The properties of water at 1 atm and thus at a saturation temperature of T_{sat} = 100°C are h_{fg} = 2256.5 kJ/kg and v_f = 0.001043 m³/kg (Table A-4).

Analysis The rate of evaporation of water is



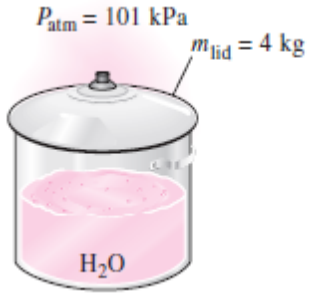
$$m_{evap} = \frac{V_{evap}}{v_f} = \frac{(\pi D^2/4)L}{v_f} = \frac{[\pi(0.25\text{ m})^2/4](0.10\text{ m})}{0.001043} = 4.704\text{ kg}$$

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

Then the rate of heat transfer to water becomes

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

3–48 A cooking pan whose inner diameter is 20 cm is filled with water and covered with a 4-kg lid. If the local atmospheric pressure is 101 kPa, determine the temperature at which the water starts boiling when it is heated.
Answer: 100.2°C

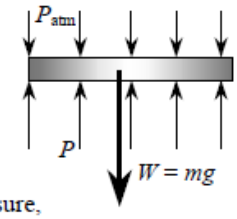


3-48 A cooking pan is filled with water and covered with a 4-kg lid. The boiling temperature of water is to be determined.

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

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

or,



$$P = P_{atm} + \frac{mg}{A}$$
$$= (101\text{ kPa}) + \frac{(4\text{ kg})(9.81\text{ m/s}^2)}{\pi(0.1\text{ m})^2}\left(\frac{1\text{ kPa}}{1000\text{ kg/m}\cdot\text{s}^2}\right)$$
$$= 102.25\text{ kPa}$$

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

$$T = T_{sat@102.25\text{ kPa}} = \mathbf{100.2°C} \qquad \text{(Table A-5)}$$

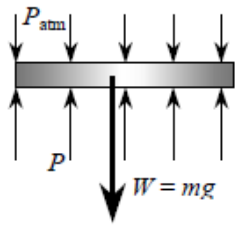
3–50 Water is being heated in a vertical piston–cylinder device. The piston has a mass of 20 kg and a cross-sectional area of 100 cm². If the local atmospheric pressure is 100 kPa, determine the temperature at which the water starts boiling.

3-50 A vertical piston-cylinder device is filled with water and covered with a 20-kg piston that serves as the lid. The boiling temperature of water is to be determined.

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

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

or,



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

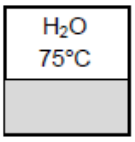
The boiling temperature is the saturation temperature corresponding to this pressure,

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

3–51 A rigid tank with a volume of 2.5 m^3 contains 15 kg of saturated liquid–vapor mixture of water at 75°C. Now the water is slowly heated. Determine the temperature at which the liquid in the tank is completely vaporized. Also, show the process on a T-v diagram with respect to saturation lines. *Answer:* 187.0°C

3-51 A rigid tank that is filled with saturated liquid-vapor mixture is heated. The temperature at which the liquid in the tank is completely vaporized is to be determined, and the T-v diagram is to be drawn.

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



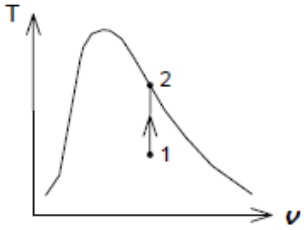
$$v = \frac{V}{m} = \frac{2.5\text{ m}^3}{15\text{ kg}} = 0.1667\text{ m}^3/\text{kg}$$

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

$$v_2 = v_g = 0.1667\text{ m}^3/\text{kg}$$

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

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

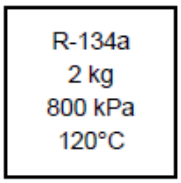


3–52 A rigid vessel contains 2 kg of refrigerant-134a at 800 kPa and 120°C. Determine the volume of the vessel and the total internal energy. *Answers:* 0.0753 m^3, 655.7 kJ

3-52 A rigid vessel is filled with refrigerant-134a. The total volume and the total internal energy are to be determined.

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

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

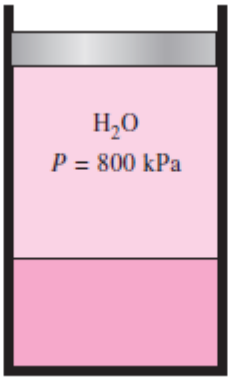


Analysis The total volume and internal energy are determined from

$$V = mv = (2\text{ kg})(0.037625\text{ m}^3/\text{kg}) = \mathbf{0.0753\ m^3}$$
$$U = mu = (2\text{ kg})(327.87\text{ kJ/kg}) = \mathbf{655.7\ kJ}$$

3–55 A piston–cylinder device contains 0.1 m^3 of liquid water and 0.9 m^3 of water vapor in equilibrium at 800 kPa. Heat is transferred at constant pressure until the temperature reaches 350°C.

(*a*) What is the initial temperature of the water?
(*b*) Determine the total mass of the water.
(*c*) Calculate the final volume.
(*d*) Show the process on a *P*-*v* diagram with respect to saturation lines.



3-55 [*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,

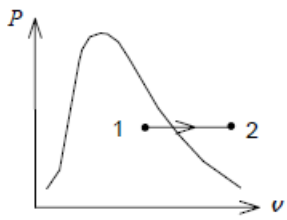
$$T = T_{\text{sat@800 kPa}} = \mathbf{170.41°C}$$

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

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

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

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



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

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

Then,

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

3–59 A piston–cylinder device initially contains 50 L of liquid water at 40°C and 200 kPa. Heat is transferred to the water at constant pressure until the entire liquid is vaporized.

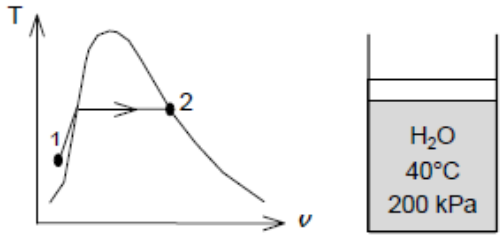
(*a*) What is the mass of the water?
(*b*) What is the final temperature?
(*c*) Determine the total enthalpy change.
(*d*) Show the process on a *T*-*v* diagram with respect to saturation lines.

Answers: (*a*) 49.61 kg, (*b*) 120.21°C, (*c*) 125,943 kJ

3-59 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 $P > P_{sat@40°C}$) that can be approximated as a saturated liquid at the specified temperature (Table A-4),

$$v_1 \cong v_{f@40°C} = 0.001008 \text{ m}^3/\text{kg}$$
$$h_1 \cong h_{f@40°C} = 167.53 \text{ kJ/kg}$$



(*a*) The mass is determined from

$$m = \frac{V_1}{v_1} = \frac{0.050 \text{ m}^3}{0.001008 \text{ m}^3/\text{kg}} = \mathbf{49.61 \ kg}$$

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

$$T = T_{sat@200\,\text{kPa}} = \mathbf{120.21°C}$$

(*c*) The final enthalpy is $h_2 = h_{g\,@\,200\,\text{kPa}} = 2706.3$ kJ/kg. Thus,

$$\Delta H = m(h_2 - h_1) = (49.61 \text{ kg})(2706.3 - 167.53)\text{kJ/kg} = \mathbf{125{,}943 \ kJ}$$

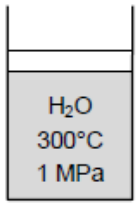
3–64 A piston–cylinder device contains 0.8 kg of steam at 300°C and 1 MPa. Steam is cooled at constant pressure until one-half of the mass condenses.

(*a*) Show the process on a *T*-*v* diagram.
(*b*) Find the final temperature.
(*c*) Determine the volume change.

3-64 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,

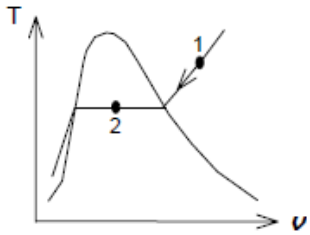
$$T = T_{\text{sat@1 MPa}} = \mathbf{179.88°C} \qquad \text{(Table A-5)}$$



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

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

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



Thus,

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

3–65 A rigid tank contains water vapor at 250°C and an unknown pressure. When the tank is cooled to 150°C, the vapor starts condensing. Estimate the initial pressure in the tank. *Answer:* 0.60 MPa

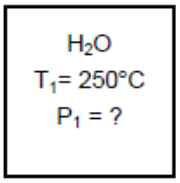
3-65 The water in a rigid tank is cooled until the vapor starts condensing. The initial pressure in the tank is to be determined.

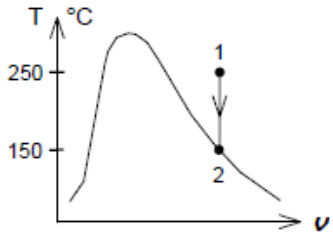
Analysis This is a constant volume process ($v = V/m$ = constant), and the initial specific volume is equal to the final specific volume that is

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

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

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





3–66 Water is boiled in a pan covered with a poorly fitting lid at a specified location. Heat is supplied to the pan by a 2-kW resistance heater. The amount of water in the pan is observed to decrease by 1.19 kg in 30 minutes. If it is estimated that 75 percent of electricity consumed by the heater is transferred to the water as heat, determine the local atmospheric pressure in that location. *Answer:* 85.4 kPa

3-66 Water is boiled in a pan by supplying electrical heat. The local atmospheric pressure is to be estimated.

Assumptions 75 percent of electricity consumed by the heater is transferred to the water.

Analysis The amount of heat transfer to the water during this period is

$$Q = fE_{\text{elect}}\text{time} = (0.75)(2\text{ kJ/s})(30 \times 60\text{ s}) = 2700\text{ kJ}$$

The enthalpy of vaporization is determined from

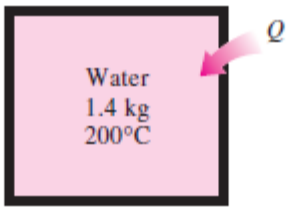
$$h_{fg} = \frac{Q}{m_{\text{boil}}} = \frac{2700\text{ kJ}}{1.19\text{ kg}} = 2269\text{ kJ/kg}$$

Using the data by a trial-error approach in saturation table of water (Table A-5) or using EES as we did, the saturation pressure that corresponds to an enthalpy of vaporization value of 2269 kJ/kg is

$$P_{\text{sat}} = \mathbf{85.4\ kPa}$$

which is the local atmospheric pressure.

3–67 A rigid tank initially contains 1.4-kg saturated liquid water at 200°C. At this state, 25 percent of the volume is occupied by water and the rest by air. Now heat is supplied to the water until the tank contains saturated vapor only. Determine (*a*) the volume of the tank, (*b*) the final temperature and pressure, and (*c*) the internal energy change of the water.



3-67 Heat is supplied to a rigid tank that contains water at a specified state. The volume of the tank, the final temperature and pressure, and the internal energy change of water are to be determined.

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

Analysis (*a*) The tank initially contains saturated liquid water and air. The volume occupied by water is

$$V_1 = mv_1 = (1.4\text{ kg})(0.001157\text{ m}^3/\text{kg}) = 0.001619\text{ m}^3$$

which is the 25 percent of total volume. Then, the total volume is determined from

$$V = \frac{1}{0.25}(0.001619) = \mathbf{0.006476\ m^3}$$

(*b*) Properties after the heat addition process are

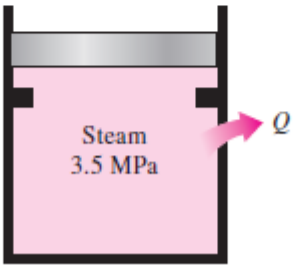
$$v_2 = \frac{V}{m} = \frac{0.006476\text{ m}^3}{1.4\text{ kg}} = 0.004626\text{ m}^3/\text{kg}$$

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

(*c*) The total internal energy change is determined from

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

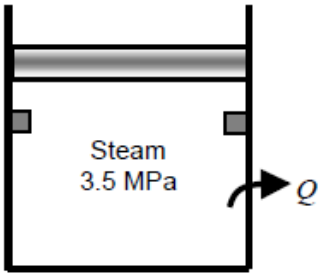
3–68 A piston–cylinder device initially contains steam at 3.5 MPa, superheated by 5°C. Now, steam loses heat to the surroundings and the piston moves down hitting a set of stops at which point the cylinder contains saturated liquid water. The cooling continues until the cylinder contains water at 200°C. Determine (*a*) the initial temperature, (*b*) the enthalpy change per unit mass of the steam by the time the piston first hits the stops, and (*c*) the final pressure and the quality (if mixture).



3-68 Heat is lost from a piston-cylinder device that contains steam at a specified state. The initial temperature, the enthalpy change, and the final pressure and quality are to be determined.

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

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



Then, the initial temperature becomes

$$T_1 = 242.6+5 = \mathbf{247.6°C}$$

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

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

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

Then, the enthalpy change of steam becomes

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

(*c*) At the final state

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

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

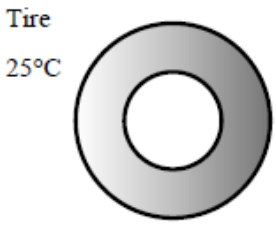
3–75 The pressure in an automobile tire depends on the temperature of the air in the tire. When the air temperature is 25°C, the pressure gage reads 210 kPa. If the volume of the tire is 0.025 m^3, determine the pressure rise in the tire when the air temperature in the tire rises to 50°C. Also, determine the amount of air that must be bled off to restore pressure to its original value at this temperature. Assume the atmospheric pressure is 100 kPa.

3-75 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 $R = 0.287$ kPa.m^3/kg.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

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \longrightarrow P_2 = \frac{T_2}{T_1}P_1 = \frac{323\text{ K}}{298\text{ K}}(310\text{ kPa}) = 336\text{ kPa}$$

Thus the pressure rise is

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

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

$$m_1 = \frac{P_1V}{RT_1} = \frac{(310\text{ kPa})(0.025\text{ m}^3)}{(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(298\text{ K})} = 0.0906\text{ kg}$$

$$m_2 = \frac{P_1V}{RT_2} = \frac{(310\text{ kPa})(0.025\text{ m}^3)}{(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(323\text{ K})} = 0.0836\text{ kg}$$

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

3–80 A 1-m^3 tank containing air at 25°C and 500 kPa is connected through a valve to another tank containing 5 kg of air at 35°C and 200 kPa. Now the valve is opened, and the entire system is allowed to reach thermal equilibrium with the surroundings, which are at 20°C. Determine the volume of the second tank and the final equilibrium pressure of air.
Answers: 2.21 m^3, 284.1 kPa

3-80 Two rigid tanks connected by a valve to each other contain air at specified conditions. The volume of the second tank and the final equilibrium pressure when the valve is opened are to be determined.

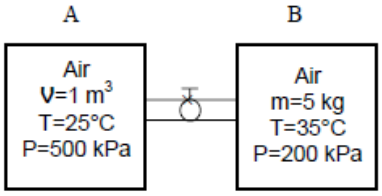
Assumptions At specified conditions, air behaves as an ideal gas.

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

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

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

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



Thus,

$$V = V_A + V_B = 1.0 + 2.21 = 3.21\text{ m}^3$$
$$m = m_A + m_B = 5.846 + 5.0 = 10.846\text{ kg}$$

Then the final equilibrium pressure becomes

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

3–84 Determine the specific volume of superheated water vapor at 10 MPa and 400°C, using (*a*) the ideal-gas equation, (*b*) the generalized compressibility chart, and (*c*) the steam tables. Also determine the error involved in the first two cases.
Answers: (*a*) 0.03106 m^3/kg, 17.6 percent; (*b*) 0.02609 m^3/kg, 1.2 percent; (*c*) 0.02644 m^3/kg

3-84 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,

$R = 0.4615$ kPa·m³/kg·K, $T_{cr} = 647.1$ K, $P_{cr} = 22.06$ MPa

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

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

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

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

H_2O
10 MPa
400°C

Thus,

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

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

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

3–90 A 0.016773-m³ tank contains 1 kg of refrigerant-134a at 110°C. Determine the pressure of the refrigerant, using (*a*) the ideal-gas equation, (*b*) the generalized compressibility chart, and (*c*) the refrigerant tables. *Answers:* (*a*) 1.861 MPa, (*b*) 1.583 MPa, (*c*) 1.6 MPa

3-90 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,

$R = 0.08149$ kPa·m³/kg·K, $T_{cr} = 374.2$ K, $P_{cr} = 4.059$ MPa

Analysis The specific volume of the refrigerant is

$$v = \frac{V}{m} = \frac{0.016773\ \text{m}^3}{1\ \text{kg}} = 0.016773\ \text{m}^3/\text{kg}$$

R-134a
0.016773 m³/kg
110°C

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

$$P = \frac{RT}{v} = \frac{(0.08149\ \text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(383\ \text{K})}{0.016773\ \text{m}^3/\text{kg}} = \mathbf{1861\ kPa}$$

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

$$\left.\begin{aligned} T_R &= \frac{T}{T_{cr}} = \frac{383\ \text{K}}{374.2\ \text{K}} = 1.023 \\ v_R &= \frac{v_{\text{actual}}}{RT_{cr}/P_{cr}} = \frac{0.016773\ \text{m}^3/\text{kg}}{(0.08149\ \text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(374.2\ \text{K})/(4059\ \text{kPa})} = 2.24 \end{aligned}\right\} P_R = 0.39$$

Thus,

$$P = P_R P_{cr} = (0.39)(4059\ \text{kPa}) = \mathbf{1583\ kPa}$$

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

$$\left.\begin{aligned} T &= 110°\text{C} \\ v &= 0.016773\ \text{m}^3/\text{kg} \end{aligned}\right\} P = \mathbf{1600\ kPa}$$

3–121 A 10-kg mass of superheated refrigerant-134a at 1.2 MPa and 70°C is cooled at constant pressure until it exists as a compressed liquid at 20°C.

(*a*) Show the process on a *T*-*v* diagram with respect to saturation lines.
(*b*) Determine the change in volume.
(*c*) Find the change in total internal energy.

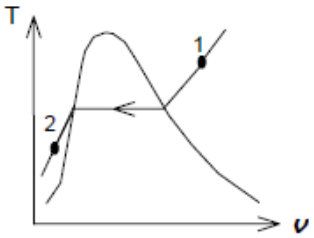
Answers: (*b*) −0.187 m³, (*c*) −1984 kJ

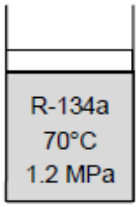
3-121 Superheated refrigerant-134a is cooled at constant pressure until it exists as a compressed liquid. The changes in total volume and internal energy are to be determined, and the process is to be shown on a *T*-*v* diagram.

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,

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

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



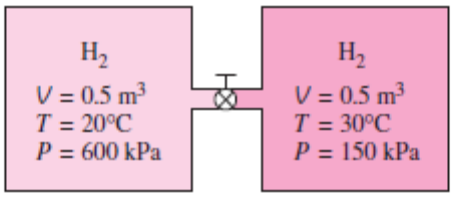


Thus,

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

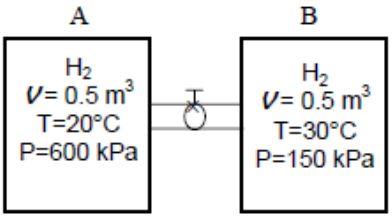
3–122 A 0.5-m³ rigid tank containing hydrogen at 20°C and 600 kPa is connected by a valve to another 0.5-m³ rigid tank that holds hydrogen at 30°C and 150 kPa. Now the valve is opened and the system is allowed to reach thermal equilibrium with the surroundings, which are at 15°C. Determine the final pressure in the tank.



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·m³/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



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

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

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

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

Then the final pressure can be determined from

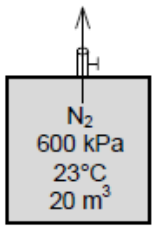
$$P = \frac{mRT_2}{V} = \frac{(0.308 \text{ kg})(4.124 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(288 \text{ K})}{1.0 \text{ m}^3} = \mathbf{365.8 \text{ kPa}}$$

3–124 A 20-m³ tank contains nitrogen at 23°C and 600 kPa. Some nitrogen is allowed to escape until the pressure in the tank drops to 400 kPa. If the temperature at this point is 20°C, determine the amount of nitrogen that has escaped. *Answer:* 44.6 kg

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·m³/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



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

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

Thus the amount of N_2 that escaped is

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

3–125 Steam at 400°C has a specific volume of 0.02 m³/kg. Determine the pressure of the steam based on (*a*) the ideal-gas equation, (*b*) the generalized compressibility chart, and (*c*) the steam tables. *Answers:* (*a*) 15,529 kPa, (*b*) 12,576 kPa, (*c*) 12,500 kPa

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,

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

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

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

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

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

(*c*) From the superheated steam table,

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