Thermodynamics: An Engineering Approach, 6th Edition
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McGraw-Hill, 2008

Chapter 3

PROPERTIES OF PURE SUBSTANCES

SOLVED PROBLEMS

Fall 2010

Table Properties

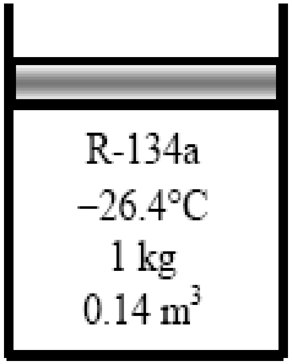
Problem (3-31)

3-31 A piston-cylinder device that is filled with R-134a is heated. The final volume is to be determined.

Analysis The initial specific volume is

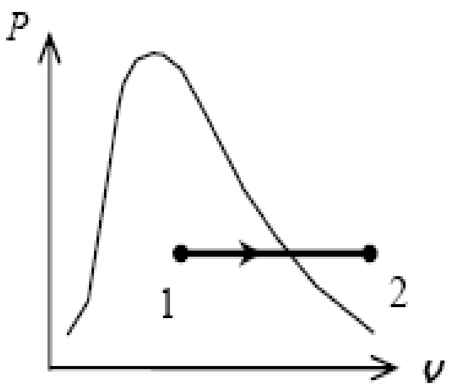
Given $T_2 = 100^\circ C$

$$v_1 = \frac{V_1}{m} = \frac{0.14\ \text{m}^3}{1\ \text{kg}} = 0.14\ \text{m}^3/\text{kg}$$



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

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



The final state is superheated vapor and the specific volume is

$T_2 > (T_1)_{sat}$

$$\left.\begin{array}{l} P_2 = 100\ \text{kPa} \\ T_2 = 100°\text{C} \end{array}\right\} v_2 = 0.30138\ \text{m}^3/\text{kg}\ \ (\text{Table A-13})$$

The final volume is then

$$V_2 = m v_2 = (1\ \text{kg})(0.30138\ \text{m}^3/\text{kg}) = \mathbf{0.30138\ m^3}$$

$(v_f < v_1 < v_g)$ *at* $T = -26.4C$

Mixture Conditions

Problem (3-36)

(U) (H)

3-36 The total internal energy and enthalpy of water in a container are to be determined.

Analysis The specific volume is

$$v = \frac{V}{m} = \frac{0.13\,\text{m}^3}{1\,\text{kg}} = 0.13\,\text{m}^3/\text{kg}$$

Closed System

m =1kg

Water
750 kPa
0.13 m³

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

$(v_f < v_1 < v_g)$ *at* $P = 750\,kPa$

Mixture Conditions

$$x = \frac{v - v_f}{v_{fg}} = \frac{(0.13 - 0.001111)\,\text{m}^3/\text{kg}}{(0.25552 - 0.001111)\,\text{m}^3/\text{kg}} = 0.5066$$

$$u = u_f + xu_{fg} = 708.40 + (0.5066)(1865.6) = 1653.5\,\text{kJ/kg}$$

$$h = h_f + xh_{fg} = 709.24 + (0.5066)(2056.4) = 1751.0\,\text{kJ/kg}$$

The total internal energy and enthalpy are then

$$U = mu = (1\,\text{kg})(1653.5\,\text{kJ/kg}) = \mathbf{1654\,kJ}$$

$$H = mh = (1\,\text{kg})(1751.0\,\text{kJ/kg}) = \mathbf{1751\,kJ}$$

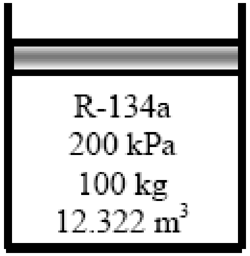
Problem (3-39)

$Given: v_2 = \frac{v_1}{2}$

$T_2 = ?$

$u_2 - u_1 = ?$

3-39 A piston-cylinder device that is filled with R-134a is cooled at constant pressure. The final temperature and the change of total internal energy are to be determined.

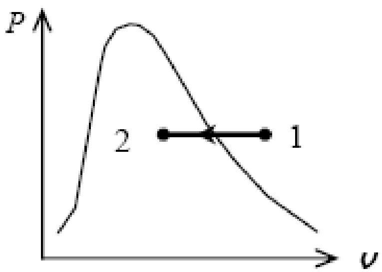


Analysis The initial specific volume is

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

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

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



The final specific volume is

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

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

$(v_f < v_2 < v_g)\ at\ P_2 = 200\, kPa$

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

$(v_g < v_1)\ at\ P_1 = 200\, kPa$

Superheated conditions

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

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

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

Hence, the change in the internal energy is

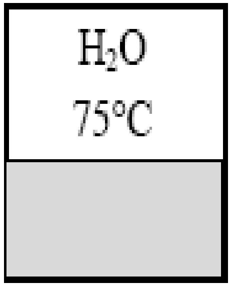
$$\Delta u = u_2 - u_1 = 152.61 - 263.08 = \mathbf{-110.47\ kJ/kg}$$

Problem (3-47)

3-47 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.

Given: $V = 2.5\,m^3$, $m = 15\,kg$

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

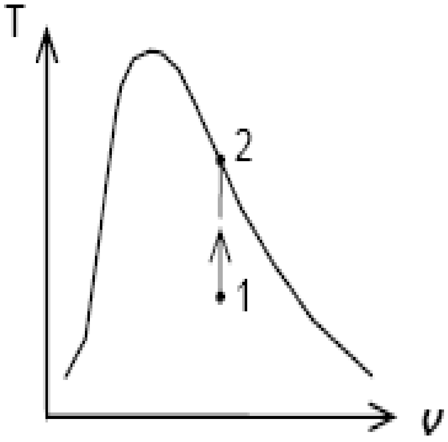


$$v = \frac{V}{m} = \frac{2.5\ \text{m}^3}{15\ \text{kg}} = 0.1667\ \text{m}^3/\text{kg}$$

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,



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

Problem (3-50)

$T_1 = ?$

$m = ?$

$V_2 = ?$

$Given\ v_f = 0.1 m^3, v_g = 0.9 m^3$

3-50 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,

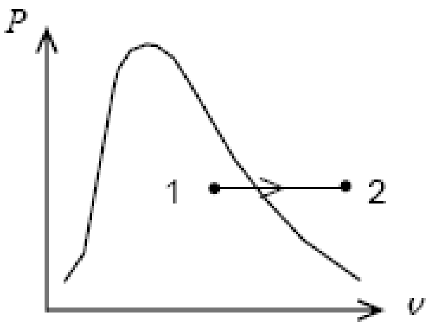
$$T = T_{\text{sat@800 kPa}} = \mathbf{170.41°C}$$

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

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

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

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



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

$T_2 > (T_1)_{sat}$

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

Then,

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

Problem (3-55)

3-55 The properties of compressed liquid water at a specified state are to be determined using the compressed liquid tables, and also by using the saturated liquid approximation, and the results are to be compared.

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

$$T = 100°\text{C} \quad \Rightarrow \quad \begin{aligned} v &\cong v_{f@100°\text{C}} = 0.001043 \text{ m}^3/\text{kg} \quad (0.72\% \text{ error}) \\ u &\cong u_{f@100°\text{C}} = 419.06 \text{ kJ/kg} \quad (1.02\% \text{ error}) \\ h &\cong h_{f@100°\text{C}} = 419.17 \text{ kJ/kg} \quad (2.61\% \text{ error}) \end{aligned}$$

From compressed liquid table (Table A-7),

Given:

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

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

Ideal Gas

Problem (3-74)

Given $T_f = 20^\circ C$

$V_B = ?$

$P_{Final} = ?$

3-74 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

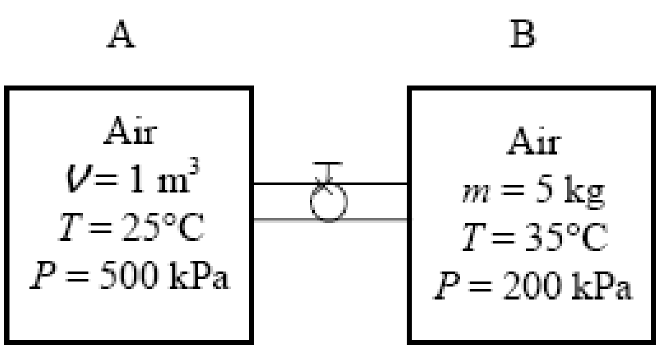
$T_{CR} = 132.5\,K$

$P_{CR} = 3.77\,MPa$

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

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

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

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

Compressibility Factor

Problem (3-84)

$v = ?$

3-84 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,

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

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

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

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

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

R-134a
0.9 MPa
70°C

Thus,

Superheated Conditions

$$v = Zv_{\text{ideal}} = (0.894)(0.03105 \text{ m}^3/\text{kg}) = \mathbf{0.02776\ m^3/kg} \quad \textbf{(1.3\%error)}$$

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

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

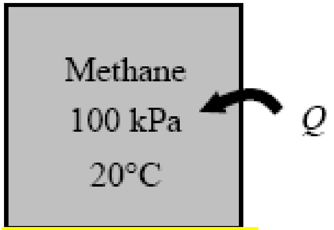
Problem (3-94)

$P_{Final} = ?$

3-94 Methane is heated in a rigid container. The final pressure of the methane is to be determined using the ideal gas equation and the Benedict-Webb-Rubin equation of state.

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

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



$T_2 = 400C$

The specific molar volume of the methane is

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

(*b*) The specific molar volume of the methane is

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

Using the coefficients of Table 3-4 for methane and the given data, the Benedict-Webb-Rubin equation of state for state 2 gives

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

$$= \frac{(8.314)(673)}{24.36} + \left(0.04260\times 8.314\times 673 - 187.91 - \frac{2.286\times 10^6}{673^2}\right)\frac{1}{24.36^2} + \frac{0.003380\times 8.314\times 673 - 5.00}{24.36^3}$$

$$+ \frac{5.00\times 1.244\times 10^{-4}}{24.36^6} + \frac{2.578\times 10^5}{24.36^3(673)^2}\left(1 + \frac{0.0060}{24.36^2}\right)\exp(-0.0060/24.36^2)$$

$$= \mathbf{229.8\,kPa}$$

THE END