ESO201A

TUTORIAL 2: PROBLEMS AND SOLUTIONS

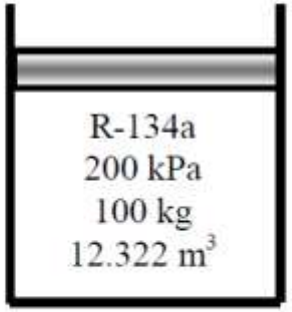
3-19C In 1775, Dr. William Cullen made ice in Scotland by evacuating the air in a water tank. Explain how that device works, and discuss how the process can be made more efficient.

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

3-42 100-kg of R-134a at 200 kPa are contained in a piston-cylinder device whose volume is 12.322 m^3. The piston is now moved until the volume is one-half its original size. This is done such that the pressure of the R-134a does not change. Determine the final temperature and the change in the total internal energy of the R-134a.

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.

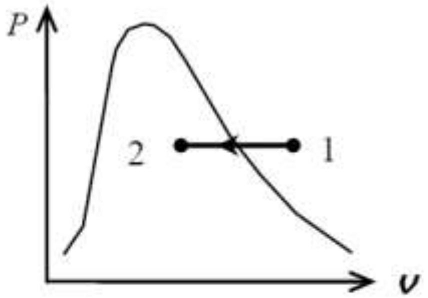
Analysis The initial specific volume is



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

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

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



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

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

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

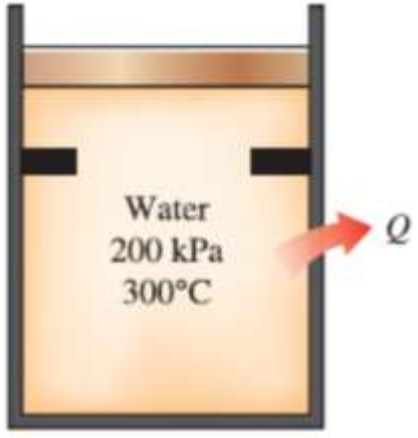
$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{(0.06161 - 0.0007532)\ \mathrm{m^3/kg}}{(0.099951 - 0.0007532)\ \mathrm{m^3/kg}} = 0.6135$$

$$u_2 = u_f + x_2 u_{fg} = 38.26 + (0.6135)(186.25) = 152.52\ \mathrm{kJ/kg}$$

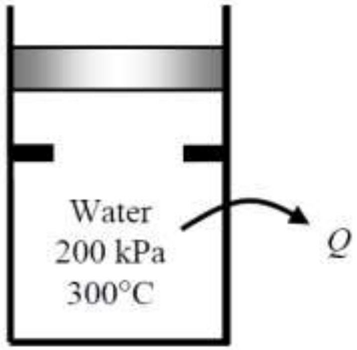
Hence, the change in the internal energy is

$$\Delta u = u_2 - u_1 = 152.52 - 263.08 = \mathbf{-110.6\ kJ/kg}$$

3-43 Water initially at 200 kPa and 300°C is contained in a piston-cylinder device fitted with stops. The water is allowed to cool at constant pressure until it exists as a saturated vapor and the piston rests on the stops. Then the water continues to cool until the pressure is 100 kPa. On the T-**ν** diagrams sketch, with respect to the saturation lines, the process curves passing through both the initial, intermediate, and final states of the water. Label the T, P and **ν** values for end states on the process curves. Find the overall change in internal energy between the initial and final states per unit mass of water.



A piston-cylinder device fitted with stops contains water at a specified state. Now the water is cooled until a final pressure. The process is to be indicated on the T-**v** diagram and the change in internal energy is to be determined.

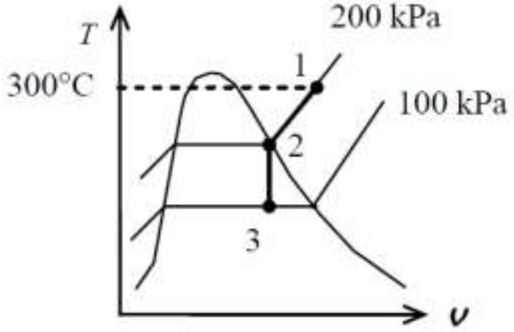


Analysis The process is shown on *T-v* diagram. The internal energy at the initial state is

$$\left.\begin{aligned} P_1 &= 200\ \text{kPa} \\ T_1 &= 300°\text{C} \end{aligned}\right\} u_1 = 2808.8\ \text{kJ/kg}\ \ (\text{Table A - 6})$$

State 2 is saturated vapor at the initial pressure. Then,

$$\left.\begin{aligned} P_2 &= 200\ \text{kPa} \\ x_2 &= 1\ (\text{sat. vapor}) \end{aligned}\right\} \boldsymbol{v}_2 = 0.8858\ \text{m}^3/\text{kg}\ \ \ (\text{Table A - 5})$$



Process 2-3 is a constant-volume process. Thus,

$$\left.\begin{aligned} P_3 &= 100\ \text{kPa} \\ \boldsymbol{v}_3 &= \boldsymbol{v}_2 = 0.8858\ \text{m}^3/\text{kg} \end{aligned}\right\} u_3 = 1508.6\ \text{kJ/kg}\ \ (\text{Table A - 5})$$

The overall change in internal energy is

$$\Delta u = u_1 - u_3 = 2808.8 - 1508.6 = \mathbf{1300 kJ/kg}$$

3-67C Propane and methane are commonly used for heating in winter, and the leakage of these fuels, even for short periods, poses a fire danger for homes. Which gas leakage do you think poses a greater risk for fire? Explain.

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

3-82 Determine the specific volume of superheated water vapor at 15 MPa and 350°C , using (a) the ideal-gas equation, (b) the generalized compressibility chart, and (c) steam tables. Also determine the error involved in the first two cases.

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.m^3/kg.K, T_{cr} = 647.1 K, P_{cr} = 22.06 Mpa

H_2O
15 Mpa
350°C

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

$$v = \frac{RT}{P} = \frac{(0.4615\ \text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(623.15\ \text{K})}{15{,}000\ \text{kPa}} = \mathbf{0.01917\ m^3/kg}\ \ \textbf{(67.0\% error)}$$

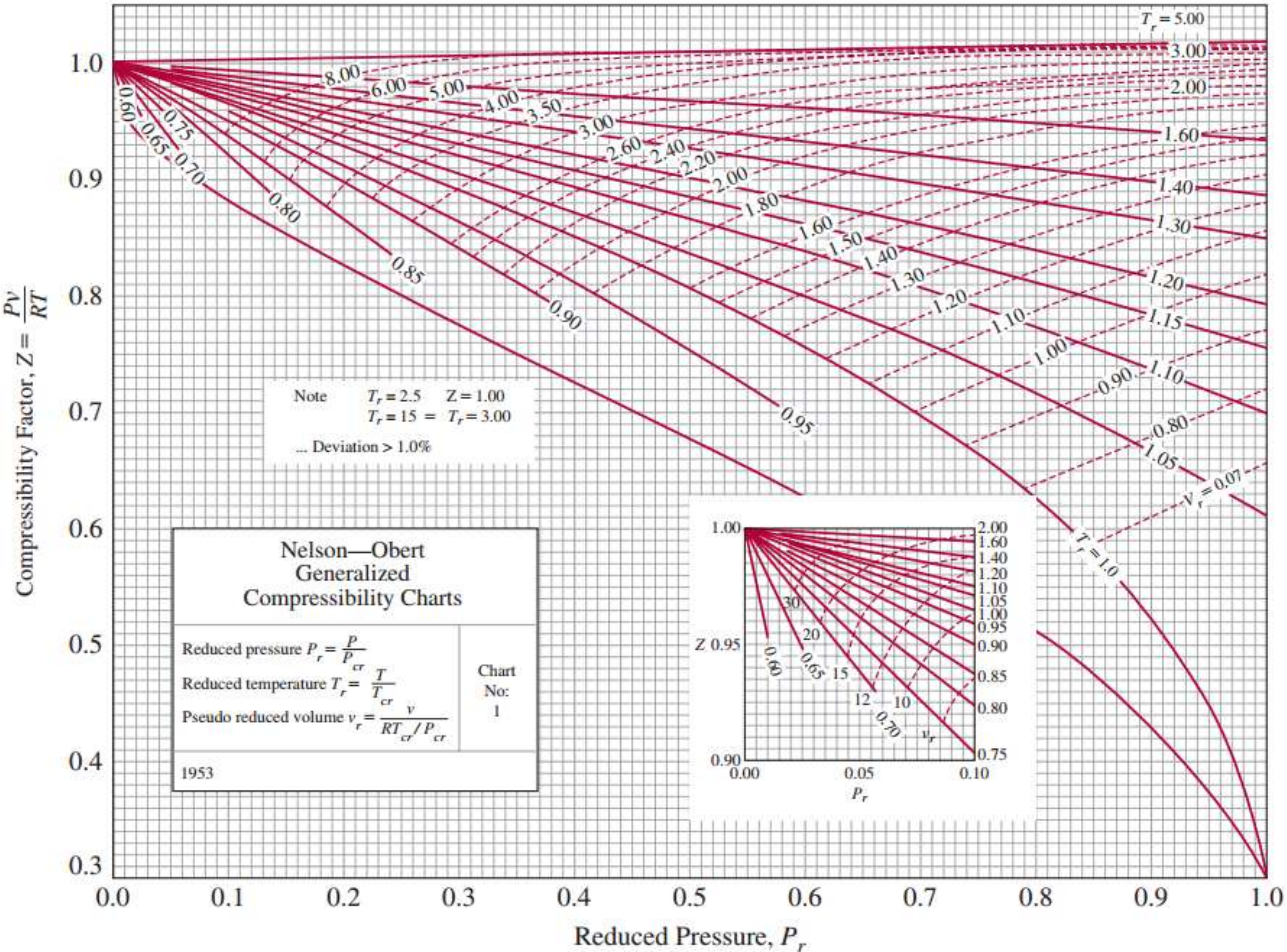
(b) From the compressibility chart (Fig. A-15 on next slide),

$$\left.\begin{aligned} P_R &= \frac{P}{P_{cr}} = \frac{15\ \text{MPa}}{22.01\ \text{MPa}} = 0.68 \\ T_R &= \frac{T}{T_{cr}} = \frac{623\ \text{K}}{647.1\ \text{K}} = 0.96 \end{aligned}\right\} Z=0.65$$

Thus,

$$v = Z\,v_{ideal} = (0.65)(0.01917\text{m}^3/\text{kg}) = \mathbf{0.01246m^3/kg}\ \ \textbf{(8.5\% error)}$$

(a) $0 < P_r < 1.0$

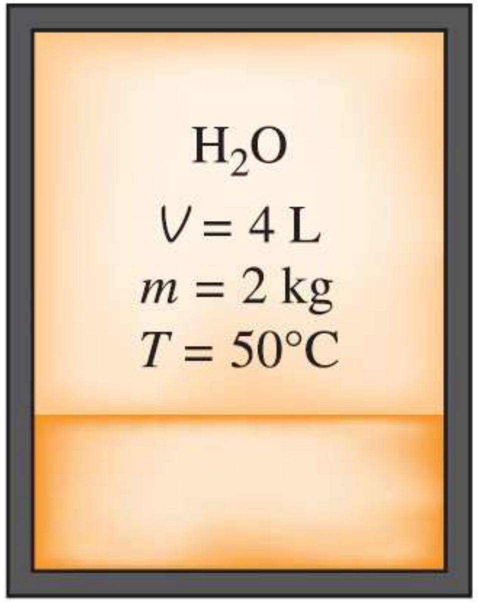


Compressibility Factor, $Z = \frac{Pv}{RT}$
Reduced Pressure, P_r
$T_r = 5.00$
Note $T_r = 2.5$ Z = 1.00
$T_r = 15$ = $T_r = 3.00$
... Deviation > 1.0%
Nelson—Obert
Generalized
Compressibility Charts
Reduced pressure $P_r = \frac{P}{P_{cr}}$
Reduced temperature $T_r = \frac{T}{T_{cr}}$
Pseudo reduced volume $v_r = \frac{v}{RT_{cr}/P_{cr}}$
Chart No: 1
1953
$T_r = 1.0$
$v_r = 0.07$

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

$$\left.\begin{array}{l} P = 15 \text{ MPa} \\ T = 350°\text{C} \end{array}\right\} \ v = \mathbf{0.01148 \ m^3/kg}$$

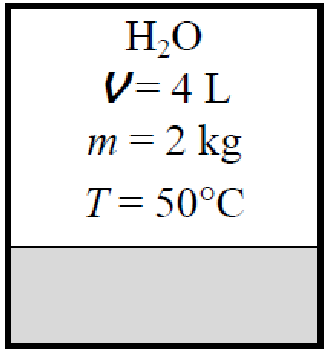
3-118 A 4-L rigid tank contains 2 kg of saturated liquid-vapor mixture of water at 50°C. The water is now slowly heated until it exists in a single phase. At the final state, will the water be in the liquid phase or the vapor phase? What would your answer be if the volume of the tank were 400 L instead of 4 L?



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 ($\mathbf{v} = \mathbf{V}/m$ = constant), and thus the final specific volume will be equal to the initial specific volume,

$\mathrm{v}_2 = \mathrm{v}_1$



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.

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

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