A system consisting of liquid water undergoes a process. At the end of the process, some of the liquid water has frozen, and the system contains liquid water and ice. Can the system be viewed as being a pure substance during the process? Explain.

The system is a pure substance. Some of the fluid has changed phase, but the chemical composition remains fixed.
3.5 Determine the phase or phases in a system consisting of 
H₂O at the following conditions and sketch p–v and T–v 
diagrams showing the location of each state.

(a) \( p = 80 \text{ lbf/in.}^2, T = 312.07^\circ \text{F} \).
(b) \( p = 80 \text{ lbf/in.}^2, T = 400^\circ \text{F} \).
(c) \( T = 400^\circ \text{F}, p = 360 \text{ lbf/in.}^2 \).
(d) \( T = 320^\circ \text{F}, p = 70 \text{ lbf/in.}^2 \).
(e) \( T = 10^\circ \text{F}, p = 14.7 \text{ lbf/in.}^2 \).

\[ 
\begin{array}{c}
\text{2-phase liquid vapor mixture} \\
\text{b.) Superheated vapor}
\end{array}
\]
c.) \( T = 400 \) \( P = 360 \)

\[ \text{Subcooled liquid} \]

\[ \text{Saturated liquid} \]

\[ \text{Saturated vapor} \]

\[ \text{Superheated vapor} \]

\[ \text{Solid} \]

d.) \( T = 320^\circ F \) \( P = 70 \text{psi} \)

e.) \( T = 10^\circ F \) \( P = 14.7 \text{psi} \)
3.7 The following table lists temperatures and specific volumes of water vapor at two pressures:

<table>
<thead>
<tr>
<th>$T$ (°C)</th>
<th>$v$ (m$^3$/kg)</th>
<th>$T$ (°C)</th>
<th>$v$ (m$^3$/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>0.2060</td>
<td>200</td>
<td>0.1325</td>
</tr>
<tr>
<td>240</td>
<td>0.2275</td>
<td>240</td>
<td>0.1483</td>
</tr>
<tr>
<td>280</td>
<td>0.2480</td>
<td>280</td>
<td>0.1627</td>
</tr>
</tbody>
</table>

Data encountered in solving problems often do not fall exactly on the grid of values provided by property tables, and linear interpolation between adjacent table entries becomes necessary. Using the data provided here, estimate:

(a) the specific volume at $T = 240$°C, $p = 1.25$ MPa, in m$^3$/kg.
(b) the temperature at $p = 1.5$ MPa, $v = 0.1555$ m$^3$/kg, in °C.
(c) the specific volume at $T = 220$°C, $p = 1.4$ MPa, in m$^3$/kg.

a.) $\text{slope} = \text{constant} = \frac{N_2 - N_1}{P_2 - P_1} = \frac{0.1483 - 0.2275}{1.15 - 1.0} = \frac{-0.1584}{1.15 - 1.0} = -0.1584$

$N = 0.2275 - (-0.1584)(1.15 - 1.0) = 0.1879$ m$^3$/kg

b.) Find $T$, $P = 1.5$ MPa, $v = 0.1555$ m$^3$/kg

$\text{slope} = \frac{T - 240}{1.555 - 0.1483} = \frac{280 - 240}{0.1627 - 0.1483}$

$T = 260$°C
3.7c

Find \( N \)

\[
\bar{T} = 220, \quad P = 1.4 \text{ MPa}
\]

This requires double interpolation!

@ \( 220 ^\circ C \) the \( N \) in middle of \( T = 200 + \bar{T} = 240 \)

\[
\text{at } 1 \text{ MPa, } T = 220 \Rightarrow N = \frac{0.2060 + 0.2275}{2}
\]

\[
N = 0.21675 \text{ m}^3/\text{kg}
\]

\[
1.5 \text{ MPa, } T = 220 \Rightarrow \frac{0.1325 + 0.1483}{2} = 0.1404 \text{ m}^3/\text{kg}
\]

Then

\[
\frac{N - 0.1404}{1.5 - 1.14} = \frac{0.21675 - 0.1404}{1.5 - 1.0} \Rightarrow
\]

\[
N = 0.1404 + \left( \frac{0.1}{0.5} \right) (0.21675 - 0.1404)
\]

\[
= 0.15567 \text{ m}^3/\text{kg}
\]
3.11 For each case, determine the specific volume at the indicated state. Locate the state on a sketch of the $T$-$v$ diagram.

(a) Water at $p = 14.7$ lbf/in.$^2$, $T = 100^\circ$F. Find $v$, in ft$^3$/lb.

(b) Ammonia at $T = -30^\circ$C, $x = 50\%$. Find $v$, in m$^3$/kg.

(c) Refrigerant 134a at $p = 1.5$ MPa, $T = 100^\circ$C. Find $v$, in m$^3$/kg.

**A**

\[ P = 14.7 \text{ psig} \]

\[ N = N_g(T_{100^\circ}F) = 0.01613 \text{ ft}^3/\text{lb} \]

**B**

\[ N_x = (1-x)N_g + xN_f \]

\[ = 0.5(1.4757 \times 10^{-3}) + 0.5(0.9634) \]

\[ = 0.4824 \text{ m}^3/\text{kg} \]

**C**

\[ N_c = 0.0174 \text{ m}^3/\text{kg} \]

*Table A-12*
3.13 For \( \text{H}_2\text{O} \), determine the specific volume at the indicated state, in m\(^3\)/kg. Locate the states on a sketch of the \( T-v \) diagram.

(a) \( T = 400^\circ\text{C}, p = 20 \text{ MPa} \).
(b) \( T = 40^\circ\text{C}, p = 20 \text{ MPa} \).
(c) \( T = 40^\circ\text{C}, p = 2 \text{ MPa} \).

\[ P_c = 22.09 \text{ MPa} \]

\[ 400^\circ\text{C} \]

\[ P = 20 \text{ mPa} \]

\[ 365^\circ\text{C} \]

\[ 212^\circ\text{C} \]

\[ 2 \text{ MPa} \]

\[ 40^\circ\text{C} \]

\[ N \]

A.) Table A-4 \( \quad N = 9.94 \times 10^{-3} \text{ m}^3/\text{kg} \)

B.) Table A-5 \( \quad N = 0.9992 \times 10^{-3} \text{ m}^3/\text{kg} \)

C.) Table A-2  \quad \text{Eqn 3.11}

\[ N(T,P) \sim N_g(T) = 1.0078 \times 10^{-3} \text{ m}^3/\text{kg} \]
3.20 A two-phase liquid–vapor mixture of a substance has a pressure of 150 bar and occupies a volume of 0.2 m$^3$. The masses of saturated liquid and vapor present are 3.8 kg and 4.2 kg, respectively. Determine the specific volume of the mixture, in m$^3$/kg.

\[
\nu = \frac{V}{m_f + m_g} = \frac{0.2 \text{ m}^3}{3.8 \text{ kg} + 4.2 \text{ kg}}
\]

\[

\nu = 0.025 \text{ m}^3/\text{kg}
\]
3.24 Water contained in a closed, rigid tank, initially saturated vapor at 200°C, is cooled to 100°C. Determine the initial and final pressures, each in bar. Locate the initial and final states on sketches of the $p-v$ and $T-v$ diagrams.

\[ P_{\text{sat}}(200^\circ \text{C}) = 15.54 \text{ bar} \]

\[ N_1 = N_2 = 0.1274 \text{ m}^3/\text{kg} = N_2 \text{ as well} \]

\[ P_2 = P_{\text{sat}}(100^\circ \text{C}) = 1.014 \text{ bar} \]
As shown in Fig. P3.31, a cylinder fitted with a piston is filled with 600 lb of saturated liquid ammonia at 45°F. The piston weighs 1 ton and has a diameter of 2.5 ft. What is the volume occupied by the ammonia, in ft³? Ignoring friction, is it necessary to provide mechanical attachments, such as stops, to hold the piston in place? Explain.

Free Body Diagram

\[ F_{\text{add}} = (P_{\text{lig}} - P_{\text{atm}}) \cdot \text{Area} - \text{Weight} \]

\[ F_{\text{add}} = (81 - 14.7) \cdot \frac{\pi}{4} \cdot (15 \text{ in})^2 - 1 \text{ ton} \cdot \left( \frac{2000 \text{ lb}}{8 \text{ ton}} \right) \]

\[ F_{\text{add}} = 44865 \text{ lb force required} \]

\[ V = m \cdot \frac{V}{m} = (600 \text{ lb}) \cdot \left( \frac{0.02548 \text{ ft}^3}{1 \text{ lb}} \right) = 15.29 \text{ ft}^3 \]

Table A-13E
3.35 From an initial state where the pressure is $p_1$, the temperature is $T_1$, and the volume is $V_1$, water vapor contained in a piston–cylinder assembly undergoes each of the following processes:

Process 1–2: Constant-temperature to $p_2 = 2p_1$.

Process 1–3: Constant-volume to $p_3 = 2p_1$.

Process 1–4: Constant-pressure to $V_4 = 2V_1$.

Process 1–5: Constant-temperature to $V_5 = 2V_1$.

On a $p$–$V$ diagram, sketch each process, identify the work by an area on the diagram, and indicate whether the work is done by, or on, the water vapor.

Closed System

Volume change is the only work mode

$$ W = \int P \, dV $$

Process 1 $\rightarrow$ 2: Work = area $1 - 2 - V_a - V_1 - 1$ $\Rightarrow$ compression

So work is done ON system.

Process 1 $\rightarrow$ 3: Work = 0 (constant $V$).

Process 1 $\rightarrow$ 4: Work = area $1 - 4 - V_4 - V_1 - 1$ $\Rightarrow$ expansion

So work is done BY system.

Process 1 $\rightarrow$ 5: Work = area $1 - 5 - V_5 - V_1 - 1$ $\Rightarrow$ expansion

Work is done BY system.
3.44 Using the tables for water, determine the specified property data at the indicated states. In each case, locate the state by hand on sketches of the \( p-v \) and \( T-v \) diagrams.

(a) At \( p = 3 \) bar, \( v = 0.5 \) m\(^3\)/kg, find \( T \) in \(^\circ\)C and \( u \) in kJ/kg.

(b) At \( T = 320^\circ\)C, \( v = 0.03 \) m\(^3\)/kg, find \( p \) in MPa and \( u \) in kJ/kg.

(c) At \( p = 28 \) MPa, \( T = 520^\circ\)C, find \( v \) in m\(^3\)/kg and \( h \) in kJ/kg.

(d) At \( T = 10^\circ\)C, \( v = 100 \) m\(^3\)/kg, find \( p \) in kPa and \( h \) in kJ/kg.

(e) At \( p = 4 \) MPa, \( T = 160^\circ\)C, find \( v \) in m\(^3\)/kg and \( u \) in kJ/kg.

A)

\[
\begin{align*}
\text{Table A-3} & \quad N < N^* < N^*_g \\
\text{\( T = 133.6^\circ\)C} \\
\lambda &= \frac{N - N^*_g}{N^*_g - N^*_f} = \frac{0.5 - 1.073 \times 10^{-3}}{1.6058 - 1.073 \times 10^{-2}} \\
\lambda &= 0.825 \\
\mu &= \mu_f + \lambda (\mu_f - \mu_f) = 561.15 + 0.825(254.36 - 561.5) \\
\mu &= 2196.7 \text{ kJ/kg} \\
\end{align*}
\]

b).

\[
\begin{align*}
\text{T = 320^\circ\)C} & \quad N = 0.03 \text{ m}^3/\text{kg} \\
\text{Table A-2} & \quad N > N^*_g @ 320^\circ\)C \\
\text{Table A-4} & \quad @ 320^\circ\)C state is between 60 and 80 bar \\
\text{P = 74.67 = 7.467 MPa \quad h = 2678.0 \text{ kJ/kg}} \\
\end{align*}
\]
3.44

C.) \( P = 28 \text{ mPa} = 280 \text{ bar} \)
\( T = 520^\circ \text{C} \)

Table A-\# Superheat

\( N^* = 0.01020 \text{ m}^3/\text{kg} \)

\( h = 3192.3 \text{ kJ/kg} \)

D.) \( T = 10^\circ \text{C} \)  \( N^* = 100 \text{ m}^3/\text{kg} \)

Table A-2  \( N_f < N^* < N_g \)  \( P = 0.01228 \text{ bar} \)

\[ X = \frac{N^* - N_f}{N_g - N_f} = \frac{100 - 1.0004 \times 10^3}{106.4 - 1.0004 \times 10^3} = 0.94 \]

\[ h = h_f + X h_{fg} = 42.01 + 0.94(4477.7) = 4371 \text{ kJ/kg} \]
3.44

e) \( P = 4 \, \text{MPa} = 40 \, \text{bar} \quad T = 160^\circ \text{C} \\
\text{Table A-3 @ 40bar} \; T_{\text{sat}} = 250.4^\circ \text{C} \\
'\text{Liquid state} (T < T_{\text{sat}}) \\
\text{Table A-5} \; \text{double interpolation} \\

\begin{align*}
T = 140^\circ \text{C} & \\
\begin{array}{c|c}
\; P = 2.5 \, \text{MPa} & 5 \, \text{MPa} \\
\hline
\frac{N}{\mu} = 1.078 \times 10^{-3} & 1.0768 \times 10^{-3} \\
\mu = 587.82 & 586.76
\end{array}
\end{align*}

\begin{align*}
T = 180^\circ \text{C} & \\
\begin{array}{c|c}
\; P = 4.0 \, \text{MPa} & 5 \, \text{MPa} \\
\hline
\frac{N}{\mu} = 1.126 \times 10^{-3} & 1.124 \times 10^{-3} \\
\mu = 761.16 & 759.6
\end{array}
\end{align*}

\begin{align*}
\text{Then at} \; 4 \, \text{MPa}, 160^\circ \text{C} \\
\frac{N}{\mu} = 1.1011 \times 10^{-3} \quad \mu = 673.71 \, m^3/kg
\end{align*}