3.4 During evaporation the system is not a pure substance. Once fully evaporated and mixed uniformly with air, it can be treated as a pure substance.
PROBLEM 3.6

(a) $p = 5 \text{ bar}$
$T = 151.9 \degree \text{C}$
two-phase liquid-vapor mixture

(b) $p = 5 \text{ bar}$
$T = 200 \degree \text{C}$
superheated vapor

(c) $p = 2.5 \text{ MPa} = 25 \text{ bar}$
$T = 200 \degree \text{C}$
subcooled (compressed) liquid

(d) $T = 160 \degree \text{C}$
$p = 4.8 \text{ bar}$
superheated vapor

(e) $T = -12 \degree \text{C}$
$p = 1 \text{ bar} = 100 \text{ kPa}$
solid
(a) At a temperature of 120°F, the specified pressure of 54 \text{ lb/in}^2 falls between the table values of 50 and 60 \text{ lb/in}^2. To determine the specific volume corresponding to 54 \text{ lb/in}^2, we think of the slope of a straight line joining the adjacent table states, as follows:

\[
\frac{v - 5.891}{60 - 54} = \frac{5.110 - 5.891}{60 - 50} \Rightarrow v = 5.891 + \frac{6}{10} (7.110 - 5.891) = 6.622 \text{ ft}^3/\text{lb}
\]

(b) At a pressure of 60 \text{ lb/in}^2, the given specific volume of 5.982 \text{ ft}^3/\text{lb} falls between the table values of 120 and 140°F. To determine the temperature corresponding to the given specific volume, we think of the slope of a straight line joining the adjacent table states, as follows:

\[
slope = \frac{T - 120}{5.982 - 5.891} = \frac{140 - 120}{6.12 - 5.891} \Rightarrow T = 120 + \left[\frac{5.982 - 5.891}{6.12 - 5.891}\right] (140 - 120) = 127.9°F
\]

(c) In this case, the specified pressure falls between the table values of 50 and 60 \text{ lb/in}^2 and the specified temperature falls between the table values of 100 and 120°F. Thus, double interpolation is required.

- At 110°F, the specific volume at each pressure is simply the average over the interval:
  - at $50 \text{ lb/in}^2$, 110°F; \[ v = \frac{7.110 + 6.836}{2} = 6.973 \text{ ft}^3/\text{lb} \]
  - at $60 \text{ lb/in}^2$, 110°F; \[ v = \frac{5.891 + 5.657}{2} = 5.775 \text{ ft}^3/\text{lb} \]

- Then, with the same approach as in (a),
  \[ \frac{v - 5.775}{60 - 50} = \frac{6.973 - 5.775}{60 - 50} \Rightarrow v = 5.775 + \frac{6}{10} (6.973 - 5.775) = 6.015 \text{ ft}^3/\text{lb} \]
PROBLEM 3.12

(a) Water. \( \nu = 0.5 \text{ m}^3/\text{kg}, P = 3 \text{ bar}. \) Find \( T \) in \( ^\circ\text{C} \).

Table A-3, \( \nu_f = 1.073 \times 10^3 \text{ m}^3/\text{kg}, \) \( \nu_g = 0.6058 \text{ m}^3/\text{kg}. \)

Since \( \nu_f < \nu < \nu_g \), the state is in the two-phase, liquid-vapor region — see \( T-\nu \) diagram.

Thus, \( T = T_{sat}(3 \text{ bar}) = 133.6 \text{ } ^\circ\text{C} \).

(b) Ammonia. \( P = 11 \text{ lb/ft}^2, T = -20^\circ\text{F}. \) Find \( \nu \) in \( \text{ft}^3/\text{lb}. \)

Table A-15E

<table>
<thead>
<tr>
<th>( \text{Temp.} )</th>
<th>( \nu \text{ in } \text{ft}^3/\text{lb} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>-20°F</td>
<td>( 0.106 \text{ ft}^3/\text{lb} )</td>
</tr>
<tr>
<td>-38.24°F</td>
<td>( 1.21 \text{ lb/ft}^2 )</td>
</tr>
</tbody>
</table>

\( \nu = 24.93 \text{ ft}^3/\text{lb} \).

(c) Propane. \( P = 1 \text{ MPa}, T = 85^\circ\text{C}. \) Find \( \nu \) in \( \text{m}^3/\text{kg}. \)

Table A-18 at 10 bar:

<table>
<thead>
<tr>
<th>( \text{Temp.} )</th>
<th>( \nu \text{ in } \text{m}^3/\text{kg} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>80°C</td>
<td>( 0.05992 \text{ m}^3/\text{kg} )</td>
</tr>
<tr>
<td>85°C</td>
<td>( 0.06152 \text{ m}^3/\text{kg} )</td>
</tr>
<tr>
<td>90°C</td>
<td>( 0.06326 \text{ m}^3/\text{kg} )</td>
</tr>
</tbody>
</table>

\( \nu = 0.06109 \text{ m}^3/\text{kg} \).
Problem 3.14

@ 120°C Table A-2
\[ \gamma = 1.603 \times 10^{-3} \text{ m}^3/\text{kg} \]
\[ \gamma_g = 0.8919 \text{ m}^3/\text{kg} \]
PROBLEM 3.21

KNOWN: A closed, rigid container holds different volumes of saturated liquid water and saturated vapor water.

FIND: Determine the quality of the mixture.

SCHEMATIC & GIVEN DATA:

![Diagram](image)

Fig. P3.21

ANALYSIS:

\[ x = \frac{m_{\text{vap}}}{m_{\text{vap}} + m_{\text{liq}}} \]

Thus, \[ m_{\text{vap}} = \frac{V_{\text{vap}}}{V_T} \]

\[ m_{\text{liq}} = \frac{V_{\text{liq}}}{V_T} \]

\[ x = \frac{V_{\text{vap}}/V_T}{(V_{\text{vap}}/V_T) + (V_{\text{liq}}/V_T)} \]

\[ V_{\text{vap}} = 3.0\,A \quad \text{and} \quad V_{\text{liq}} = 2.0\,A \]

Where area A is in the same units as the vertical measure shown. Then

\[ x = \frac{(3.0\,A/V_T)}{(3.0\,A/V_T) + (2.0\,A/V_T)} = \frac{1}{1 + \frac{2.0(V_T/V_T)}{3.0(V_T/V_T)}} = \frac{1}{1 + \frac{2.0(V_T/V_T)}{3.0(V_T/V_T)}} \]

Simplify to appear in the last expression, the quantities can be in any consistent units.

1. Using \( V_T \) and \( V_T \) from Table A-2 at 150°C,

\[ V_T = 1.0905 \times 10^{-3} \text{ m}^3/\text{kg} \]

\[ V_T = 0.3926 \text{ m}^3/\text{kg} \]

\[ x = \frac{1}{1 + \frac{2.0(0.3926)}{3.0(1.0905 \times 10^{-3})}} = 0.0041 \quad (0.41\%) \]

1. Using \( V_T \) and \( V_T \) at 302°F (150°C) from Table A-2:

\[ V_T = 0.017468 \text{ ft}^3/\text{lb} \]

\[ V_T = 6.292 \text{ ft}^3/\text{lb} \]

This gives the same value for x, as can be verified.
**Problem 3.25**

\[
T_1 = 10^\circ C \quad X_1 = ? \\
T_2 = 50^\circ C \quad X_2 = 100\% \\
V = 1.5 \text{ m}^3
\]

\[V \text{ and } M \text{ are constant.}\]

@ 50°C \[N_2 = N_g(50^\circ C) = 0.01505 \text{ m}^3/\text{kg}\]

\[\rho_2 = \rho_1\]

\[X_1 = \frac{V_1 - V_6}{V_5 - V_6} = \frac{V_2 - V_6}{V_5 - V_6} = 0.294\]

\[M_{\text{vapor}, 2} = \frac{V}{N_2} = \frac{1.5 \text{ m}^3}{0.01505 \text{ m}^3/\text{kg}} = 99.67 \text{ kg}\]

\[M_{\text{vapor}, 1} = X_1 (M_{\text{total}}) = 0.294 (99.67) = 29.3 \text{ kg}\]
Problem 3.32

**Known:** Water is compressed at a constant pressure between two specified states.

**Find:** Determine the temperatures at the initial and final states, and the work for the process.

**Schematic & Given Data:**

\[ P = 250 \text{ lbf/in}^2 \]
\[ V_i = 6.88 \text{ ft}^3 \]

**State 2:** Sat. Vap.

\[ m = 2 \text{ lb} \]

**Governing Equations:** 1. The given quantity of water is the closed system. 2. Volume change is the only work mode. 3. The process occurs at constant pressure.

**Analysis:**

The initial specific volume is:

\[ V_i = \frac{V_i}{m} = \frac{6.88 \text{ ft}^3}{2 \text{ lb}} = 3.44 \text{ ft}^3/\text{lb} \]

From Table A-4E, with \( v_i = 3.44 \text{ ft}^3/\text{lb} \) and \( p_i = 250 \text{ lbf/in}^2 \)

\[ T_1 = 1000 \text{ } ^\circ \text{F} \]

The final specific volume is \( v_f \) at \( 250 \text{ lbf/in}^2 \).

From Table A-2E

\[ V_2 = v_f @ 250 \text{ ps} = 1.845 \text{ ft}^3/\text{lb} \]

Thus

\[ T_2 = 401.04 \text{ } ^\circ \text{F} \]

The final volume is:

\[ V_2 = m V_2 = (2 \text{ lb})(1.845 \text{ ft}^3/\text{lb}) = 3.69 \text{ ft}^3 \]

To evaluate the work:

\[ W = \int_1^2 p \text{d}V = p(V_2 - V_i) \]

\[ = (250 \text{ lbf/in}^2) \left(144 \text{ in}^2\right) \left[3.69 - 6.88\right] \text{ ft}^3 \left( \frac{1 \text{ Btu}}{778 \text{ ft}^3 \text{ lb} \text{f}} \right) \]

\[ = -147.6 \text{ Btu} \]

Water is compressed, thus the work is negative.
**Problem 3.35**

**Known:** From an initial state, water vapor contained within a piston-cylinder assembly undergoes four different 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 $V_5 = 2V_1$.

**Find:** Sketch each process on a $p-V$ diagram, identify work by an area on the diagram, and comment.

**Schematic & Given Data:**

![Diagram showing initial state at $p_1$, $T_1$, $V_1$ with processes 1-2, 1-3, 1-4, 1-5 indicated on a $p-V$ diagram.]

**Engineering Model:**
1. The water vapor is the closed system.
2. Volume change is the only work mode.

**Analysis:** Since volume change is the only work mode, the work in this application is given by Eq. 2.17:

$$W = \int p \, dV$$

- Process 1-2: Magnitude of work = Area(1-2-a-b-1). The water vapor is compressed, so work is done on the water vapor.

- Process 1-3: There is no work in this constant-volume process.

- Process 1-4: Magnitude of work = Area(1-4-c-b-1). The water vapor expands to a larger volume, so the water vapor does work.

- Process 1-5: Magnitude of work = Area(1-5-c-b-1). The water vapor expands to a larger volume, so the water vapor does work.
PROBLEM 3.42  Water is the substance.

(a) \( p = 2 \text{ MPa}, \ T = 300^\circ \text{C} \), find \( u, \ w \) \( \text{kJ/kg} \).

Table A-4:
\[
\frac{u}{E} = 2772.15 \frac{\text{kJ}}{\text{kg}}
\]

(b) \( p = 2.5 \text{ MPa}, \ T = 200^\circ \text{C} \), find \( u, \ w \) \( \text{kJ/kg} \).

Table A-5:
\[
\frac{u}{E} = 849.9 \frac{\text{kJ}}{\text{kg}}
\]

(c) \( T = 170^\circ \text{F} \), \( x = 50\% \), find \( u, \ w \) \( \text{Btu/lb} \).

Table A-2E:
\[
u x = \nu_f + x(\nu_g - \nu_f)
= 137.95 + 0.5(1065.4 - 137.95)
= 601.78 \frac{\text{Btu}}{\text{lb}}
\]

(d) \( p = 100 \text{ lbf/in}^2 \), \( T = 300^\circ \text{F} \), find \( h, \ w \) \( \text{Btu/lb} \).

Table A-2E:
with Eq. 3.14,
\[
\begin{align*}
\nu &= 299.7 \frac{\text{Btu}}{\text{lb}}
\end{align*}
\]

(e) \( p = 1.5 \text{ MPa}, \ \nu = 0.2095 \text{m}^3/\text{kg} \), find \( h, \ w \) \( \text{kJ/kg} \).

Table A-4E:
\[
\begin{align*}
\frac{v_y}{E} &= 0.1318 \frac{\text{m}^3}{\text{kg}}, \\
\Rightarrow \nu &> v_y \\
h &= 829.15 \frac{\text{kJ}}{\text{kg}}
\end{align*}
\]