ME 201
Thermodynamics

Homework #5 Solution

1. Determine the internal energy change as saturated liquid steam at 60°F goes to a two phase mixture of quality 0.40 at 60°F. Provide answers in SI units.

Solution:

Substance Type: Phase Change (steam)
Problem Type: Process

<table>
<thead>
<tr>
<th>State 1</th>
<th>State 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁ = 60°F = 15.6°C</td>
<td>T₂ = 60°F = 15.6°C</td>
</tr>
<tr>
<td>P₁ = 1.79 kPa</td>
<td>P₂ = 1.79 kPa</td>
</tr>
<tr>
<td>u₁ = 66.31 kJ/kg</td>
<td>u₂ = 998.62 kJ/kg</td>
</tr>
<tr>
<td>phase: sat.liq.</td>
<td>phase: 2 phase</td>
</tr>
<tr>
<td></td>
<td>x₂ = 0.40</td>
</tr>
</tbody>
</table>

*Italicized* values are from tables, *bold* values are calculated.

At state 1 we know the temperature and that the phase is saturated liquid, so that the state is fixed. Then we can go to the saturation temperature table, Table C.1aSI, and find through interpolation

\[ P₁ = 1.79 \text{ kPa and } u₁ = 66.31 \text{ kJ/kg} \]

For state 2 we know the temperature and that the phase is a two phase mixture with a quality, x₂, of 0.40. Then the pressure at state 2 must be the saturation pressure at 60°F or P₂ = 1.77 kPa

We use the definition of quality to determine the enthalpy at state 2.

\[ x = \frac{u₂ - u_f}{u_g - u_f} = \frac{u₂ - u_f}{u_f} \]

and solving for u₂ gives

\[ u₂ = u_f + x \cdot u_g \]

At 60°F we have

\[ u_f = 66.31 \text{ kJ/kg and } u_g = 2331.54 \text{ kJ/kg} \]

which gives

\[ u₂ = 66.31 + (0.40)(2331.54) = 998.93 \text{ kJ/kg} \]

So that our enthalpy change is

\[ u₂ - u₁ = 998.93 - 66.31 = 932.62 \text{ kJ/kg} \]

2. Give the behavior of entropy for steam when
a. pressure increases, constant temperature

Solution:
We can go to the superheat table and move from one pressure sub-table to another pressure sub-table at constant temperature to find

*As P increases at constant T, s decreases.*
b. quality increases

**Solution:**
For a two phase mixture we have

\[ s = s_f + x \cdot s_{fg} \]

**So as x increases, s must increase.**

c. temperature increases, constant pressure

**Solution:**
We go to the superheat tables at a given pressure and observe

**As T increases at constant P, s increases.**

d. pressure decreases, constant entropy

**Solution:**
Obviously,

**As P decreases at constant s, s stays constant.**

3. Saturated vapor water at 130°C undergoes an isometric process to 0.4 MPa. Determine the final fluid phase and the enthalpy change.

**Solution:**

<table>
<thead>
<tr>
<th>Substance Type: Phase change substance (saturated vapor water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem Type: Process (constant volume)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>State 1</th>
<th>State 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁ = 130°C</td>
<td>T₂ = 311.18°C</td>
</tr>
<tr>
<td>P₁ = 270.156 kPa</td>
<td>P₂ = 0.40 MPa</td>
</tr>
<tr>
<td>v₁ = 0.66819 m³/kg</td>
<td>v₂ = 0.66819 m³/kg</td>
</tr>
<tr>
<td>h₁ = 2719.86 kJ/kg</td>
<td>h₂ = 3089.17 kJ/kg</td>
</tr>
<tr>
<td>phase: sat. vap.</td>
<td>phase: sup. vap.</td>
</tr>
</tbody>
</table>

*Italicized* values are from tables, *bold* values are calculated.

At state 1 we know the temperature and that we have saturated vapor, so that the state is fixed and we can go to the saturated temperature table, C.1aSI, and find

\[ P₁ = 270.156 \text{ kPa}, \ v₁ = 0.66819 \text{ m}³/\text{kg}, \ h₁ = 2719.86 \text{ kJ/kg} \]

At state 2, we know the pressure, 0.35 MPa, and since we have an isotropic process

\[ v₂ = v₁ = 0.66819 \text{ m}³/\text{kg} \]

Next we must determine the phase at state 2. Going to the saturation pressure table, C.1bSI, at 0.40 MPa, we find 0.001

\[ v_f = 0.001084 \text{ m}³/\text{kg} \text{ and } v_g = 0.4624 \text{ m}³/\text{kg} \]

Since \( v₂ \) is greater than \( v_g \), we have superheated vapor. Going to the superheat table at 0.4 MPa we find at \( v₂ \)

\[ T₂ = 311.18°C \text{ and } h₂ = 3089.17 \text{ kJ/kg} \]

and our change in enthalpy is 369.31 kJ/kg.
4. Refrigerant-12 as saturated vapor at 0.5 MPa is isentropically compressed by a compressor in a refrigeration plant to 0.9 MPa. Determine the enthalpy change for the process and the final fluid phase.

Solution:

Substance Type: Phase Change (R-12)
Problem Type: Process (Isentropic, const. s)

<table>
<thead>
<tr>
<th>State 1</th>
<th>State 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_1 = 15.70 , ^\circ C$</td>
<td>$T_2 = 40.08 , ^\circ C$</td>
</tr>
<tr>
<td>$P_1 = 0.5 , MPa$</td>
<td>$P_2 = 0.9 , MPa$</td>
</tr>
<tr>
<td>$h_1 = 194.06 , kJ/kg$</td>
<td>$h_2 = 204.37 , kJ/kg$</td>
</tr>
<tr>
<td>$s_1 = 0.6899 , kJ/(kg \cdot K)$</td>
<td>$s_2 = 0.9240 , kJ/(kg \cdot K)$</td>
</tr>
<tr>
<td>phase: sat.vap.</td>
<td>phase: sup.vap.</td>
</tr>
</tbody>
</table>

*Italicized* values are from R-134a tables, *bold* values are calculated.

At state 1 we know the pressure and that we have saturated liquid, so that the state is fixed. Going to the saturation pressure table, Table A-12, we find

$T_1 = 15.70 \, ^\circ C, \; s_1 = 0.6899 \, kJ/(kg \cdot K), \; h_1 = 194.06 \, kJ/kg$

At state 2 we know the pressure and that we have an isentropic process or

$s_2 = s_1 = 0.6899 \, kJ/(kg \cdot K)$

To determine the fluid phase, we go to the saturation pressure table at 0.9 MPa and find

$s_f = 0.2640 \, kJ/(kg \cdot K)$ and $s_g = 0.6832 \, kJ/(kg \cdot K)$

Since $s_2 > s_g$, we have a superheated vapor at state 2. Going to the superheat tables, we find after interpolating

$T_2 = 40.08 \, ^\circ C, \; h_2 = 204.37 \, kJ/kg$

Our enthalpy change is then

$\Delta h = h_2 - h_1 = 204.37 - 194.06 = 10.31 \, kJ/kg$