Lect 3 Thermo I – Concepts & Pure Substance Properties

1. Able to describe what Energy is to a RU freshmen and describe three primary forms of energy, from a molec. level.
2. Able to describe what the temperature equality and zeroth law mean.
3. Able to describe various temperature scales Temperature Scale.
4. Able to explain the temperature and volume behavior of a pure substance under constant pressure.
5. Able to interpret the various phase regions on a phase diagram.
6. Able to explain and calculate quality.

Mind Map
Thermal Equilibrium - Simple

http://http://jersey.uoregon.edu/vlab/Thermodynamics/index.html

Thermal Equilibrium - Real

Sidebar – the meaning of temperature
http://hyperphysics.phy-astr.gsu.edu/Hbase/thermo/temper.html#c1
Motivation for Property Understanding → Design

Pure Substance P vs. T phase diagram

Pressure

Vapor-pressure curve

Temperature

03_02
Constant Pressure (Isobaric) Heat Transfer Process

Phase Diagram – Fig 3.3 & Back to Isobaric Process

Constant Pressure

Saturated-liquid line

Saturated-vapor line

Critical point

Liquid water

Water vapor

Water vapor

Liquid water
Lect 4
Pure Substance Properties

1. Able to explain the significance of "independent" properties for pure substances.
2. Able to use Appendix B to calculate pure substance properties.
3. Able to use EES calculate pure substance properties.

Mind Map
Motivation: Properties $\rightarrow$ Component Design

Temperature vs. Volume: Isobaric Process

Constant Pressure
Temperature vs. Volume: Isobaric Process

Quality….and I’m not talking about workmanship
Simple Process - Isochoric

- Initial pressure $p_1 = 1$ bar
- Initial composition $x_1 = 0.5$
- Final pressure $p_2 = 1.5$ bar
- Final composition $x_2 = 1.0$

Volume $V = 0.5$ m$^3$

$T$ vs $V$ graph showing:
- 1 bar
- 1.5 bar

Quality

- Total mass $M_{\text{mix}} = M_{\text{vap}} + M_{\text{liq}}$

Mass fraction $X = \frac{m_{\text{vap}}}{m_{\text{liq}} + m_{\text{vap}}} = \frac{m_{\text{vap}}}{m_{\text{mix}}}$
Water Phase Diagram

Pressure – Temperature Diagram: Water

5kPa

0.01°C
Carbon dioxide

Critical Points of Various Materials

**Some Critical-Point Data**

<table>
<thead>
<tr>
<th>Material</th>
<th>Critical Temperature, °C</th>
<th>Critical Pressure, MPa</th>
<th>Critical Volume, m³/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>374.14</td>
<td>22.09</td>
<td>0.003 155</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>31.05</td>
<td>7.39</td>
<td>0.002 143</td>
</tr>
<tr>
<td>Oxygen</td>
<td>-118.35</td>
<td>5.08</td>
<td>0.002 438</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>-239.85</td>
<td>1.30</td>
<td>0.032 192</td>
</tr>
</tbody>
</table>

03_01tbl
### Triple Points of Various Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Temperature, °C</th>
<th>Pressure, kPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen (normal)</td>
<td>-259</td>
<td>7.194</td>
</tr>
<tr>
<td>Oxygen</td>
<td>-219</td>
<td>0.15</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>-210</td>
<td>12.53</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>-56.4</td>
<td>520.8</td>
</tr>
<tr>
<td>Mercury</td>
<td>-39</td>
<td>0.000 000 13</td>
</tr>
<tr>
<td>Water</td>
<td>0.01</td>
<td>0.6113</td>
</tr>
<tr>
<td>Zinc</td>
<td>419</td>
<td>5.086</td>
</tr>
<tr>
<td>Silver</td>
<td>961</td>
<td>0.01</td>
</tr>
<tr>
<td>Copper</td>
<td>1083</td>
<td>0.000 079</td>
</tr>
</tbody>
</table>

---

### Property Finding Options

1. **Hand Calc or Computer Tools**
   - The Givens
   - Equations of State
   - Ideal Gas
   - Compressibility Equation
   - Unique Equations of State
   - EES

2. **Tables**
   - Steam
     - Hydrogen, Air, Water, N-10, P-12, N-104
   - Nitrogen

3. **Online**
Example 3.1 Water – Using Table B.1.1

Find phase and place on P-v, T-v, and P-T

<table>
<thead>
<tr>
<th>T [°C]</th>
<th>P [kPa]</th>
<th>(v_f) [m^3/kg]</th>
<th>(v_g)</th>
<th>(u_f) [kJ/kg]</th>
<th>(u_g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>198.5</td>
<td>1.06e-3</td>
<td>0.8908</td>
<td>503.48</td>
<td>2025.7</td>
</tr>
</tbody>
</table>

Corrected.
Example 3.2a Amonia – Appendix B

Find phase and place on P-v, T-v, and P-T

a. Ammonia, 30°C, 1000 kPa

<table>
<thead>
<tr>
<th>T [°C]</th>
<th>P [kPa]</th>
<th>v_f [m^3/kg]</th>
<th>v_fg</th>
<th>v_g</th>
<th>u_f [kJ/kg]</th>
<th>u_fg</th>
<th>u_g</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>1167</td>
<td>1.68e-3</td>
<td>0.1088</td>
<td>0.1104</td>
<td>320.46</td>
<td>1016.9</td>
<td>1337.4</td>
</tr>
</tbody>
</table>

Liner Interpolation Example 3.3 – Superheated Vapor Temperature

379.8°C
Propane Compressibility, Ex. 3.13

Sat. vapor

$T_r = 2.0$

$T_r = 0.78$

Sat. liquid

$T_r = 0.7$

$P_{r_{sat}} = 0.2$, $Z_f = 0.035$, $Z_g = 0.83$

Water & I.G. Errors

Ideal gas

Error < 1%

0.2%

0.1%

1%

17.6%

270%

100%

10 MPa

50%

1 MPa

7.5%

100 kPa

1.5%

10 kPa

1%

0.3%

1%

$T$ [°C]

Specific volume $v$ [m$^3$/kg]