Lab #1b
Determination of Steam Quality
Outline

• Goal of lab
• Phase diagram of water
• Saturated steam table
• Steam quality
• Determination of steam quality
• Thermos flask
• Boiler
  – Fire tube, water tube
• Steam trap
  – Mechanical, thermostatic, thermodynamic
Goal of the Lab

- Determination of steam quality ($x$) in our pilot plant using mass and energy balances
- Familiarization with types of boilers
Within the dome, water exists as steam, which is a mixture of liquid and vapor. Here, temperature and pressure are constant and are called the saturation temperature and pressure respectively.

As we move from left to right within the dome, more and more of the water is in vapor phase. The fraction that is in vapor phase is called steam quality (denoted by ‘x’). It varies from 0 to 1 OR 0% to 100%.

Latent heat of vap. ($\lambda_{vap}$) at any temp. or pr. = $H_v - H_c$ at that temp. or pr.
**Saturated Steam Table**

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Vapor pressure (kPa)</th>
<th>Specific volume (m³/kg)</th>
<th>Enthalpy (kJ/kg)</th>
<th>Entropy (kJ/[kg K])</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Liquid</td>
<td>Saturated vapor</td>
<td>Liquid</td>
</tr>
<tr>
<td>100</td>
<td>101.35</td>
<td>0.0010435</td>
<td>1.6729</td>
<td></td>
</tr>
<tr>
<td>105</td>
<td>120.82</td>
<td>0.0010475</td>
<td>1.4194</td>
<td>440.15</td>
</tr>
<tr>
<td>110</td>
<td>143.27</td>
<td>0.0010516</td>
<td>1.2102</td>
<td>461.30</td>
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<tr>
<td>115</td>
<td>169.06</td>
<td>0.0010559</td>
<td>1.0366</td>
<td>482.48</td>
</tr>
<tr>
<td>120</td>
<td>198.53</td>
<td>0.0010603</td>
<td>0.8919</td>
<td>503.71</td>
</tr>
<tr>
<td>125</td>
<td>232.1</td>
<td>0.0010649</td>
<td>0.7706</td>
<td>524.99</td>
</tr>
<tr>
<td>130</td>
<td>270.1</td>
<td>0.0010697</td>
<td>0.6685</td>
<td>546.31</td>
</tr>
<tr>
<td>135</td>
<td>313.0</td>
<td>0.0010746</td>
<td>0.5822</td>
<td>567.69</td>
</tr>
<tr>
<td>140</td>
<td>361.3</td>
<td>0.0010797</td>
<td>0.5089</td>
<td>589.13</td>
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<td>145</td>
<td>415.4</td>
<td>0.0010850</td>
<td>0.4463</td>
<td>610.63</td>
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<tr>
<td>150</td>
<td>475.8</td>
<td>0.0010905</td>
<td>0.3928</td>
<td>632.20</td>
</tr>
</tbody>
</table>

What is the latent heat of vaporization of water at atmospheric pressure?

\[ \lambda_{\text{vap}} (\text{at atm. Pr.}) = H_v (\text{at atm Pr.}) - H_c (\text{at atm. Pr.}) = 2676.1 - 419.04 = 2257.06 \text{ kJ/kg} \]
Steam Quality (x)

- The term “Steam” generally refers to saturated steam and not superheated steam
- “Steam” is a mixture of liquid (condensate) and vapor
- The enthalpy of steam ($H_s$) is a weighted mean of enthalpy of condensate ($H_c$) and enthalpy of vapor ($H_v$)
  - $H_s = x H_v + (1 - x) H_c$
  - Rearranging, $x = (H_s - H_c)/(H_v - H_c)$
  - Note that $x = 0$ when $H_s = H_c$
  - Also, $x = 1$ when $H_s = H_v$
  - Higher the steam quality, higher the value of $H_s$
  - $0 \leq x \leq 1$ \hspace{1cm} OR \hspace{1cm} $0\% \leq x \leq 100\%$

Note: $H_c$ & $H_v$ at saturation temperature & pressure are determined from steam tables
Determination of Steam Quality

$m_s$, quality of $x$; Pressure, $P$ OR Temperature, $T$

$m_c$, $c_{p(c)}$, $T_c$  \hspace{2cm} m_h$, $c_{p(h)}$, $T_h$

Cold water  \hspace{2cm} Hot water

Introduce cold water of known mass ($m_c$) and temperature ($T_c$) in a flask
Introduce steam into flask till water becomes hot ($T_h$)
Determine specific heat of water at $T_c$ and $T_h$ from table of properties of water

Mass balance: $m_c + m_s = m_h$

Energy balance: $m_c \{c_{p(c)}\} T_c + m_s (H_s) = m_h \{c_{p(h)}\} T_h$

Determine $H_s$ from above equation

Also, $H_s = (x) H_v + (1 – x) H_c$

with $H_v$ and $H_c$ being determined from steam tables at the absolute (not gauge) steam pressure of $P$ or steam temperature of $T$

Thus, $x = (H_s – H_c)/(H_v – H_c)$

$m$, $c_p$, $T$: Mass, specific heat, temperature resp.

Subscripts: ‘c’ for cold; ‘h’ for hot

Use interpolation for:
$c_{p(c)}$, $c_{p(h)}$, $H_c$, $H_v$
Thermos Flask

Conduction and convection heat loss: Decreased by vacuum, stopper, glass, cork, air
Radiation heat loss: Decreased by reflective (silvered) glass
Generation of Steam

- Water is converted to steam (in a boiler) using a basic source of energy
  - Fuel oil, natural gas, wood, coal, heating element
  - One of the above is used to generate hot gases which heat the metallic surface (usually steel) in contact with water to generate steam
Fire Tube Boiler

- Hot gases are inside tubes surrounded by water
- The heat vaporizes water and converts it to steam
- As needed, steam is released from the boiler
- Fire tubes boilers are well suited for applications where there are large fluctuations in demand for steam
Fire Tube Boiler
Water Tube Boiler

- Hot gases are outside tubes through which water flows
- The heat vaporizes water and converts it to steam
- As needed, steam is released from the boiler
- Rate of heat transfer is higher in a water tube boiler
  - This is due to turbulence of water in the tubes
- Water tube boilers operate at larger capacities and higher pressures
- They are more flexible and safer
  - Safety relates to phase change taking place in small tubes and not in a large vessel
Water Tube Boiler
Steam Trap

- **What is a steam trap?**
  - A device that separates the liquid and vapor phases of steam

- **Functions of a steam trap**
  - Prevent steam from escaping through it
  - Allow condensate to pass through it
  - Discharge air and any other gas through it
Types of Steam Traps

• Mechanical
  – Based on density difference between vapor and condensate (inverted bucket)

• Thermostatic
  – Based on temperature difference between vapor and condensate

• Thermodynamic
  – Based on pressure difference as vapor condenses