Title: Measurement of dryness fraction by Separating Calorimeter, Throttling Calorimeter, Separating and Throttling Calorimeter.

Learning objectives:
1. Intellectual skills:
   a) Measurement of Dryness fraction of steam.

   b) Understanding various methods of measurement of Dryness fraction.

2. Motor skills:
   a) Arrangement of various components for set up of Throttling, Separating, Separating and Throttling calorimeter.

   b) To measure the quality of steam.

1. Separating calorimeter:
The quality of wet steam is usually defined by its dryness fraction. When the dryness fraction, pressure and temperature of the steam are known, then the state of wet steam is fully defined. In a steam plant it is at times necessary to know the state of the steam. For wet steam, this entails finding the dryness fraction. When the steam is very wet, we make use of a separating calorimeter.

Construction of separating calorimeter is as shown in figure:
The steam is collected out of the main steam supply and enters the separator from the top. The steam is forced to make a sharp turn when it hits the perforated cup (or any other mechanism that produces the same effect). This results in a vortex motion in the steam, and water separates out by the centrifugal action. The droplets then remain inside the separator and are collected at the bottom, where the level can be recorded from the water glass. The dry steam will pass out of the calorimeter into a small condenser for the collection of the condensate. However, not all the water droplets remain in the collector tank. Some water droplets pass through to the condenser, and hence this calorimeter only gives a close approximation of the dryness fraction of the steam.

From the results obtained from the two collectors, the dryness fraction may then be found from:

\[
\text{Dryness fraction} = \frac{\text{mass of dry steam}}{\text{mass of wet steam containing dry steam}}
\]
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This can be expressed as:

\[ x = \frac{M}{m + M} \]

Where, \( M \): is the mass of dry steam and \( m \): is the mass of suspended water separated in the calorimeter in the same time.

**Procedure:**

1. Observe the setup
2. Identify all the connected equipments
3. Check the range of pressure gauge
4. Open the steam supply valve for a few seconds
5. Measure the condensate formed due to condensation of the moisture in the steam.
6. Measure the condensate formed due to condensation of the dry steam

**Observation Table:**

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Parameters</th>
<th>Reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Boiler steam pressure, ( p_1 ) (bar)</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>Mass of condensate collected, ( m ) (kg)</td>
<td>0.7</td>
</tr>
<tr>
<td>3</td>
<td>Mass of dry steam, ( M ) (kg)</td>
<td>0.175</td>
</tr>
</tbody>
</table>

**Calculation:**

\[
\text{Dryness fraction} \ (x) = \frac{\text{mass of dry steam}}{\text{mass of wet steam containing dry steam}}
\]
Result:

The dryness fraction of the sample taken from the main stream is ___________.

**Throttling calorimeter:**

If we have steam that is nearly dry, we make use of a throttling calorimeter as shown in figure. This calorimeter is operated by first opening the stop valve fully so that the steam is not partially throttled as it passes through the apparatus for a while to allow the pressure and temperature to stabilize. If the pressure is very close to atmospheric pressure, the saturation should be around 100°C, it may be assumed that the steam is superheated.

When the conditions have become steady, the gauge pressure before throttling is read from the pressure gauge. After throttling, the temperature and gauge pressure are read from the thermometer and manometer respectively. The barometric pressure is also recorded.

**From equation** $h_1 = h_2$,

We have $h_{w} \text{ at } p_1 = h_{sup} \text{ at } p_2$

$$h_{f_1} + x \times h_{fg_1} = h_{g_2} + C_p (T_{sup} - T_{sat})$$

And thus $$x = \frac{h_{g_2} + C_p (T_{sup} - T_{sat}) - h_{f_1}}{h_{fg_1}}$$
**Procedure:**

1. Observe the setup
2. Identify all the connected equipment’s.
3. Check the range of pressure gauge.
4. Check the range of thermometer.
5. Check the range of manometer.
6. Open the steam supply valve for a short time.
7. Measure the steam chest pressure ($P_1$).
8. Measure the steam outlet pressure ($P_2$).
9. Measure the outlet steam temperature ($T_2$).
Observation Table:

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</thead>
<tbody>
<tr>
<td>1</td>
<td>Boiler steam pressure, $P_1$ (bar)</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>Steam outlet pressure, $P_2$ (bar)</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Steam outlet temperature $T_2$ (°C)</td>
<td>115</td>
</tr>
</tbody>
</table>

Required readings from steam table:

Steam properties at steam chest pressure:

a. Enthalpy of feed water ($h_{f1}$): ________________

b. Enthalpy of wet steam ($h_{fg1}$): ________________

Properties of outlet steam:

a. Saturation temperature at ($P_2$): ________________

b. Degree of superheat: Outlet steam temperature – Saturation temperature

$T_{sup} - T_{sat} = ________________$

c. Enthalpy of superheated steam ($h_{g2}$): ________________

Result:

The dryness fraction of the sample taken from the main stream ______.
**Separating and throttling calorimeter:**

If the steam whose dryness fraction is to be determined is very wet then throttling to atmospheric pressure may not be sufficient to ensure superheated steam at exit. In this case it is necessary to dry the steam partially, before throttling. This is done by passing the steam sample from the main through a separating calorimeter as shown in figure. The steam is made to change direction suddenly, and the water, being denser than the dry steam is separated out. The quantity of water which is separated out ($m_w$) is measured at the separator, the steam remaining which now has a higher dryness fraction, is passed through the throttling calorimeter. With the combined separating and throttling calorimeter it is necessary to condense the steam after throttling and measure the amount of condensate ($m_s$). If a throttling calorimeter only is sufficient, there is no need to measure condensate, the pressure and temperature measurements at exit being sufficient.

![Fig. 3 Separating and throttling calorimeter.](image-url)
Let,

State 1 = Properties of steam Coming to Separating Calorimeter
State 2 = Properties of steam leaving Separating Calorimeter
State 3 = Properties of steam leaving Throttling Calorimeter

\( x_1 \) = Dryness fraction of the steam at Separating Calorimeter

\( x_2 \) = Dryness fraction of the steam at Throttling Calorimeter

Dryness fraction at 2 is \( x_2 \), therefore, the mass of dry steam leaving the separating calorimeter is equal to \( x_2 \times m_s \) and this must be the mass of dry vapour in the sample drawn from the main at state 1.

Hence fraction in main, \( x_1 = \frac{\text{mass of dry vapour}}{\text{total mass}} = \frac{m_s}{m_w + m_s} \)

The dryness fraction \( x_2 \) can be determined as follows:

\[
\begin{align*}
    h_3 &= h_2 = h_{f2} + x_2 \times h_{fg2} \quad \text{...............at } p_2 \\
    h_3 &= h_{f3} + h_{fg3} + C_p s(T_{sup3} - T_{sat3}) \quad \text{.........................at pressure } p_3
\end{align*}
\]

From \( \text{Enthalpy at 2} = \text{Enthalpy at 3} \)

\( x_2 = \frac{h_3 - h_{f2}}{h_{fg2}} \)

The values of \( h_{f2} \) and \( h_{fg2} \) are read from steam tables at pressure \( P_2 \). The pressure in the separator is small so that \( P_1 \) is approximately equal to \( P_2 \)

**Procedure:**

1. Observe the setup
2. Identify all the connected equipment’s
3. Check the range of pressure gauge
4. Check the range of thermometer
5. Check the range of manometer

6. Open the steam supply valve for a short time

7. Measure the steam chest pressure \(P_1\)

8. Measure the steam outlet pressure \(P_2\)

9. Measure the outlet steam temperature.

**Observation Table:**

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<tbody>
<tr>
<td>1</td>
<td>Boiler steam pressure, (P_1) (bar)</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>Boiler steam temperature, (T_1) (°C)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Water condensate formed in separating calorimeter, (m_w) (kg)</td>
<td>1.8</td>
</tr>
<tr>
<td>4</td>
<td>Steam outlet pressure at throttling calorimeter, (P_2) (bar)</td>
<td>1.013</td>
</tr>
<tr>
<td>5</td>
<td>Outlet steam temperature from throttling calorimeter, (T_3) (°C)</td>
<td>110</td>
</tr>
<tr>
<td>6</td>
<td>Outlet steam pressure from throttling calorimeter, (P_3) (bar)</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>Condensate collected at the throttling calorimeter, (m_s) (kg)</td>
<td>34.2</td>
</tr>
</tbody>
</table>

**Readings required from steam table:**

a. Enthalpy of feed water at state 2, \(h_{f2}\) : __________________

b. Enthalpy of wet steam at state 2, \(h_{fg2}\) : ___________________

c. Temperature of the output steam \((T_3)\) : ___________________

d. Saturation temperature at \(P_3\) : ___________________

e. Degree of superheat: Outlet steam temperature – Saturation temperature
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\[ (T_{sup3} - T_{sat3}) = \text{______________} \]

f. Enthalpy of feed water at \( P_3 \): ________________

g. Enthalpy of wet steam at \( P_3 \): ________________

h. Enthalpy of Superheated steam at \( P_3 \): ________________

Calculations:

1. \( x_1 = \frac{\text{mass of dry vapour}}{\text{total mass}} \)

\[ x_1 = \frac{ms}{mw+ms} \]

\[ x_1 = \text{______________} \]

2. \( h_3 = h_{f3} + h_{fg3} + C_{ps} (T_{sup3} - T_{sat3}) \)

\[ h_3 = \text{______________} \]

3. \( h_3 = h_2 = h_{f2} + x_2 \times h_{fg2} \)

\[ x_2 = \frac{h_3-h_{f2}}{h_{fg2}} \]

\[ x_2 = \text{______________} \]

4. \( h_2 = h_{f2} + x_2 \times h_{fg2} \)

\[ h_2 = \text{______________} \]

Actual dryness fraction of the steam entering the combined separating and throttling calorimeter, \( x = x_1 \times x_2 \)

Result:

The dryness fraction of the sample taken from the main stream is ________.