Vapour pressure of water at high temperature
(Item No.: P2340100)

Curricular Relevance

<table>
<thead>
<tr>
<th>Area of Expertise:</th>
<th>Education Level:</th>
<th>Topic:</th>
<th>Subtopic:</th>
<th>Experiment:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physics</td>
<td>University</td>
<td>Thermodynamics</td>
<td>Thermal Properties and Processes</td>
<td>Vapour pressure of water at high temperature</td>
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Difficulty | Preparation Time | Execution Time | Recommended Group Size
---|------------------|----------------|------------------|
Difficult | 10 Minutes | 30 Minutes | 2 Students |

Additional Requirements:
- Distilled water

Experiment Variations:

Keywords:
boiling point, heat of vaporisation, Clausius-Clapeyron equation, Van't Hoff law, Carnot cycle

Overview

Short description

Principle
Water is heated in a closed pressure chamber; as much water vaporises as to make the pressure in the chamber correspond to the vapour pressure at the temperature at any time. The heat of vaporisation is determined at various temperatures from the measurement of vapour pressure as a function of temperature.

Area of Expertise: Physics
Education Level: University
Topic: Thermodynamics
Subtopic: Thermal Properties and Processes
Experiment: Vapour pressure of water at high temperature
Equipment

<table>
<thead>
<tr>
<th>Position No.</th>
<th>Material</th>
<th>Order No.</th>
<th>Quantity</th>
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<tbody>
<tr>
<td>1</td>
<td>High pressure vapour unit</td>
<td>02622-10</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Heating apparatus for glass jacket system</td>
<td>32246-93</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Tripod base PHYWE</td>
<td>02002-55</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Heat conductive paste, 50 g</td>
<td>03747-00</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Boss head</td>
<td>02043-00</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Lab thermometer, -10..+250°C</td>
<td>38065-00</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>Pipette with rubber bulb, long</td>
<td>64821-00</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Support rod, stainless steel, l = 250 mm, d = 10 mm</td>
<td>02031-00</td>
<td>1</td>
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</table>

Tasks

1. To measure the vapour pressure of water as a function of temperature.
2. To calculate the heat of vaporisation at various temperatures from the values measured.
3. To determine boiling point at normal pressure by extrapolation.

Set-up and procedure

Set up the experiment as shown in Fig. 1. Fill the high pressure steam unit with distilled water, with the aid of a pipette, ensuring that there are no air bubbles in the line leading to the pressure gauge.

Now screw the vessel together carefully (the lead seals may need replacing).

The unit is fastend with a bosshead and lays on the electric heater. Put the thermometer in the hole provided, which should be filled with heat conductive paste.

Heat the pressure vessel until the gauge reads 4 MPa 40 bar. Now switch off the heater and record the pressure and temperature as the equipment cools down.

Check the locking screws from time to time while the equipment is being heated and cooling down and tighten them if necessary.

Theory and evaluation
The thermal energy which must be taken up by one mole of liquid, to vaporise at constant temperature is called the molar heat of vaporisation $\Delta$. 

At a given temperature $T$ resp. $\vartheta$ in degrees Celsius there is a vapour pressure $p$ at which liquid and gaseous phase are in equilibrium (Fig. 2). When a liquid boils the vapour pressure is equal to the external (atmospheric) pressure.

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**Fig. 2: Vapour pressure curve: water**

The Clausius-Clapeyron differential equation

$$\frac{dp}{dT} = \frac{\Delta}{T(V_{\text{vap}} - V_{\text{liq}})}$$

(1)

where $V_{\text{vap}}$ and $V_{\text{liq}}$ are the molar volumes of vapour and liquid respectively and $\Delta$ is the heat of phase transition, applies here to the binodal curve bounding two phases.

The phase equilibrium when $T$ and $p$ are constant is governed by the function

$$G = U + pV - TS$$

(2)

where $G =$ free enthalphy, $U =$ internal energy, $S =$ entropy.

Along the binodal curve

$$G_1(T,p) = G_2(T,p)$$

(3)

or in differential form

$$\left(\frac{\partial G_1}{\partial p} - \frac{\partial G_2}{\partial p}\right)dp + \left(\frac{\partial G_1}{\partial T} - \frac{\partial G_2}{\partial T}\right)dT = 0$$

(4)

$p_t = 6.1$ hPa$\vartheta_t = 0.01$ °C,

$p_c = 22.12$ MPa$\vartheta_c = 374.2$ °C.

With

$$\frac{\partial G_1}{\partial p} = -S \text{ and } \frac{\partial G_2}{\partial p} = V$$

(5)

It follows from (3) that

$$(V_2 - V_1)dp = (S_2 - S_1)dT$$

(6)

The difference in entropy between the two phases can be expressed by the reversible latent heat of transformation

$$S_2 - S_1 = \frac{\Delta}{p}$$

(7)

(6) and (7) together give (1) for the binodal curve between the liquid and the vapour phase.
At low vapour pressures $p \ll p_c$, $V_{\text{liq}} \ll V_{\text{vap}}$. can be disregarded. In this range the vapour behaves very like an ideal gas and

$$V_{\text{vap}} = \frac{RT}{p}$$

(8)

where $R = 8.3141 \text{ J/(K\cdot mol)}$, the universal gas constant.

From (1), therefore:

$$\frac{dp}{p} = \frac{\sigma}{R} \cdot \frac{dT}{T^2}$$

(9)

Assuming $\Delta$ to be constant, by integrating we obtain the Van't Hoff equation

$$\ln p = -\frac{\Delta}{R} \cdot \frac{1}{T} + \text{const.}$$

(10)

The semi-logarithmic plot of the measured values (Fig. 3) shows an almost linear relationship between $\ln p$ and $1/T$. The heat of vaporisation changes with the temperature.

By fitting to a regression line in the ranges 190 °C–250 °C and 150 °C–190 °C, for example, we obtain the heat of vaporisation at 220 °C and 170 °C:

<table>
<thead>
<tr>
<th>°C</th>
<th>Molar $\lambda/10^3$ J mol$^{-1}$</th>
<th>Specific $\lambda$/J g$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>220</td>
<td>36.2</td>
<td>2012</td>
</tr>
<tr>
<td>170</td>
<td>38.3</td>
<td>2126</td>
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</tbody>
</table>

By extrapolating the straight line in the low temperature range we can read off the boiling point of water at normal pressure, $T_b$. The measurements we have taken give:

$\theta_b = 97 \, ^\circ\text{C}$

The boiling point determined by extrapolation is too low because the curve for $\ln p = f(T)$ (Fig. 3) is slightly convex owing to differences in the heat of vaporisation.