23rd IYPT Problem 7: Two Flasks

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Abstract
Two similar flasks (one is empty, one contains water) are each connected by flexible pipes to a lower water reservoir. The flasks are heated to 100°C and this temperature is held for some time. Heating is stopped and as the flasks cool down, water is drawn up into the tube. Investigate and describe in which tube the water goes up faster and in which the final height is greater. How does this effect depend on the time of heating?

For the dry flask, the air in the flask expands when it is heated. When the flask cools down, pressure difference between flask and atmosphere causes water to be sucked up into the tube. For the flask containing water, in addition to the expansion of air, water becomes vapor, replacing most of the air inside the flask. When the flask cools down, the vapor condenses, resulting in a greater pressure difference. Thus, the water in the tube rises faster and higher for the flask containing water. Also, this effect is almost independent of the time of heating after reaching 100°C.

Experimental Setup

(a) 1300 ml flask
(b) Hot plate
(c) Oil bath (for heating dry flask)
(d) Thermocouple
(e) Pressure sensor
(f) Long ruler and transparent tube
(g) Water reservoir

Theory

Newton’s Law of cooling
\[
\frac{dT}{dt} = -\alpha (T - H) \quad T(t) = T_R + (T_H - T_R) e^{-\alpha t}
\]

Dry flask: Ideal gas assumption (~19 kPa)
\[
PV = nRT
\Rightarrow (V_0 - hA)(P_0 - h\rho g) = n_1RT
\]
\[
T(t) = T_R + (T_H - T_R) e^{-\alpha t}
\]
\[
h(t) = h_0 - B\sqrt{C + De^{-\alpha t}}
\]

Wet flask: Antoine’s equation (~101 kPa)
\[
P = k \exp \left( \frac{20.386 - 5132}{T} \right)
\]
\[
k \approx 133.3 \text{ Pa}, \quad (T \text{ in K}, P \text{ in Pa})
\]
\[
\exp \left( \frac{20.386 - 5132}{T_R + (T_H - T_R) e^{-\alpha t}} \right) = P_o - h\rho g
\]
\[
h(t) = h_0 - B \exp \left( C - \frac{D}{E + F \exp(-t/G)} \right)
\]

Results

Dry flask

Wet flask

<table>
<thead>
<tr>
<th>Time span of boiling at 100°C/ maximum height</th>
<th>1 min</th>
<th>2 min</th>
<th>5 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Flask (Theoretical Dry Flask)</td>
<td>1.72m</td>
<td>2.25m</td>
<td>2.25m</td>
</tr>
<tr>
<td>Wet Flask (Ideal gas law)</td>
<td>8.65m</td>
<td>8.66m</td>
<td>8.42m</td>
</tr>
<tr>
<td>Wet Flask (Antoine equation)</td>
<td>9.12m</td>
<td>9.12m</td>
<td>9.12m</td>
</tr>
</tbody>
</table>

Conclusion

- The drawing up of water by the flasks are due to two different mechanisms. The dry flask draws up water mostly due to the expansion and contraction of air, while the flask with water draws water up by creating a large pressure difference by vapor condensation. Therefore the water rises up faster and higher in the flask containing water.
- The maximum water height is almost independent of the time of heating after the flask reaches 100°C.