Physics 524, Unit 5: Cooling and Thermal Management

Lab Experiment

The latent heat of evaporation of water

Theory, Definition

Introduction

The latent heat of evaporation ***L (J.kg^{-1})*** relates the amount of heat ***Q*** (Joules) that must be supplied to a substance to transform a mass ***m*** (kg) of it from liquid to vapor.

Ideally (in a lossless environment), to evaporate a sample of mass ***m***, we must supply ***Q* = *m·L*** in heat energy (Joules).

In this experiment, we examine the latent heat of evaporation of water. The heat ***Q*** is supplied by a gooseneck kettle whose power output ***P*** (Watts) can be selected and timed. The loss of water by evaporation is calculated from the change in mass of water measured on a sensitive electronic balance placed under the kettle. The amount of water in the evaporator (of which a fraction ***m*** will be evaporated in the short duration of the experiment) is chosen to allow it to be raised from ambient laboratory temperature to 100 ˚C in a short time to allow the experiment to be concluded in a timely manner.

The lost mass of water ***m*** due to evaporation is measured, allowing us to calculate ***L***.

Fig. 1: Schematic of the evaporator

Evaporator: a Gooseneck kettle with a capacity of around 1 litre and maximum power (110V) around 1kW

Electronic balance - for measuring the mass of water lost by evaporation;

Barometric pressure gauge – since ***L*** *evap* depends on pressure;

Water temperature probe – to know when the pressure-dependent boiling temperature has been reached.

Electrical power source – A Variable transformer (Variac)

Fig. 2: Illustration of the Variable voltage AC transformer (Variac): the output voltage and current are chosen, (depending on the max power rating and resistance of the heating element in the kettle used) for 200 and 400 Watts (need to specify V, I in each case)

Formalism

The energy, ***Q***, (J) supplied to evaporate the water is defined by ***P.t*** where ***P*** is the power (W) applied to the heater for ***t*** seconds. Ideally, this heat would all be absorbed by the water to change phase, as per the basic equation ***Q = m·L*** where ***m*** is the mass of water evaporated (kg) and ***L*** the latent heat of vaporization ($J.kg^{-1}$). However, there will be non-negligible heat loss, Q_{lost}. We therefore rewrite the basic equation as:

$$Q = m \cdot L + Q_{lost} \qquad \textbf{Eq. (1)}$$

where Q_{lost} is an unknown amount of heat lost from the original heat input ***Q***.

However, since we can control the power ***P*** (Watts) of the water heater, we can also control the total amount ***Q*** of supplied heat input, since ***Q = P·t***. By repeating the experiment twice for different power settings (P_1, P_2), but for the same length of time ***t***, to evaporate different masses of water (m_1, m_2) and assuming the heat lost will be roughly the same in both instances of the experiment, we can eliminate Q_{lost} from our computations:

First run: $P_1 \cdot t = m_1 \cdot L + Q_{lost}$

Second run: $P_2 \cdot t = m_2 \cdot L + Q_{lost}$

Subtracting the two equations we can recast ***L*** as:

$$L = t\,\frac{P_1 - P_2}{m_1 - m_2} \qquad \textbf{Eq. (2)}$$

Even this correction is an approximation since Q_{lost} will be larger in the higher power run than the lower power run, but it will certainly help. It can be seen that Eq. (2) is generic: it assumes that different masses of water (m_1, m_2) are evaporated and measured in the two runs.

Measurement Procedure

(1) Fill the kettle with water to about ¾ full.

(2) Atmospheric pressure should be noted (as Latent heat of evaporation varies slightly with atmospheric pressure – see fig. (3));

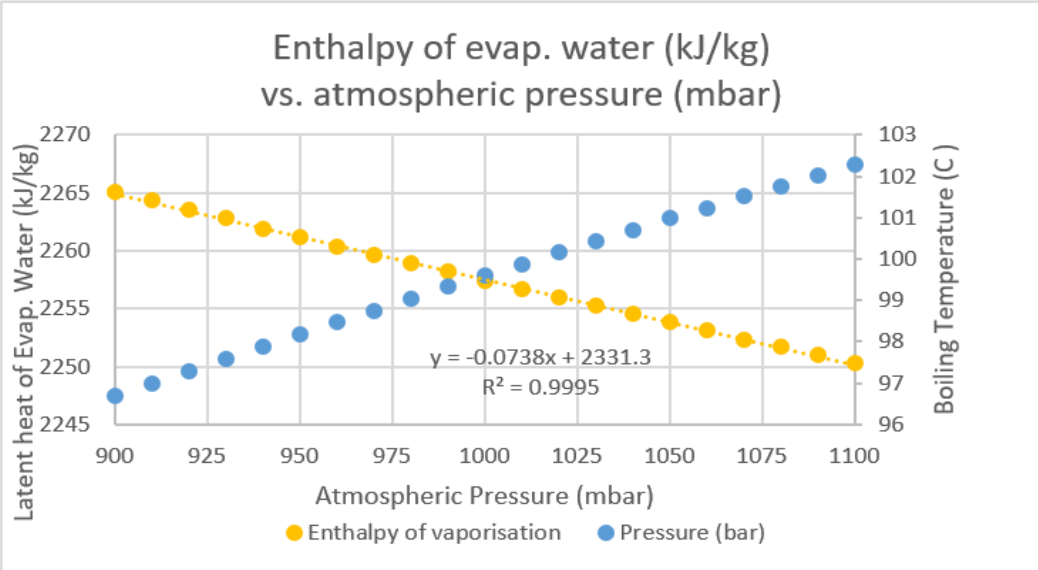

Fig. 3. Variation of the Latent Heat of evaporation and the boiling temperature of water with atmospheric pressure: *L (kJ/kg) = -0.0738*P(mbar) + 2331.2.*

(3) Heat the water with the kettle at its full power (~1000W). When the water reaches its boiling point, the kettle will power off automatically. **Remove the kettle plug from the electric socket.**

(4) Attach a duct tape to the kettle switch to prevent it from jumping up. **Make sure the kettle plug is removed from the electric socket when doing this. Try not to touch the kettle wall as it might be hot.**

(5) Place the kettle on a scale; connect the kettle plug to an extension cord and connect the cord to the Variac.

(6) Turn on the Variac and set the voltage to about 80V.

(7) The water inside the kettle should be slightly below the boiling point. Wait for the water to boil again. In the meantime, use an AC clamp meter to measure the voltage V_1 and current I_1 (connect the jaw of the clamp meter around the black wire of the extension cord) and calculate the power $P_1 = I_1V_1$.

(8) Because of the duct tape, the kettle won't turn off when the water boils. Once the water boils at a steady rate, use a timer (in your cellphone) to record the mass of the kettle + water as a function of time in intervals of 30 seconds for 5 minutes (300s). The mass of water evaporated in 5 minutes m_1 is the difference between the recorded initial and final masses.

(9) Reduce the Variac voltage to about 60V. Use an AC clamp meter to measure the voltage V_2, current I_2 and calculate the power $P_2 = I_2V_2$.

(10) Once the water boils at a reduced steady rate, start the timer to record the weight of the kettle + water as a function of time in intervals of 30 seconds for 5 minutes (300s), and calculate the mass of water evaporated in 5 minutes m_2.

(11) Turn off the Variac.

(12) Calculate the latent heat of evaporation of water L using equation (2).

Error Analysis

For **Eq. (2)**, the % error in the measurement of ***L***, ***δL/L***, can be established as:

$$\frac{\delta L}{L} = 100\% \cdot \sqrt{\left(\frac{\delta t}{t}\right)^2 + \left(\frac{\delta P_1 + \delta P_2}{P_1 - P_2}\right)^2 + \left(\frac{\delta m_1 + \delta m_2}{m_1 - m_2}\right)^2} \qquad \textbf{Eq. (3)}$$

All errors are dependent on the instruments used. Probable uncertainties are as follows:

- $M_{initial}$, M_{final} – measured using an electronic balance: δm_1, δm_2: ±0.5g;
- ***t*** – measured either using a stopwatch or an Arduino to sense the OFF-ON-OFF transitions of the voltage from the power supply (monitor of the voltage output): ***δt*** : ±1 sec;
- ***P*** – using the Voltage from the power source and current: δP_1, δP_2: to ± 3% probably;

Latent Heat of Evaporation Data Sheet

First Run

Voltage: V_1 = _____, Current: I_1 = ______, Power: P_1 = ________.

Time (s)	Mass (g)	Time (s)	Mass (g)
0		180	
30		210	
60		240	
90		270	
120		300	
150			

Mass of water evaporated: m_1 = ____________.

Second Run

Voltage: V_2 = _____, Current: I_2 = ______, Power: P_2 = __________.

Time (s)	Mass (g)	Time (s)	Mass (g)
0		180	
30		210	
60		240	
90		270	
120		300	
150			

Mass of water evaporated: m_2 = ____________.

$$L = t\frac{P_1 - P_2}{m_1 - m_2} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.$$

$$\frac{\delta L}{L} = 100\% \cdot \sqrt{\left(\frac{\delta t}{t}\right)^2 + \left(\frac{\delta P_1 + \delta P_2}{P_1 - P_2}\right)^2 + \left(\frac{\delta m_1 + \delta m_2}{m_1 - m_2}\right)^2}$$

= __________________.

So L = (____________) ± (_________) kJ/kg.

Atmosphere pressure = _______________,

Expected L (kJ/kg) = -0.0738*$P_{atm}(mbar)$ + 2331.2 = _______________,

Difference between measured and expected L = _____________.