23rd IYPT Problem 7: Two Flasks

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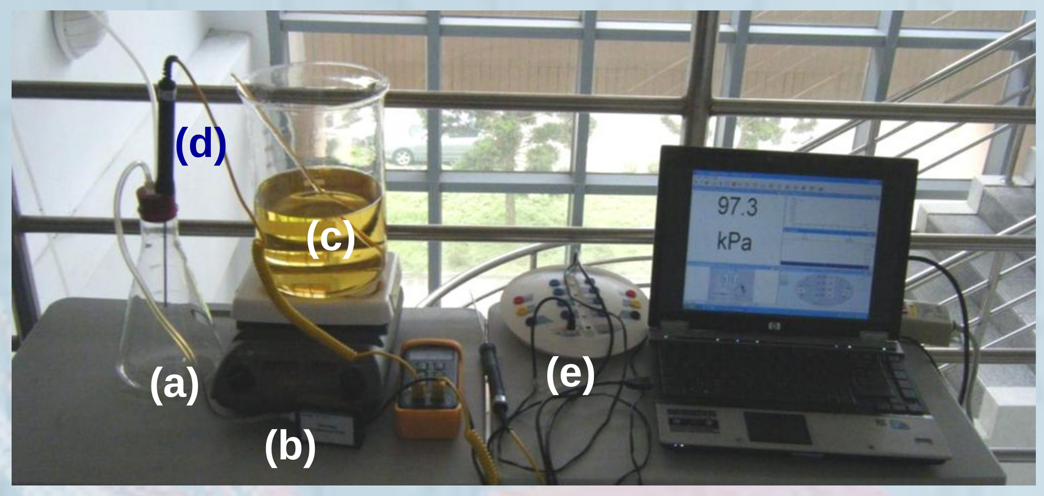
Abstract

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 the tubes. 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)1300ml 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

$$\frac{dT}{dt} = -\alpha(T-H) \longrightarrow T(t) = T_R + (T_H - T_R)e^{-\alpha t}$$

■Dry flask: Ideal gas assumption (~19 kPa)

$$PV = nRT$$

$$\Rightarrow (V_0 - hA)(P_0 - h\rho g) = n_1 RT$$

$$T(t) = T_R + (T_H - T_R)e^{-\alpha t}$$

$$h(t) = h_0 - B\sqrt{C + De^{-\alpha t}}$$

- V0: initial volume
- P0:initial pressure
- N1: initial mole of gas
- A cross section of tube
- R: Ideal gas constant
- T: temperature at a given time

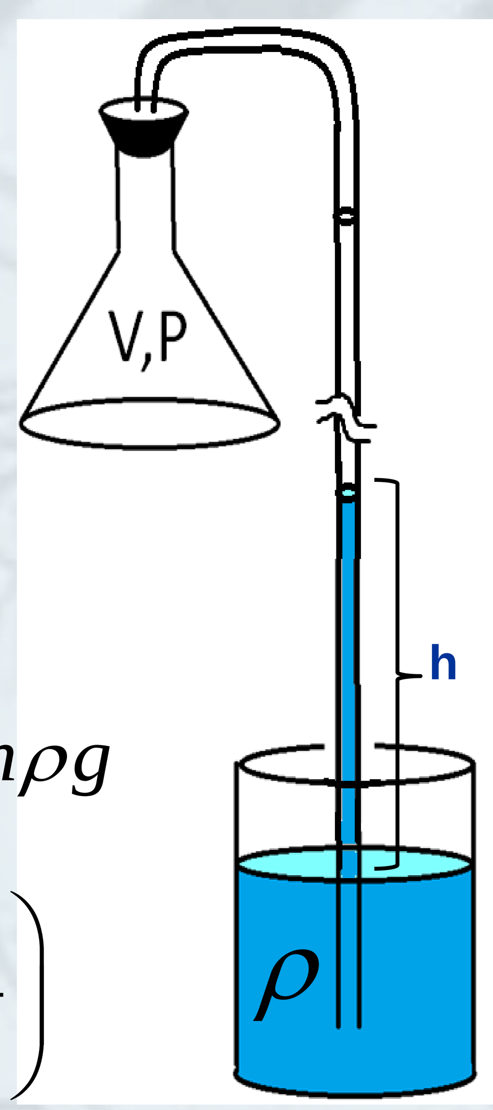
■Wet flask: Antoine's equation (~101 kPa)

$$P = k\exp\left(20.386 - \frac{5132}{T}\right)$$

$$k \approx 133.3\,Pa, \quad (T \text{ in } K, P \text{ in } Pa)$$

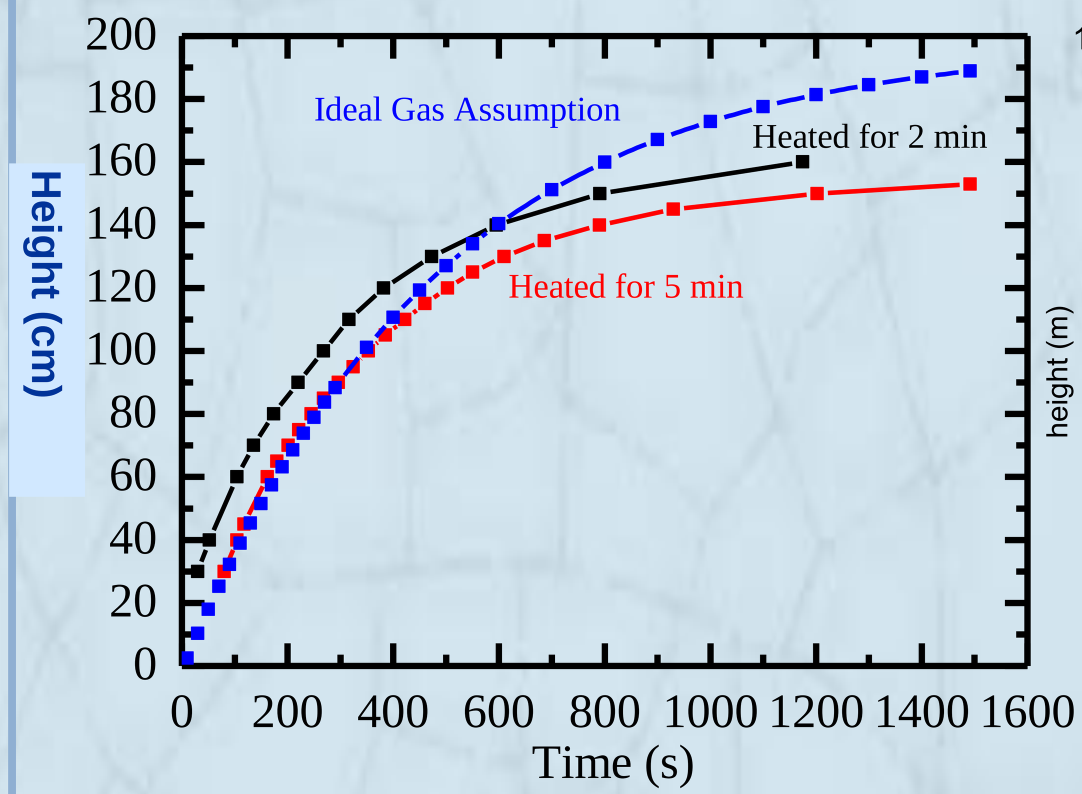
$$\exp\left(20.386 - \frac{5132}{T_R + (T_H - T_R)e^{-\alpha t}}\right) = P_o - h\rho g$$

$$h(t) = h_0 - B\exp\left(C - \frac{D}{E + F\exp(-t/G)}\right)$$

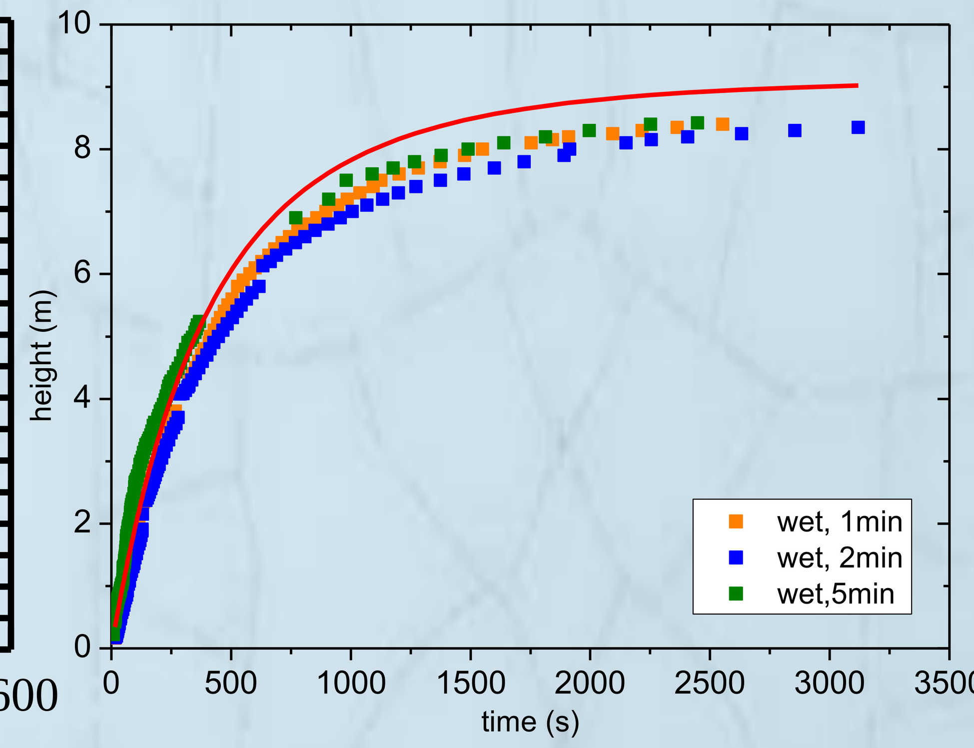


Results

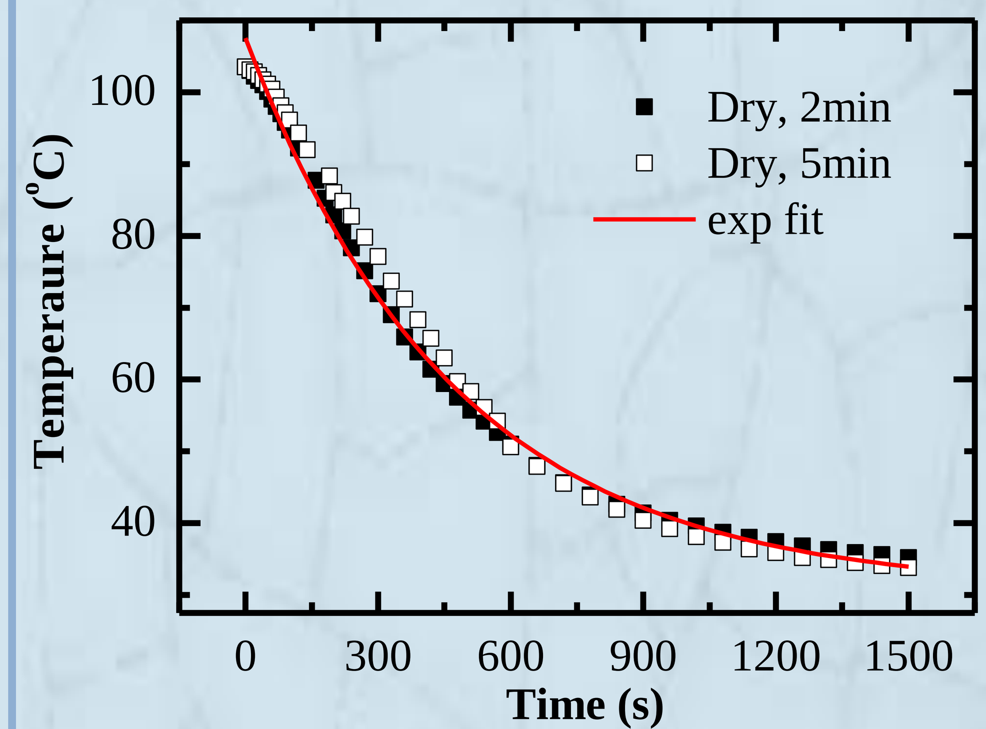
■Dry flask

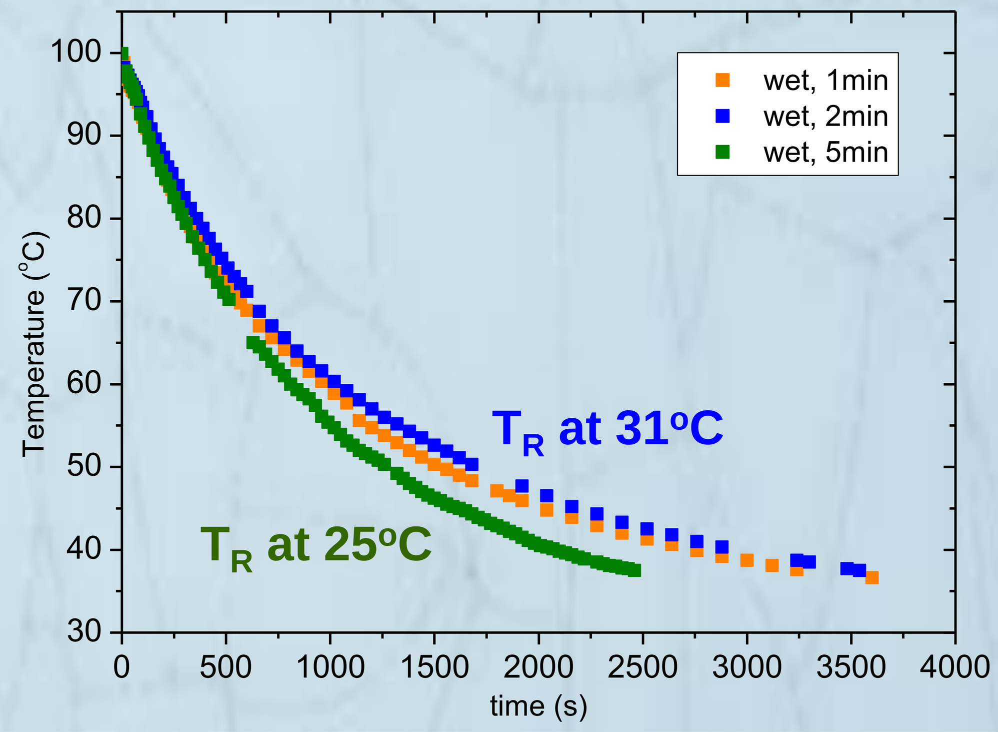


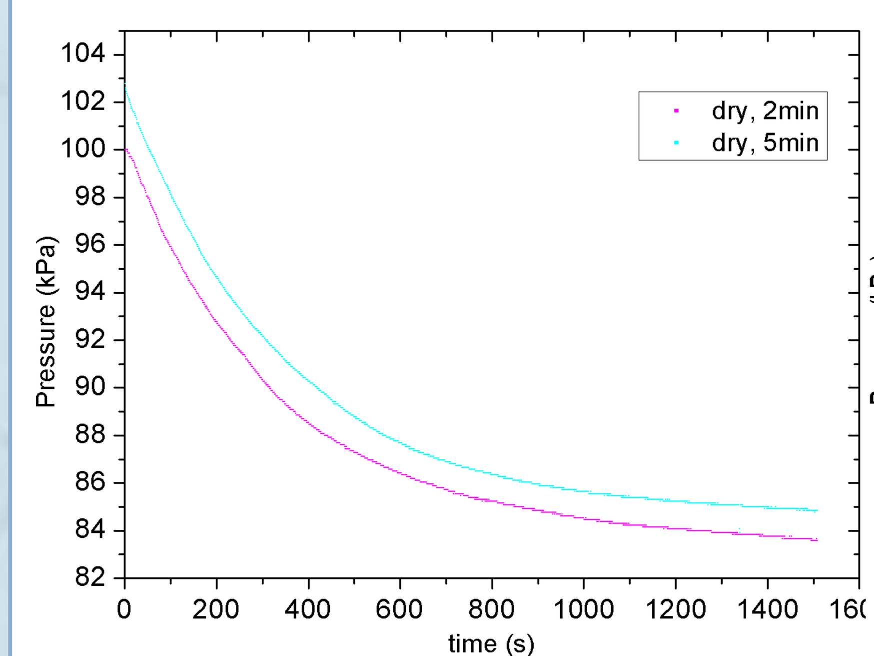
■Wet flask

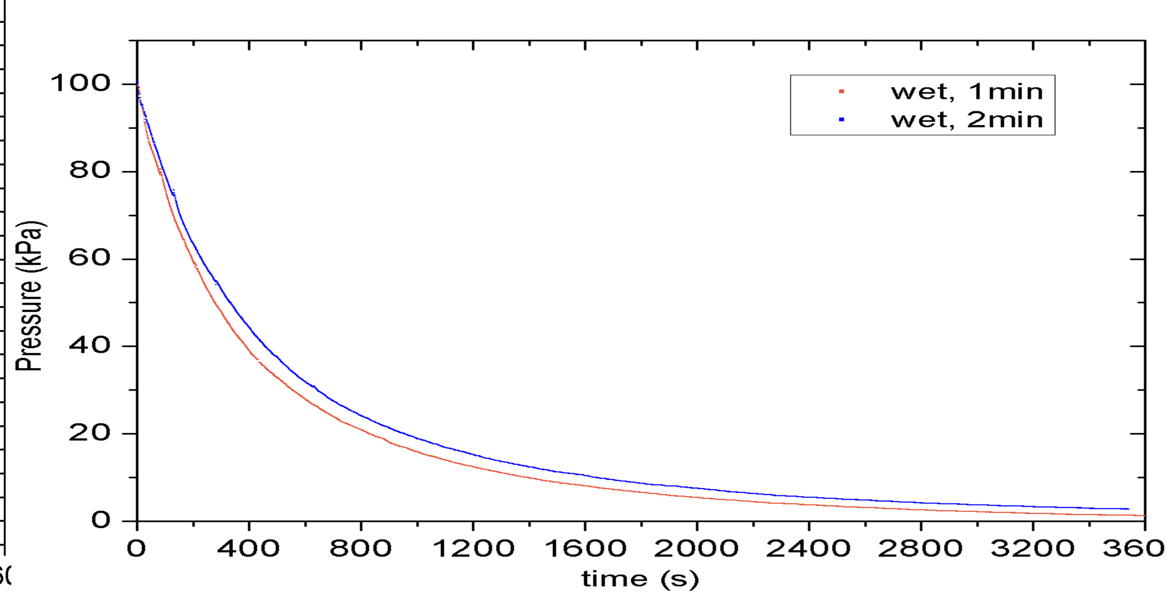


Dry Flask after heated at 100 °C for 2 minutes









Time span of boiling at100°C/ maximum height	1min	2min	5min
Dry Flask		1.72m	1.69m
Theoretical Dry Flask (Ideal gas law)		2.25m	2.25m
Wet Flask	8.65m	8.66m	8.42m
Theoretical Wet Flask (Antoine equation)	9.12m	9.12m	9.12m

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 reaches100°C.