Warm Water Boiling at Low Pressure

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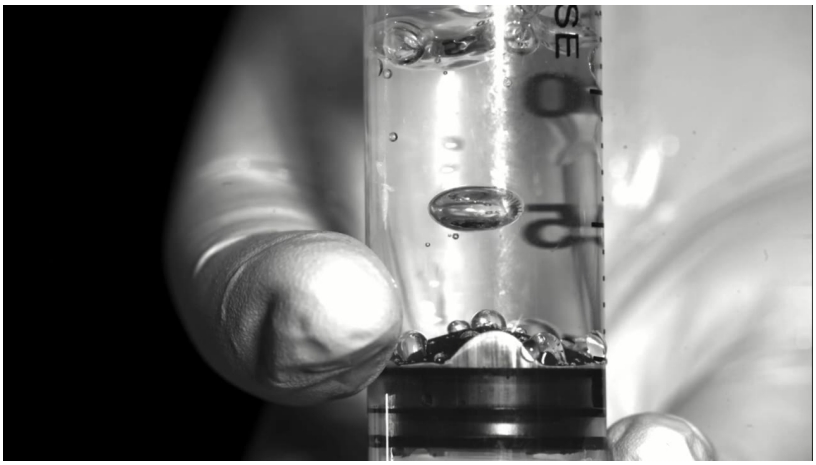


Figure 1: Still from the video. Vapor bubbles rise. Video: `https://www.flowvis.org/2026/10/22/2026-team-second-will-cole/`

Context and Purpose

This report covers the second team assignment in Flow Vis. The videos were captured with assistance from Alex Osten and Rylan Hodgson. Alex operated the lights, Rylan operated the Phantom v2012 camera, and I pulled the syringe. We set off on this flow visualization with the goal of causing water to boil at a low temperature by lowering the pressure acting on it. I initially thought of this idea after watching a similar phenomenon: epoxy off-gassing in a vacuum chamber. After some experimenting at home, I found that the pressure around water could be lowered enough to make it boil in an ordinary 30 mL syringe from McGuckin Hardware.

Apparatus and Flow Physics

The syringe used in this flow was of the common 30 mL size. It was chosen due to its large clear sides, as well as being long enough to allow for good retraction. The barrel had a 22 mm inner diameter. We began the experiment by collecting some lukewarm tap water in a beaker. We then cycled the water in and out of the syringe to clear bubbles from the inside. Once we were satisfied with the number of bubbles, approximately 10 mL of water was drawn in to start the demonstration. Next, the syringe was moved to a stable place on the table in front of the camera and light, which were both then focused on the syringe. With the plunger placed firmly on the table and the tip sealed with a finger, the barrel of the syringe was pulled up until boiling began (Fig. 2). The barrel was pulled continually so that the boiling lasted long enough to capture the flow. We chose to wear nitrile gloves to keep the viewer's focus off the fingers and hands.

The water inside the syringe boils because of the lower pressure around it. Here the pressure in the barrel is lowered by pulling on it without letting any atmospheric air in. Physically, the pressure acting on the fluid falls until it matches the fluid's vapor pressure. At Boulder's atmospheric pressure of

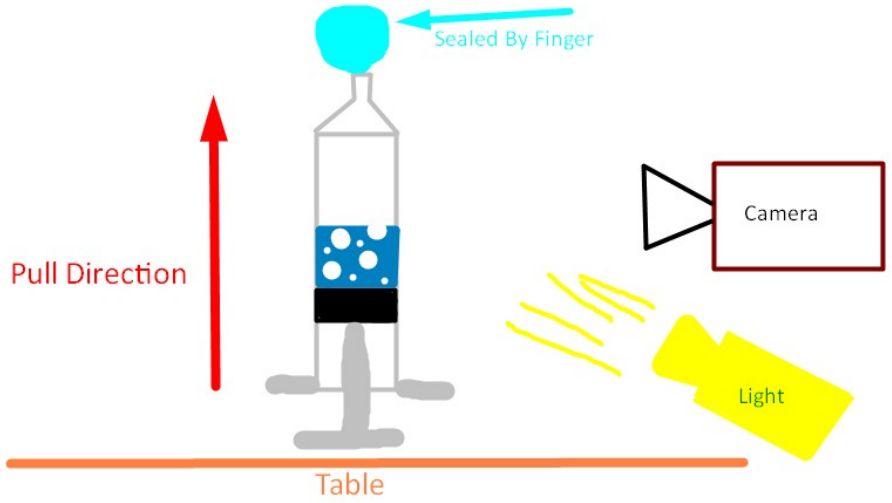


Figure 2: Sketch of the apparatus from the side view. The syringe is held vertically with the tip sealed by a finger. Pulling the barrel up lowers the pressure.

approximately 83 kPa, water boils at about 95 °C. By contrast, water at 40 °C boils at only 7.4 kPa [1]. The bubbles in the syringe form in the same places again and again, which is not an accident. Small imperfections on the plunger act as nucleation sites, which are the easiest places for a bubble to form [2, 3].

The bubbles can be seen growing as they rise (Fig. 3). We believe this is because liquid evaporates into each bubble as it rises. Hydrostatic pressure alone cannot account for this effect, because the vertical distance traveled is too small to create a large enough pressure difference (only about 4% over the height of the frame).

Table 1: Values used in the calculations. Water properties are for saturated liquid at 40 °C [1].

Quantity	Symbol	Value	Source
Water temperature	T	40 °C	estimated
Liquid density	ρ_l	992.2 kg/m^3	NIST
Dynamic viscosity	μ	6.527×10^{-4} Pa s	NIST
Vapor pressure	p_{sat}	7.385 kPa	NIST
Atmospheric pressure	p_{atm}	83 kPa	Boulder, typical
Syringe inner diameter	D	22 mm	measured
Bubble equiv. diameter	d_e	6.0 mm	measured from video
Rise speed on playback	u_{play}	1.8 mm/s	measured from video
Frame rate, shot / playback	f_s, f_p	3000 / 30 fps	camera setting
Exposure time	t_{exp}	240 µs	camera setting
Real rise speed	$U = u_{\text{play}} f_s / f_p$	0.18 m/s	calculated

$$F = (p_{\text{atm}} - p_{\text{sat}}) \frac{\pi D^2}{4} = (83\,\text{kPa} - 7.385\,\text{kPa}) \frac{\pi \left(22 \times 10^{-3}\,\text{m}\right)^2}{4} = 29\,\text{N} \tag{1}$$

$$Re = \frac{\rho_l U d_e}{\mu} = \frac{\left(992.2\,\text{kg/m}^3\right)\left(0.18\,\text{m/s}\right)\left(6.0 \times 10^{-3}\,\text{m}\right)}{6.527 \times 10^{-4}\,\text{Pa s}} = 1600 \tag{2}$$

Equation 1 predicts the force required to pull the barrel up in the experiment. It is based on the pressure difference between the atmosphere and the fluid inside, acting on the area of the plunger; about 29 N is

needed. Equation 2 is the Reynolds number of a rising bubble, using the bubble's equivalent diameter as the length scale and its real rise speed, measured from the video, as the velocity scale (Table 1). With a Reynolds number around 1600, the water's inertial forces dominate and viscosity has very little effect. This is shown by the unsteady, wobbling way the bubbles rise in the video [4].

Visualization Technique

The bubbles are made visible by light reflecting and refracting at the gas–water interface, so no dyes were used; the setup relied only on the optics of the bubbles themselves (Fig. 1). We used a standard 30 mL syringe and ordinary tap water at approximately 40 °C. About 10 mL of water was used, and the syringe tip was sealed with a finger. The setup was lit with a powerful LED light placed about 45° off the camera axis.

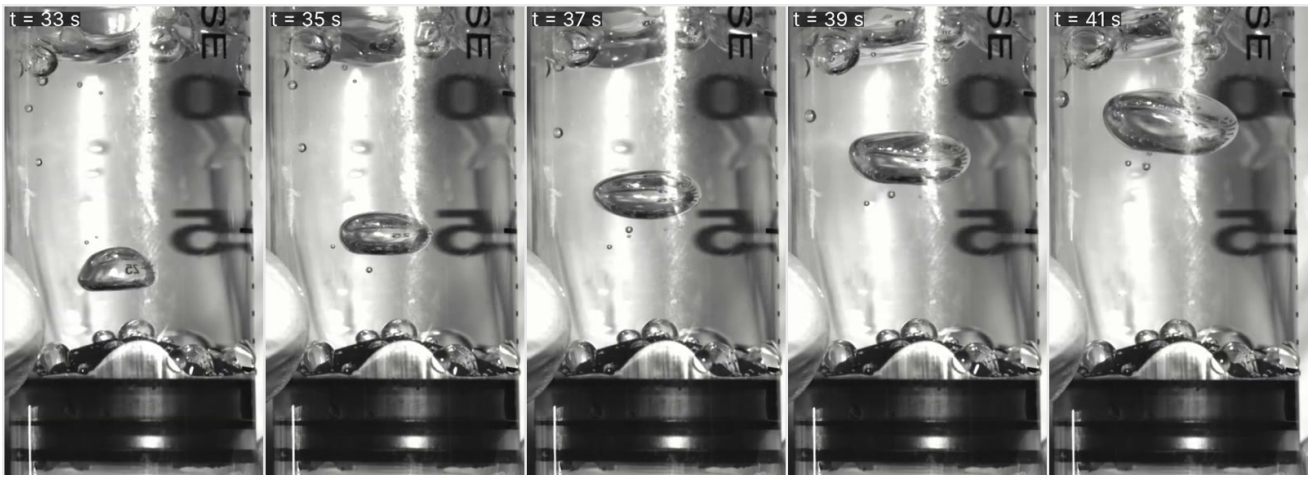


Figure 3: One bubble rising from the plunger. It rises in the syringe, wobbles, and grows as vapor diffuses into it.

Photographic Technique

The video was filmed with a Phantom v2012 high-speed camera and a 180 mm lens at f/5.6, both supplied by Rylan and his lab. The long focal length let the syringe fill the frame, giving a field of view of about 80 × 45 mm (Eq. 3). At this magnification the depth of field is only about 2 mm, so only bubbles near the center of the barrel are perfectly sharp. The camera recorded at 3000 fps with a 240 µs exposure. The footage is played back at 30 fps, slowing it down 100 times, so the whole clip covers only about 0.47 s of real time. The final video is 1280 × 720 pixels (the v2012 sensor is 1280 × 800). The video speed was changed in post to help focus the viewing on the flow.

$$\text{FOV} = \frac{1280 \times 720 \text{ px}}{16.0 \,\text{px/mm}} \approx 80 \times 45 \text{ mm}, \qquad \text{blur} = U\, t_{\text{exp}} = (0.18\,\text{m/s})\,(240\,\mu\text{s}) = 43\,\mu\text{m} \approx 0.7 \text{ px} \quad (3)$$

Discussion

I think we captured the boiling of the water really well, from bubbles forming at the same spots on the plunger to their collapse once the barrel is released (Fig. 4), and we are very happy with it. The video would have been improved by a more controlled setup, such as a vacuum chamber with a larger

reservoir, to capture more of the flow more clearly. This would also let us remove the gloved hand from the frame for better viewing. I also do not like that we were unable to eliminate all of the air bubbles trapped in the syringe.

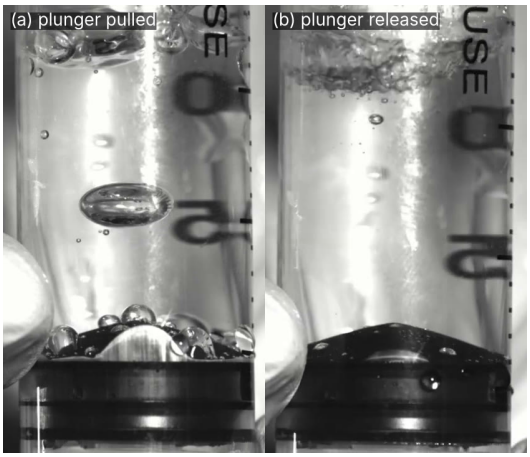


Figure 4: (a) While under vacuum the bubbles are visible. (b) After it is released, the large bubbles collapse.

References

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