



The Formation of Antibubbles

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Abstract

Antibubbles are structures in which a core of liquid surrounded by an air film is suspended in a bath of that same liquid. These structures can affect mixing of liquids when poured. Antibubble formation has been well studied in soapy water systems, but not in single component systems such as oil. In either type of system, a jet of liquid strikes a bath of the same liquid. For a range of jet speeds, antibubbles can form if instabilities in the flow occur. High speed video is used to illustrate the various steps in the process of antibubble formation in an oil system and some of the parameters controlling the dynamics of the process are measured from these videos. The disturbances in the jet necessary for antibubble formation in the oil system are studied in detail.

What are Antibubbles?

Common soap bubbles are created when a sphere of air is separated from the surrounding air by a thin shell of liquid. In antibubbles a thin shell of air separates a sphere of liquid, or globule, from the surrounding liquid (Fig. 1). Antibubbles are formed when a liquid jet incident on the same liquid is somehow disrupted. The disruption results in the liquid jet entraining air into the liquid bath.

Due to surface tension the creation of surfaces requires energy. Since spheres has the least surface area per unit volume, a stable surface for the air in antibubbles is to form a spherical shell. This means the air will tend to become a sphere, in some cases separating a globule of liquid inside it.

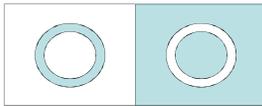


Fig. 1. A simple visualization of the difference between bubbles and antibubbles. The left half is a standard soap bubble and the right an antibubble. Blue indicates liquid and white is air.

Apparatus

Our apparatus setup is shown below in Fig 2. A pump lifts canola oil, from a reservoir into a burette. A nozzle at the base of the burette keeps a steady liquid jet cross-sectional area. Kinetic energy of this jet is determined entirely by the height of oil in the burette. This jet pours into an aquarium where antibubbles form. Extra oil drains over two lowered sides to maintain a constant depth. The jet incident on the aquarium is disrupted to make an antibubble. To get the oscillations required the apparatus sits on a large counter which is vibrated by a simple rubber mallet. The vibration oscillates the nozzle causing the disruption.

In our experimental setup we took high quality digital videos at 1200 fps at a close range using a Casio EX-FI. ImageJ was then used to process the images. ImageJ calculates the depth achieved by the bottom of each antibubble before pinching off as well as each antibubble's cross-sectional area in pixels. Films are also taken of a stationary centimeter ruler in the camera focal plane each day and again whenever the camera is adjusted. These "calibration films" are then used to convert the data taken from pixels to centimeters.⁽⁴⁾

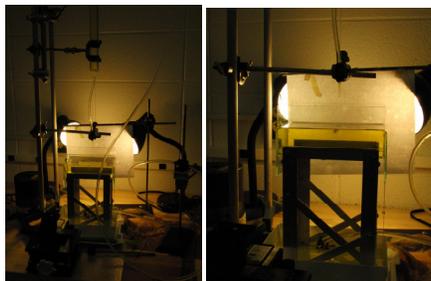


Fig. 2. (Left) A typical setup. (Right) Close-up of antibubble aquarium.

Objectives

- To explain what antibubbles are and discuss the different ways to form them.
- Examine the differences in formation between oscillation-formed antibubbles and disruption-formed antibubbles.
- To study oscillation-formed antibubbles with regard to incident energy, specifically the conservation of energy requirements to form an antibubble.

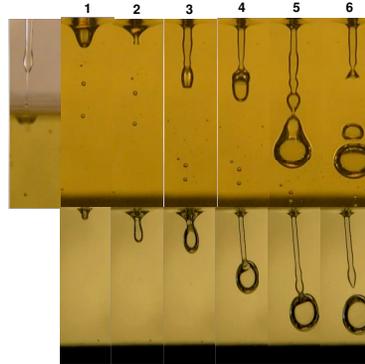


Fig. 3. (Top row) Progression of oscillation formed antibubbles with far left frame showing disruption. (Bottom row) Progression of disruption formed antibubbles. Frames are not necessarily evenly separated by the same time span.

Antibubble Formation

Previously, most research on antibubbles^(1,2,3) has been done by moving a globule of a liquid below a surface. This is similar to the bottom row of Figure 3. The disruption creating this formation is a gap in the incident jet, caused by breaking a jet or pouring discrete drops from a pitcher. Another way to form antibubbles is to create an oscillation in the incident jet, in our case by vibrating our nozzle. This vibration can be seen in the very top left frame in figure 3. The steps in forming an oscillation-antibubble are shown in the top half of Figure 3.

Unlike disruption-formation, oscillation-formation antibubbles start with an open cylindrical sheath of air where the incident oil is free to flow into the bath (first 3 frames). The air entrained by this builds up below the surface and results in the bell structure of frame 3. This air squeezes the oil tube inside until it is energetically favorable for the air on either side to pull together and make the bottom half of a sphere. In other words, the whole surface decreases its surface energy to the most stable state, spherical. Oil can no longer flow into the bath, so instead it fills the bubble and we get frame 4. Progression of the antibubble now follows the normal progression of antibubble formation, the liquid fills the bath, pushing it lower and making the bubble larger until pinch off occurs.

It is also worth noting that oscillation-formed antibubbles appear to entrain more air per unit volume than their disruption-formed counterparts.

Theory

Antibubble creation must conserve energy so we have:

$$E_{total} = KE_{ab} + W_{space} + E_{surface}$$

Energy total is determined by the height of the column of oil in our burette, but it is also directly related to the depth achieved by the antibubbles, as a result we can think of E_{total} as $E(R)$ where h is depth. Kinetic energy of the antibubble after formation is generally zero or nearly zero. W_{space} is the work required to push the surrounding material away to make room for the antibubble. W_{space} is given by $(P_o + \rho gh) \cdot V_{ab}$ according to the Ideal Gas Law. The energy of a surface is surface area times surface tension, γ . So substituting in volume of a sphere⁽¹⁾:

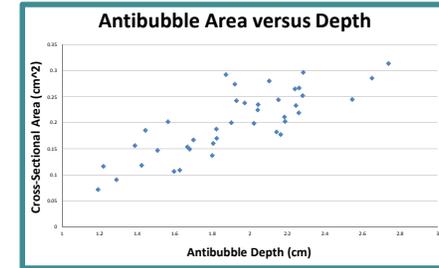
$$E(h) = (P_o + \rho gh) \frac{4\pi R^3}{3} + 4\pi R^2 \gamma$$

Note that ρgh is very small compared to atmospheric pressure P_o and γ is negligible compared to $P_o R/3$. Simplify this to get cross sectional area ($A = \pi R^2$) as a function of incident energy, which is proportional to depth achieved.

$$Area = \frac{3 E(R)}{4 P_o R}$$

Results

Cross sectional area and depth were measured⁽⁴⁾ for a variety of incident energies by adjusting the height of oil in the burette. This resulted in the graph below of antibubble area versus depth. The graph depicts the range of possible area and depth. We found antibubbles from the regions where $1cm \leq Depth \leq 3cm$ and $0.05cm^2 \leq Area \leq 0.35cm^2$. This range corresponds with the range of possible heights in the burette, which determine the incident energy of the jet. It was observed that above a maximum burette height antibubbles would not form and below a minimum height antibubbles also would not form. Further the graph indicates that within this energy range, $Area \propto Depth$ as predicted.



Conclusions

From this we conclude that surface energies play a large part in when antibubbles form. More incident energy pushes the antibubble deeper and thus $Depth \propto E_{incident}$ (This is also supported by the lack of an air tube in other antibubble systems^(1,2,3)). Meanwhile $E_{surface} \propto 4\pi R^2 \gamma$ making $Area \propto E_{surface}$.

Thus from the above graph we approximate that $E_{surface} \propto E_{incident}$. This conclusion then gives us that the range where antibubbles can be formed is determined by their incident energy, and within this antibubble range the energy can roughly control the size of the antibubbles.

Importance

- While many research projects on antibubbles focus on disruption-antibubbles, oscillation-antibubbles form more consistently than disruption-antibubbles in canola oil. This makes them notably easier to study.
- Some antibubbles generated during this project formed from simply walking on the concrete floor near our apparatus. Oscillation-antibubbles could be generated in many fluid systems exposed to any vibration including human footsteps. Antibubbles form in soapy water^(1,2,3), canola oil and numerous other liquids. This means any processing of liquids may develop antibubbles whether they are desired or not.

References

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- S. Dorbolo, H. Caps and N. Vandewalle, "Fluid instabilities in the birth and death of antibubbles", *New Journal of Physics* **5**, 161.1-161.9 (2003)
- All image processing was done using ImageJ, a public domain Java image processing program available from <http://rsb.info.nih.gov/ij/download.html>.

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