Behavior of Bubbles in a Vibrating Liquid

THE UNIVERSITY OF ARIZONA

Project Description

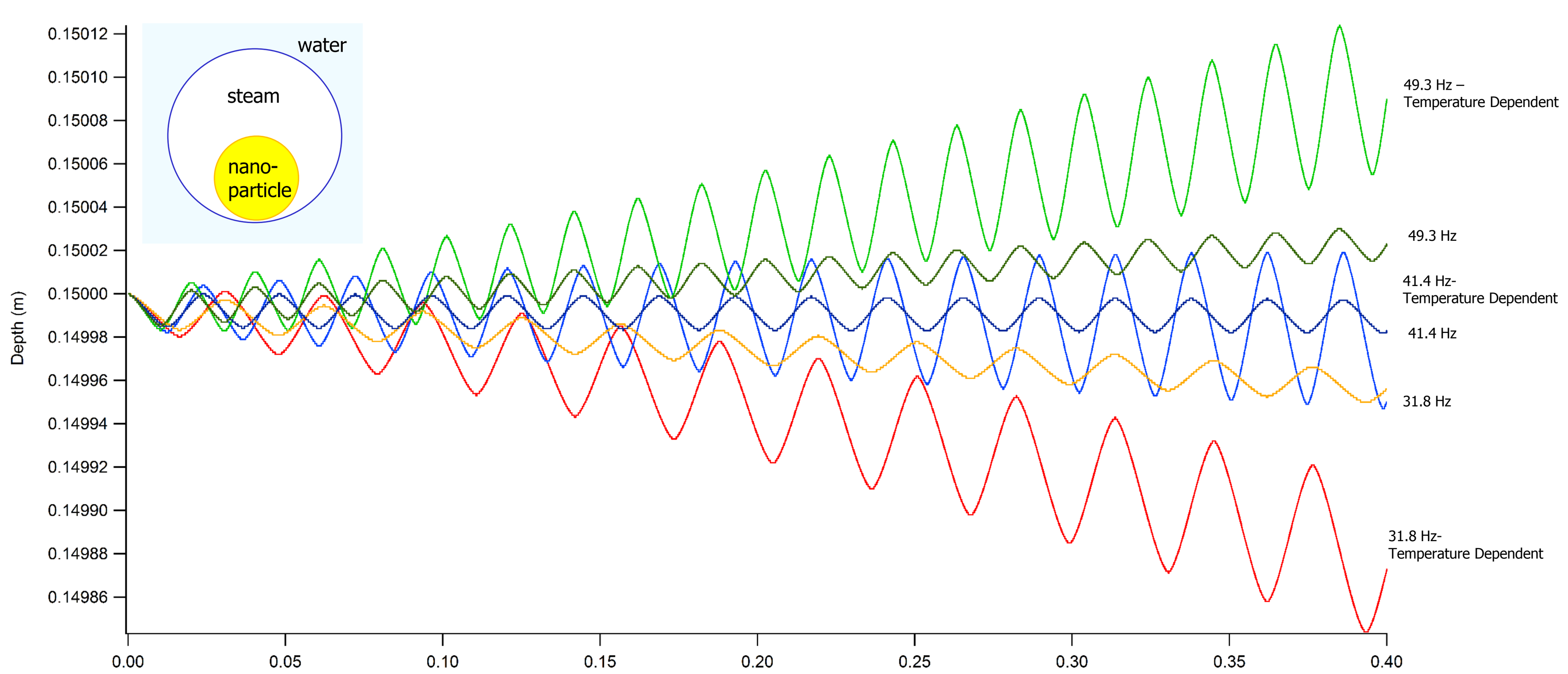
- Experiments have found that oscillating bubbles can sink, which is a very contradictory phenomenon. This happens when the Archimedes force acting on the bubbles is defeated by the gravitational force acting on the attached mass.
- Attached mass is the primary reason that oscillating bubbles sink. The mass of the water surrounding the bubble is dragged along and imparts additional mass to the bubble proportional to the bubble's kinetic energy.
- When the liquid that bubbles are generated in is subjected to vibrations, the bubbles within that liquid oscillate and will sink under certain frequencies [3]. An interesting phenomenon develops when plasmonic nano-particles are added to a liquid. By heating the nano-particles, one can cause the formation of bubbles and increase the internal temperature of the bubble, thereby increasing its volume[2].
- The model shows when the equations are applicable, and if the solutions fit the observed phenomenon.
- Our model was designed to simulate the bubble dynamics over a range of varying frequencies and initial conditions. An additional temperature term was added to show the effects of plasmonic nano-particles excited by incident laser light.

Scientific Challenges

- The bubbles generated by nano-particles can, through the use of vibrations, accumulate at a particular level in the liquid where they can coalesce and form larger bubbles.

Potential Applications

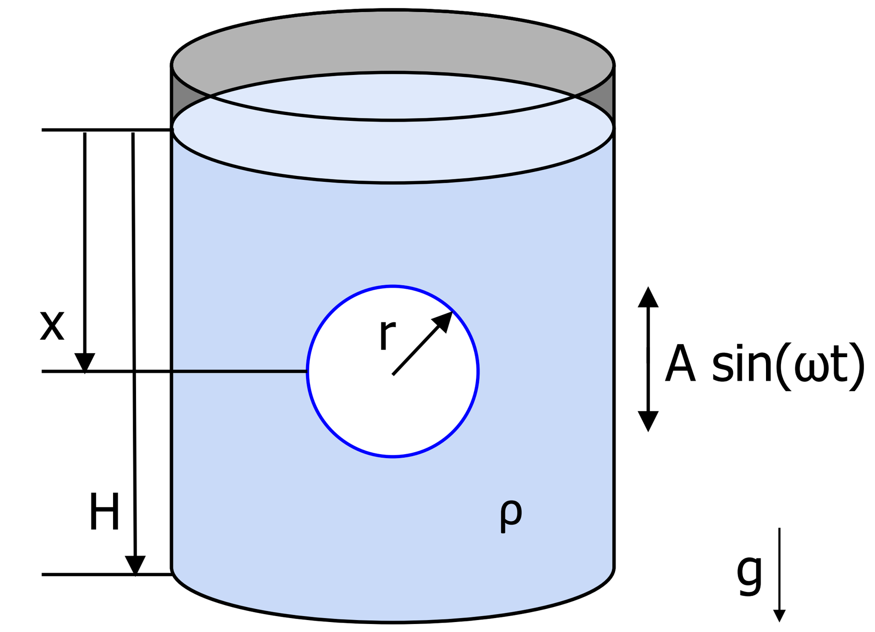
- One of the many potential applications is the sterilization of water by exciting nano-particles.



This graph illustrates how changing the frequency and the addition of temperature affects the bubble movement through the fluid. The larger amplitude lines represent the addition of temperature. Red and orange are 200 rad/s (31.8 Hz), blues are 260.15 rad/s (41.4 Hz), and greens are 310 rad/s (49.3 Hz).

Team Members:

Mohammed Ghallab
Jaggar Henzerling
Aaron Kilgallon
Michael McIntire
James Wymer



Methods

1. The bubble kinematics are described via fluid mechanics, and a general equation of motion is developed [4].

$$(m + m_{att})\ddot{x} + \dot{m}_{att}\dot{x} = -F(\dot{x}) + (m - \rho V(t))(Aw^2 \sin(\omega t) + g)$$

2. The attached mass is equal to one half the mass of the displaced fluid.[1], [5]

$$\frac{2}{3}\rho_{dis}\pi R_{bub}^3$$

3. These solutions are split into "slow" and "fast" solutions [4]. We show that the fast solution time average to zero. The slow solutions are unstable as shown by the bifurcation diagram.
4. The differential equation of motion is integrated using the Verlet Method in order to describe the full bubble dynamics.
5. An additional term for the volume of the bubbles was added based on the generation of heat by the nano-particles through the use of incident light, solar/laser [2], [3]. I is the incident intensity, σ is the cross sectional area of the nano-particle, and k is the thermal conductivity of gold.

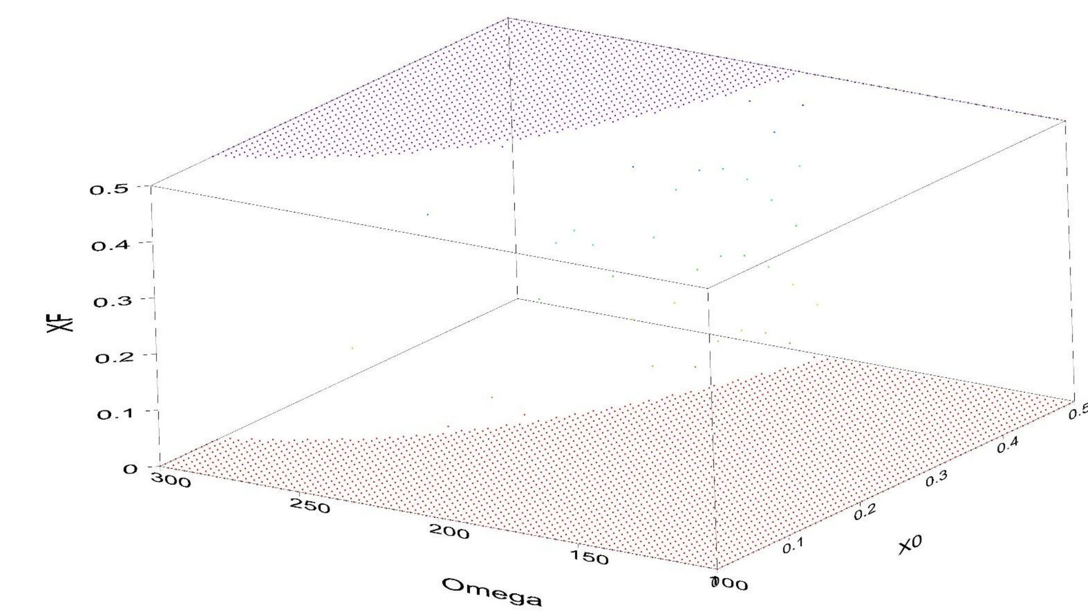
$$V(t) = \frac{P(0)V(0)\left(1 + \frac{I_{inc}\sigma t}{T(0)4\pi k R_{np}}\right)}{P(0) + \rho g x + \rho x A\omega^2 \sin(\omega t)}$$

Results

1. Our models show that when the frequency is above 260.15 rads/sec, and at the initial depth of 0.15 m used in the model, the bubbles will sink.
2. When the nano-particles have plasmonic excitation they increase the rate of sinking or rising by increasing the volume of the bubble through the addition of steam inside the bubble.
3. The increasing temperature of the steam in the bubbles has an affect on the kinematics of the bubbles.

Glossary of Technical Terms

Verlet method: A second order centered difference method that does not require direct velocity integration.
Separation of Variables: A harmonic analysis method to simplify solutions into fast and slow equations of motion.
Attached Mass: The fluid that is dragged along with an object that is moving through the fluid.



The stability regime depends on three parameters, the initial position of the bubbles (X0), the frequency of oscillations (Omega), and the final bubble position (XF). In this graph the red indicates rising bubbles and blue indicates inking bubbles.

References

1. Brennen, C. E., comp. "A Review of Added Mass and Fluid Inertial Forces." (1982): Naval Civil Engineering Laboratory. Web. 8 Mar. 2014. authors.library.caltech.edu/233/1/BRE052.pdf
2. Fang, Zheyu et al. "Evolution of Light-Induced Vapor Generation at a Liquid-Immersed Metallic Nanoparticle." *Nano Letters* (2013): 130325111245005. *CrossRef*. Web. 25 Apr. 2014.
3. Neumann, Oara, Alexander S. Urban, Jared Day, Surbhi Lal, Peter Nordlander, and Naomi J. Halas. "Solar Vapor Generation Enabled by Nanoparticles." *ACS Nano* 7, no. 1 (January 22, 2013): 42–49. doi:10.1021/nn304948h.
4. Sorokin, V. S., I. I. Blekhman, and V. B. Vasilkov. "Motion of a Gas Bubble in Fluid under Vibration." *Nonlinear Dynamics* 67, no. 1 (January 2012): 147–58. doi:10.1007/s11071-011-9966-9.
5. Techet, A. "Object Impact on the Free Surface and Added Mass Effect." (2005): Massachusetts Institute of Technology. Web. 8 Mar. 2014.

Acknowledgments

This project was mentored by Professor Ildar R Gabitov, whose help is acknowledged with great appreciation.