Dynamic Stabilization of Rayleigh-Taylor Systems

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ME241 Group 4A Proposal

6 March 2014

Introduction

When any two fluids of varying density are accelerated into each other, the denser fluid will move through the less dense fluid to a relative “bottom”, while the less dense fluid will move up to the relative “top”. A simple case of this occurs when two fluids are placed in a container together and are accelerated in the same direction by gravity. This system will naturally proceed to the lowest energy configuration – the denser fluid will sink to the bottom and the lighter will end up on the top [1]. If this system is inverted with the denser fluid on top, such that mixing does not occur, then the liquids are no longer at the lowest combined potential and are instead at a maximum potential. This is an unstable arrangement similar to standing a ball on top of an upside down bowl; as long as the system remains entirely free from outside influence and is perfectly balanced, its arrangement will not change. Realistically, the ball will not stay balanced indefinitely. Similarly, in our system, outside interference causes perturbations (called fingers) to form at the fluid interface. These fingers propagate along the interface and cause the system to become unstable. This phenomenon is called the Rayleigh-Taylor Instability (RTI) and is a challenge in nuclear fusion reactors where the heavier spherical shell material collapses into lighter gaseous core as it is compressed. It can be shown mathematically that this system can be stabilized such that a more dense fluid will stay above a less dense fluid [2]. The metastable state requires that controlled waves be introduced perpendicular to the fluid interface to stop the random waves propagating and thus preventing the fluids from mixing.

Procedure

A system will be assembled that can vibrate such that the inverted fluid system is stabilized. This system as shown in Figure 1 will consist of a compact electrodynamic shaker (d) driven by an adjustable signal generator (a) and linear power amplifier (b). The shaker will be mounted securely to an apparatus (f) serving two purposes: to keep the shaker upright while the experiment is being setup and to flip it after the vibration has started, and to isolate it from outside interference. Preferably this mounting piece will have the capability to lock the shaker into two positions, vertically at 0° and 180°. The fluid container (e), a sealable clear cylinder, will be attached to the top of the shaker and will allow us to view the fluid configuration inside to observe the success of the experiment and prevent any liquids from spilling when the system is inverted and stability inevitably degrades. An accelerometer will be attached to the cylinder so that the linear acceleration of the shaker can be recorded.

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| Figure 1. The experimental setup. [3] |

The procedure will begin with the setup of the system as described and pictured above. The system will then be ready for testing.

On each day of testing, the aim is to test each fluid combination being examined twice. In these sessions, the first step will be to measure the density and viscosity of the fluids experiencing the RTI. The parameters for the shaker operation can then be estimated based on these measurements. The mounting piece will be attached to the ground or a rigid table to prevent motion. The shaker will be loaded into the mounting piece in the upright 0° position. The testing fluid(s) will be poured into the cylindrical container and then the container will be sealed.

With the system set up in this position, the components will all be turned on and set to the appropriate frequency, voltage, and current settings based on the fluid properties. Once the shaker is moving at the appropriate settings, it will be carefully flipped 180°. This rotation will need to be carefully controlled to avoid upsetting the fluid system. At this point the fluid can be observed inside the transparent cylinder to see whether or not the RTI stabilization is successful.

If the settings for the shaker successfully inhibit the RTI, the parameters will be recorded. If the stabilization is unsuccessful, the system will be shut down and new parameters will be calculated and tested. The steps from pouring the liquid through recording of the shaker parameters will be repeated until there is a successful test, and then repeated once more to confirm the result.

Assuming a smooth acquisition of system components, the week of 3/17-3/21 will be taken for setup. Over the course of the weeks of 3/24-3/28, 3/31-4/4, 4/7-4/11, 4/14-4/18, there will be ample time to conduct 6 testing sessions. After testing is completed, the data will be analyzed and a written account of the results will be presented.

Results

The primary data recorded will be the specific parameters present when the RTI was inhibited. Fluid properties (density and viscosity), the amplitude and frequency of the vibrational sine waves, and the acceleration of the system are all important factors that will be recorded. All of these parameters affect how and when the RTI will occur. Whether or not a trial is deemed successful depends on if the RTI is inhibited and for how long. If a trial is successful then the more dense fluid will be suspended above the less dense fluid for an observable amount of time.

Discussion/Conclusions

The overall goal of this research is to inhibit the Rayleigh-Taylor Instability on the boundary between two fluids. If the experiments are successfully then a denser fluid will be suspended over a less dense fluid in a metastable state. This state will not last indefinitely but will exist long enough to be observed and recorded. Data recorded will include the effects of the fluid properties as well as the amplitude and frequency of the oscillations and how they affect the metastable state.

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| Figure 2. An example of results. This data represents the upper and lower boundary of the frequency and relative acceleration required to inhibit the RTI for two fluids (SAE140 and a honey water solution) at two different cylinder diameters. More information can be found in the source. [3] |

With enough data and an understanding of the results, this data can be used to predict whether or not the RTI will occur based on the fluid properties and the nature of the vibrational wave supplied, and to predict how long the RTI will be inhibited at a given vibrational frequency. Additionally, the efficacy of other vibrational methods such as ultrasound in liquids or laser pulses for the nuclear fusion application can be estimated.

References

[1] Rajeev, S. G. Professor of Physics and Mathematics, University of Rochester. Personal Communication. 11 February 2014.

[2] Wolf, G. H. "Dynamic Stabilization of the Interchange Instability of a Liquid-Gas Interface." *Physical Review Letters* 24.9 (1970): 445-46. Web.

[3] Prieto, G. R., A. R. Piriz, J. J. Lopez Cela, and N. A. Tahir. "Dynamic Stabilization of Rayleigh-Taylor Instability: Experiments with Newtonian Fluids as Surrogates for Ablation Fronts." *Physics of Plasmas* 20.012706 (2013). Web.