Langmuir-Pockels Trough with Double Wall Couette for Measuring Interfacial Rheology of Insoluble Surfactants

by
Christine Turner

A THESIS

submitted to

Oregon State University

University Honors College

in partial fulfillment of
the requirements for the
degree of

Honors Baccalaureate of Science in Chemical Engineering
(Honors Scholar)

Presented May 27, 2016
Commencement June 2016

AN ABSTRACT OF THE THESIS OF

Christine Turner for the degree of Honors Baccalaureate of Science in Chemical Engineering presented on May 27, 2016. Title: Langmuir-Pockels Trough with Double Wall Couette for Measuring Interfacial Rheology of Insoluble Surfactants
.

Abstract approved: ____

Travis W. Walker

Insoluble surfactants are unique molecules that have the ability to manipulate interfacial properties, becoming useful in numerous applications such as detergents, wetting agents, emulsifiers, foaming agents, dispersants, and more. Interfacial rheology is a field that attempts to characterize the flow properties of insoluble surfactants by exerting a stress on the fluid and measuring the strain, or fluid deformation, in response. These measurements are inherently small, constraining rheology equipment to acute sensitivity along with an immense cost. The objective was to design a customized device to accurately and efficiently perform rheological characterizations under simultaneously controlled surface pressure that would fit into the established equipment scheme at a reasonable price.

The methodology described in this thesis outlines a brief history of a few interfacial rheology pioneers, a design requirement inventory, a technology review, as well as a proposed design and experimental laboratory setup. A series of design modifications were made to the double wall Couette and trough to customize a device to fit existing equipment in Dr. Walker’s lab. The proposed design will allow the study of interfacial properties to occur under controlled surface pressure at a significantly lower cost than the current market price, while giving the potential to expand the device functionality in the future.

Key Words: rheology, interfacial rheology, insoluble surfactants, design, double wall Couette, Langmuir trough.

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APPROVED:

Travis W. Walker, Mentor, representing Chemical Engineering

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I understand that my project will become part of the permanent collection of Oregon State University, University Honors College. My signature below authorizes release of my project to any reader upon request.

Christine Turner, Author

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INTRODUCTION

Opportunity

Insoluble surfactants are oil-based compounds with both hydrophilic and hydrophobic ends that form an interface between two fluids. Surfactants have the ability to influence the flow and stability properties of these interfaces, specifically by reducing surface tension. The ability to manipulate interfacial properties allows insoluble surfactants to be utilized in several ways such as detergents, wetting agents, emulsifiers, foaming agents, and dispersants [1]. One of the more common applications is human lung surfactant. Humans rely on this naturally occurring mixture of lipids and proteins to reduce the surface tension on the water/air interface on the alveoli. Reducing the surface tension stabilizes the alveoli to prevent from complete air loss and fluid filling during expiration and minimizes the work required for alveolar expansion during inhalation, facilitating adequate gas exchange [2].

Interfacial rheology studies the flow properties of fluid interfaces typically by measuring their 2-dimensional flow properties, or shear flow properties. Interfacial rheology is done by exerting a force on an interface and then measuring the force and fluid deformation in response [3]. However, because rheological properties are so small, the instruments used to study them need to be extremely sensitive. The overall quality and sensitivity of the equipment required to study in this field makes researching in rheology very expensive. Interfacial rheology is an established field that is making an impact in numerous applications, but it can be difficult to obtain the necessary research equipment.

Dr. Travis Walker and his lab specialize in the fundamental physics concerning a variety of transport phenomena. Areas of study revolve around rheology, with an interest in interfacial rheology and its applications to various industries.

Objective

With the desire to pursue interfacial rheology further, Dr. Walker needed a device to delve further into the interfacial properties in a more continuous and controlled fashion. From the developments of Langmuir, Blodgett, and Pockels, a series of design modifications were made to the double wall Couette and trough to customize a device to fit existing equipment in Dr. Walker's lab. The proposed design will allow the study of interfacial properties to occur under controlled surface pressure at a significantly lower cost than the current market price, while giving the potential to expand the device functionality to three-dimensional dilational rheology research in the future.

HISTORY

Agnes Pockels (1862-1935)

Agnes Luise Wilhelmine Pockels was born on February 14th, 1862, in Venice, Italy to a German family. She had a younger brother, Friedrich, who was three years younger than Agnes [4]. Pockels' family lived in Italy for her early childhood because her father was stationed there for his position in the Austrian army. During those times, much of northern Italy was classified as a malarial zone, and both of Agnes' parents contracted the disease from infected mosquitoes. The malaria contributed to life-long poor health for her parents, limiting Agnes' options later in life [4]. Her father's illness forced him to retire in 1871, when the family moved to Brunswick, Lower Saxony, Germany.

Agnes attended high school separate from her brother, because gender segregation in schools was custom at the time. Friedrich was sent to a technical school high school before going onto university to study physics. Agnes was not educated past the age of 15 because most universities refused to admit female students at that time [5]. She was still interested in science, however, so she used with her brother's old university textbooks to teach herself what she could [4].

At home Agnes was expected to care for her invalid parents, while her brother went on to earn his Ph.D. and become a well-known physicist [4]. Agnes spent most of her time cleaning the house and working in the kitchen, where she noticed the surface of water behaved differently when contaminated while doing dishes [5]. After a few years at home, Agnes expressed interest in applying to some universities that had started to admit women. Since no one else was available to care for her parents, however, she was forced to let her dream go [4].

Agnes was determined to understand the phenomena that she observed on the water used for washing dishes [5]. Making the most of her time at home, she performed her own scientific experiments in her kitchen sink. She learned most of what she knew from her make-shift experiments starting when she was just 18 years old [5]. By the time she was 20, she had invented a preliminary model of the trough used in rheology research today to try and explain what she was seeing [6]. The apparatus used measured surface tension, called the Pockels trough, consisted of a rectangular container filled to the top with water [4]. Pockels placed a tin strip on the container top so it was in contact with the liquid, perpendicular to the long side of the container. The tin strip divided the water’s surface in half but also allowed her to slide the strip down the container to increase the concentration of the contaminants at the water surface [4].

Agnes measured surface tension by observing the amount of force needed to pull a floating button off the surface [4]. She was able to quantify this force by use of a balance scale made from buttons hung on a little wooden beam, as it tipped from side to side [4]. On one side, buttons functioned as a weight, while the other side consisted of a single button hanging down onto the water’s surface [4]. She was able to measure the amount of tension needed to lift the button by leveling the balance and carefully pulling the button away from the water [4].

Through her experiments, Agnes discovered that she could add certain substances to the water that would decrease the surface tension. She correlated the lower surface tension to the increased contamination of the water, as she moved the tin strip on the top of the trough [4]. Agnes discovered that normally water molecules are attracted to each other, but if soluble substances are added, the water molecules are distracted from each other as they gather around the new molecules [4]. The intermolecular interactions between surface-active molecules at a solvent interface produces a measurable decrease in the water's surface tension [4].

Agnes knew that she had influential data. But, without the academic credentials, she knew that she would not be taken seriously by the scientific community on her own. Years after her initial experiments, she learned that Lord Rayleigh was researching surface tension, and she wrote him a letter describing her findings [4]. After communicating back and forth to confirm the authenticity of the work, her data was determined to be sound enough to be published in *Nature* in 1891, thanks to Lord Rayleigh who wrote on her behalf [5]. For the first time, Pockels' work was recognized by the scientific community. She took a job in the University of Heidelberg physics department, where she published her research for the remainder of her life [4].

Throughout her career, she published sixteen articles relating to the water trough, horizontal balance, surface tension, contact angles, effect of contamination on the water surface, monolayer thickness on water, properties of surfactants, and surface tension of liquid solutions [5]. Her work set the foundation for a new scientific field now known as interfacial rheology, and she was honored for her accomplishments later in life. A large tribute to her work was made on her 70th birthday, and she went on to be awarded the Laura Leonard Prize for "Quantitative Investigation of the Properties of Surface Layers and Surface Films" as well as an honorary doctorate from the Carolina-Wilhemina University of Brunswick [6].

Irving Langmuir (1881-1957)

Irving was born into the Langmuir family on July 31st, 1881, in New York. From an early age, his parents encouraged him to be a careful observer of nature and his surroundings. Irving took a special delight in observing the world around him, after his eyesight was corrected at age eleven. He continued the practice of being an excellent observer all his life, keeping detailed diaries of all his work [7].

Langmuir graduated with a degree in metallurgical engineering from Columbia University, before receiving his doctorate under the physical chemist, Walther Nernst, from Gottingen University in Germany [7]. He came back to the US to work at the Stevens Institute of Technology in New Jersey, but he quickly became bored after teaching just one year of college [8]. Irving left teaching to become a researcher at General Electric Company (GE), where he made some important developments in the incandescent light bulb, elaborated on the concept of the "covalent" bond, and more [8]. But, he received his Nobel Prize in chemistry in 1932 for his work in surface chemistry. He developed a new concept of adsorption: the adhesion of atoms or molecules to a surface [8]. What is important, however, is that the layer of atoms/molecules being accumulated at the adsorbent surface is only one molecule thick. Irving made these conclusions from researching on a device that he modified from Agnes Pockels. He used the Pockels trough to create what is known as the Langmuir trough, and it is pictured in Figure 1 [9].

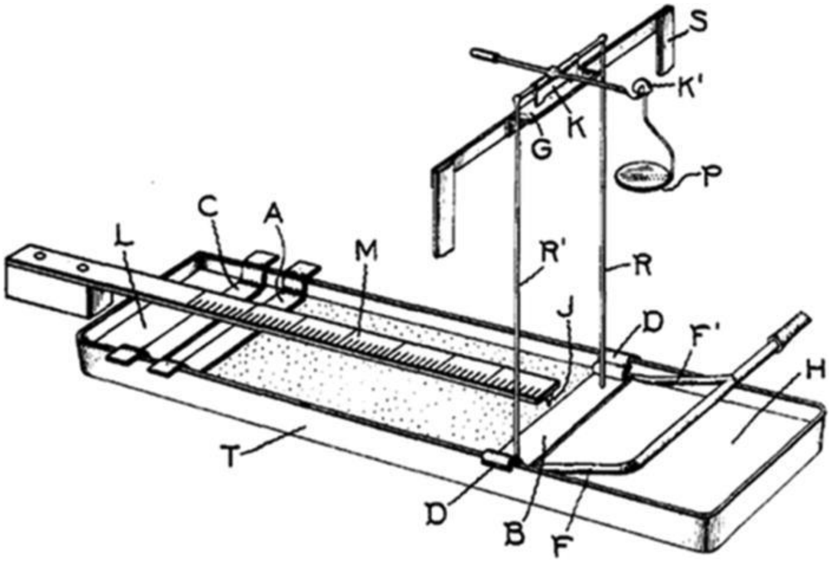


Figure 1. "Schematic illustration of a Langmuir trough. Liquid [usually water] is placed in the tray (T). Above the tray is a balance with knife edge (K) resting on a glass plate (G) fastened to a support (S). One end of the balance beam has a counterweight, while the other has a knife edge (K'), from which hangs a pan (P). Glass rods (R) and (R'), cemented to the knife edge, pass through two small holes in a strip of paper (B), which floats upon the surface of the water in the tray. To prevent the paper from being softened by the water, it is dipped in a solution of paraffin in benzene. The length of the paper strip (B) is less than the width of the tray so that it can move freely without touching the sides of the tray. The surface of the water between the strips (A) and (B) is covered by an oil film. As strip (A) is moved toward (B), the oil film is pushed ahead of it until it begins to exert a force on the paper strip (B)" [9].

Langmuir was the first industrial scientist to bring the rigor of deep scientific methods for the development of useful devices, as well as win the Nobel Prize [7]. More specifically, he was the first person to win the Nobel Prize for surface science, which spurred the dedication of the surface science journal, "Langmuir," by the American Chemical Society [7]. He was not completely alone in his endeavors, however. Langmuir collaborated with his long-time mentee, Katharine Blodgett, while at GE. Together, they were able to change the world of rheology [8].

Katharine Blodgett (1898-1979)

Katharine Blodgett was born on January 10th, 1898, in Schenectady, New York [10]. She was raised by her mother, as her father, GE's patent department director, passed away just weeks before her birth [10]. After years living abroad, Katharine's family moved back to the US to start school [10]. She attended an exclusive technical high school, before receiving a scholarship to study physics at Bryn Mawr [10]. At the age of 18, Blodgett visited the GE research labs where her father once worked and where she met Irving Langmuir [10]. Langmuir was impressed by her intellect and willingness to learn, so he offered her a position at GE after she obtained her master's degree in physics [10]. She received her master's degree in physics from the University of Chicago and returned to GE to follow up with Langmuir on his offer of employment [10]. At 20 years old, Katharine became the first woman research scientist ever hired by GE [10]. She worked as Langmuir's research assistant and helped develop a way to produce oily monomolecular films on water by perfecting the device Pockels had used in her studies [8]. This device is now known as the Langmuir-Blodgett trough, and it was part of the work that would earn Langmuir the Nobel Prize [8]. The modified Pockels trough is pictured in Figure 2 [11].

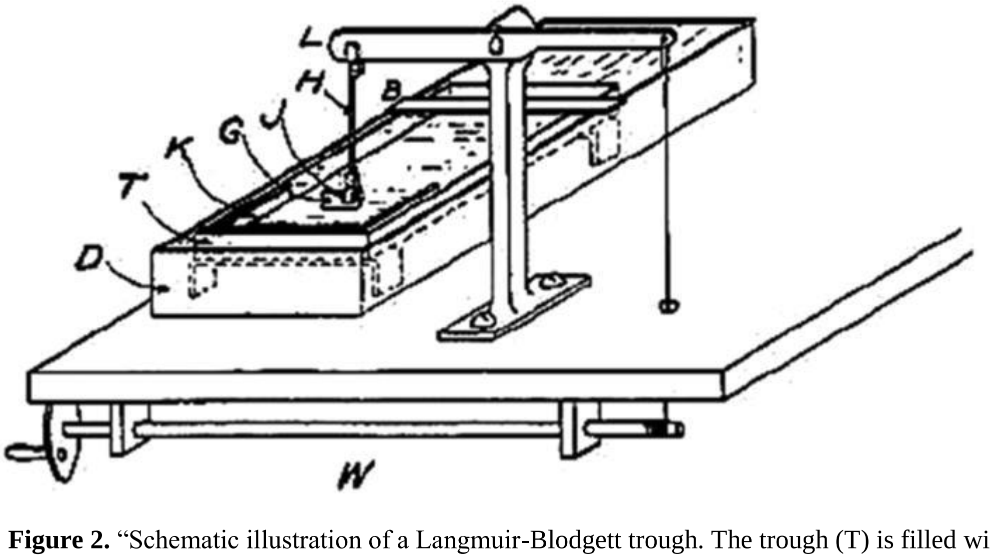


Figure 2. "Schematic illustration of a Langmuir-Blodgett trough. The trough (T) is filled with water and set in a temperature-controlled water bath (D). The edges and inner surface of the trough and the metal barrier (B) are coated with paraffin. Three detachable glass strips (K) serve to contain the benzene solution of stearic fatty acid on the water surface and prevent the benzene reaching the paraffin. The glass substrate (G) is lifted and lowered by a balance (L) operated by a hand pulley (W)" [11].

Blodgett then went on to be the first woman to earn a Ph.D. in physics from Cambridge University [11]. She returned to GE and worked further to develop thicker films from individual monolayers. She created a 44-molecule-thick film of barium stearate, a type of soap, on glass, which is more typically known as non-reflective glass today [11]. Now, most all lenses have non-reflective coatings to permit efficient passage of light.

Developments by these scientists set the stage for countless people to build on the science of surface chemistry. Being able to examine a field with so many influential females who pioneered this science is an honor, especially during a time when women were discriminated against or heavily discouraged from entering a technical field.

BACKGROUND

Rheology

This branch of physics is the study of the flow of matter, whether it is solid or liquid [12]. This thesis, however, will focus on the rheology of liquid matter. Rheology studies how materials deform in response to forces exerted on them [13]. Everything may indeed flow, but in different ways depending on how much force is applied, in what direction, and for how long [13].

The three basic quantities measured in rheology are the stress, strain, and the shear rate. The stress is the amount of force applied to a specified area, while the strain is the degree to which the material deforms under that stress [13]. The ratio of stress to rate of strain defines the elastic modulus for solids, and the viscosity for liquids [13].

A liquid with a constant viscosity at a certain temperature is called a Newtonian fluid [13]. More specifically, it is a fluid in which the viscous stresses are linearly proportional to the strain rate [14]. Therefore, a Newtonian fluid's viscosity does not depend on the stress state or the flow velocity. This relationship is demonstrated in Equation 1,

$$\tau = \mu \frac{du}{dy} \tag{1}$$

where τ is the stress in the fluid, μ is the viscosity of the fluid, and $\frac{du}{dy}$ is the strain rate [14]. Very few fluids possess this capability, however. The large majority of fluids are known as non-Newtonian fluids. These fluids have viscosities that change with the relative flow velocity [12]. Much of rheology is spent characterizing the behaviors of different non-Newtonian fluids by relating stresses with the strain rates [12].

Types of stress differ by the direction in which the force is exerted [13]. Shear stress occurs when a force is exerted parallel to the surface of a fluid, shown in Figure 3. Shear rheology characterizes fluids by exerting shear stresses and measuring the response of the fluid [12].

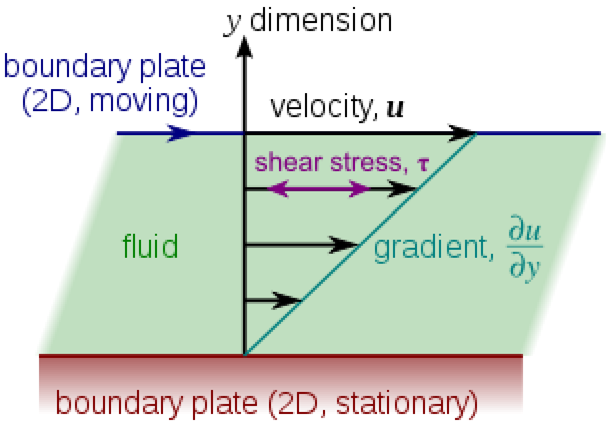


Figure 3. Laminar shear force exerted on a fluid between two plates. The force required to complete this action is a measure of the fluid's viscosity [15].

Strain is a mechanism to measure the amount of deformation in a given material [13]. However, strain can be difficult to quantify, depending on the specific qualities of the experiment and calculations required. Once the strain of a material is recorded over several stress values, the behavior of the material can be classified on a range from viscous to elastic. If the strain reaches a limit, the fluid is considered elastic; versus if the strain continues to increase in response to continuous stress, the fluid would be viscous [13]. In this context, elasticity is a material's ability to return to its initial shape after a force is exerted. The elastic modulus remains constant for an ideal elastic material, because all work done to the substance is stored inside the storage modulus and elastically recovered when the stress is removed [13]. In a viscous material, the ratio of stress to strain rate defines the viscosity. An ideal viscous material changes strain in proportion to the time the stress is applied, losing the applied energy as heat [13].

Although a few ideal elastic and viscous materials exist, most substances have qualities of both, and they are known as viscoelastic fluids. The storage modulus (*G'*) and loss modulus (*G''*) determine the presence of elastic and viscous qualities, respectively, and are dependent on strain rates and magnitudes [13]. Differentiating the two effects by performing oscillatory deformations at different frequencies in necessary to alter the time scales [13].

Interfacial Rheology

Interfacial rheology studies the chemical forces at the boundary of two different fluids [3]. Interfaces are unique in that they are mobile and deformable between two fluids, differing from the properties of the surrounding bulk fluids [17]. Complex fluid-fluid interfaces are common to biological systems, crude oil, food products, foams & emulsions, and more [17]. Complex interfaces happen when surface-active molecules gravitate toward the interfacial regions, rendering the interfaces nonlinear in their response to flow and deformation [16]. Most of these surface-active molecules are amphiphilic molecules, which means they consist of both hydrophilic and hydrophobic ends. Two types of fluid interfaces exist, depending on the amphiphile, also known as a surfactant. Soluble surfactants that produce Gibbs monolayers and insoluble surfactants that form what are known as Langmuir films [16].

When adding a soluble surfactant to a solvent, the surfactant molecules establish equilibrium by aligning themselves on the surface as well as in the bulk fluid. By measuring interfacial properties of the soluble surfactant, a relationship between bulk fluid concentration and surface concentration can be determined mathematically.

Insoluble surfactants, molecules holding more interest to our studies, cannot dissolve into the bulk phase because the hydrophobic portion of the molecules is so large. Phenomena caused by insoluble surfactants are extremely important for applications like creating the building blocks for cell membranes [17]. Insoluble surfactants create a Langmuir monolayer that is characterized by measuring surface tension, surface pressure, viscous forces, and the elastic surface modulus in terms of temperature or concentration [17]. These common rheological properties are typically measured using a Langmuir trough, which allows the variation of available area, A, and surface pressure, Π. Researchers usually determine the surface pressure as a function of area at a certain temperature to get a $\Pi - A$ isotherm [16]. In general, the surface pressure increases as the area decreases, but phase transitions can occur as molecules rearrange themselves with the decreasing space. The phase transitions along the $\Pi - A$ isotherm are demonstrated in Figure 4.

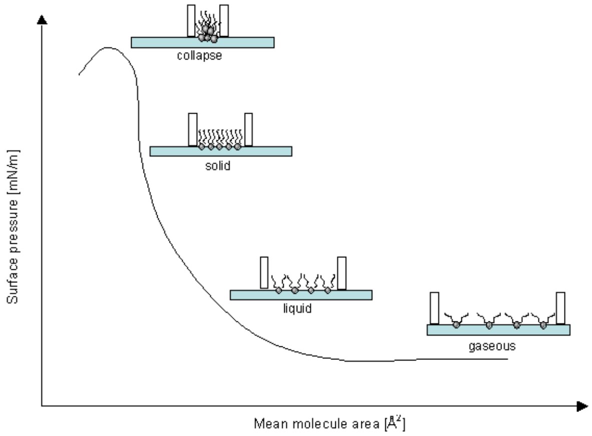


Figure 4. Typical Surface Pressure to Molecular Area Curve as Langmuir trough barriers are pressed towards each other, accompanied by the different phase transitions [19].

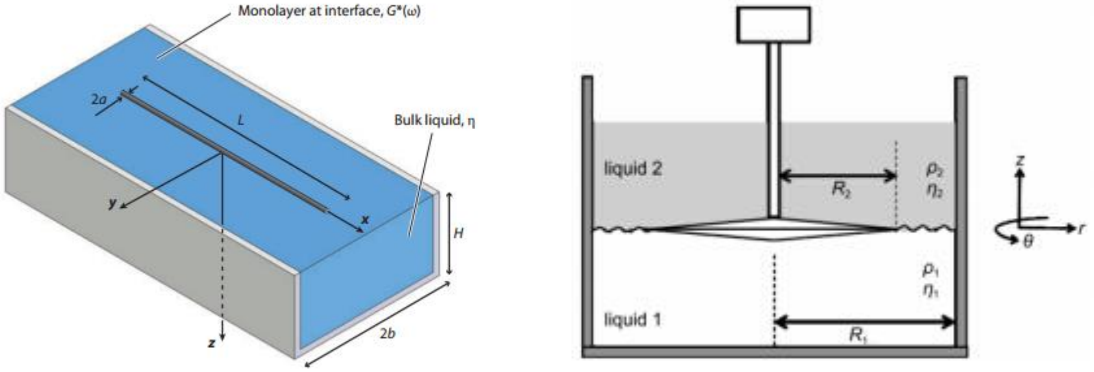
One of the major challenges in designing interfacial rheology equipment is dealing with the coupling between the interfacial and bulk fluid stresses [16]. The coupling of stresses complicates the research process because the bulk phases are going to respond with stresses along with the desired surface stress, making it difficult to differentiate between the two. The best practice of interfacial rheology is to operate in a condition where interfacial drag dominates the bulk drag [20]. Identifying a dominating interfacial condition can be done by referring to the Boussinesq number. The Boussinesq number (Bo) is a dimensionless number that measures the ratio of interfacial stress to bulk stress [20]. The Boussinesq number can be calculated from Equation 2,

$$Bo = \frac{\eta_s}{\eta L}, \tag{2}$$

where η_s is the surface shear viscosity, η is the average bulk viscosity, and L is the characteristic length scale, which is dependent on the dimensions of the measurement geometry [20]. When the Bo $\gg$ 1, the interfacial stresses dominate, and the surface rheological properties can be accurately calculated from the measurements. If the Bo $\leq$ 1, the bulk properties dominate the measured response [20]. A good design should minimize the characteristic length, or the ratio of the contact area between the geometry and the surrounding sub-phases to the contact perimeter between the surface probe and the interface [20].

Previous Technologies

Different technologies developed in the past have set the stage for the equipment used in interfacial rheology research today. Two common devices are a magnetic rod interfacial stress rheometer (ISR) and a bi-cone geometry attachment, pictured in Figure 5a and 5b, respectively. A magnetic rod ISR utilizes a magnetic field to force a magnetic rod to oscillate within a channel along the interface to induce shear flow [16]. A bi-cone geometry attaches to a rotational rheometer that exerts torsional oscillation around the Z-axis to induce shear flow at the interface [18].



(a) **(b)**

Figure 5. (a) A magnetic rod ISR consisting of a cylindrical rod at a liquid interface that fills a rectangular container [16]. (b) A bi-cone rheometer at a liquid interface that fills a cylindrical container [18].

Each technology has their strengths and drawbacks. The magnetic rod ISR facilitates measurements with minimal contact area, which leads to a low characteristic length and, therefore, a high Boussinesq number [20]. But, the ISR has a limited dynamic range for readings. On the other hand, the bi-cone geometry has a large dynamic range for measurements and sharp edges for pinning the interface surface. However, the high characteristic length and low Boussinesq number create limited sensitivity for the bi-cone geometry [20]. Because of the low Boussinesq number, more pronounced sub-phase flow effects are present on the interfacial deformation profile [20]. Both the ISR and bi-cone geometries have either been viewed as cumbersome to perform experiments with or require extensive mathematical corrections [20]. Moving forward to the presented design, acknowledging and learning from the past interfacial rheology devices was imperative to improve certain design features.

METHODOLOGY

Goals

The overarching aim of the thesis was to design a customized device to accurately and efficiently perform rheological characterizations under simultaneously controlled surface pressure into the equipment scheme at a reasonable price.

Methods

A literary review was integral in compiling the data necessary to design the ideal equipment piece. The modified double ring-wall Couette attached to the Langmuir trough presented by Vandebril et al. [20] proved most promising because the device features the large Bo number of the ISR, the larger dynamic range and sharp edges for pinning interfaces of the bi-cone geometry, and the capacity to perform experiments under controlled surface pressure and concentration variations [20].

An inventory audit and dimensional analysis was conducted on current lab equipment to identify possible configurations to support a single device at the same time because both major design components require ancillary equipment to function properly. The Langmuir trough in the lab is a medium standard KSV NIMA Langmuir trough. The complete trough setup and standard trough dimensions as pictured in Figure 6 [22].

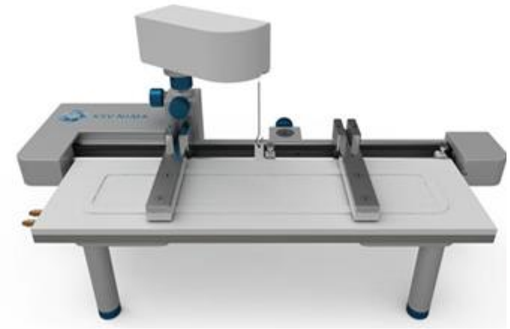


Figure 6. The Medium Standard KSV NIMA Langmuir trough setup with associated robotics. The trough is 364 mm long, 75 mm wide, and 4 mm deep [22].

The Langmuir trough setup comes with a motorized system for barrier compression that ranges in speeds from 0.1 to 270 mm/min, as well as an ultra-sensitive surface pressure sensor that can detect from 0 to 300 mN/m with 0.1-µN/m resolution [22].

The second design piece is the double wall Couette from Vandebril et al. [20], and it requires a sensitive rotational rheometer. The current rheometer is a Discovery Hybrid Rotational-3 (DHR-3) rheometer from TA instruments with oscillatory torque ranging from 0.5 nN/m to 200 mN/m, frequencies ranging from 10^{-7} to 100 Hz, and an additional surface pressure sensor [23]. Gaining familiarity with the DHR-3 dimensions and capabilities was necessary to determine the most optimal design configuration. The DHR-3 rheometer and setup with the double wall Couette is shown in Figure 7.

Figure 7. The DHR and zoomed in configuration with the double wall Couette [23].

The dimensions regarding the Langmuir trough and the double wall Couette were brought together and customized into a succinct final design that could fit on current lab instruments and be machined on a sole piece of Teflon (PTFE). The standard Langmuir trough dimensions, available on Biolin’s website, were a helpful starting point when designing this section of the device. The double wall Couette has specific dimensions regarding the interface, so the Couette dimensions were not altered.

Virgin PTFE was chosen for its high melting temperature and hydrophobicity that give it strength, chemical stability, and easy sanitation by bleach and autoclave capabilities [20].

The device went through several design iterations using SolidWorks software. Solidworks was used to accommodate the machinists who are most familiar with the program.

DESIGN

Overview

The complete design consists of the double wall Couette with the Langmuir-Pockels trough attached by a narrow channel. The SolidWorks design drawing is shown in Figure 8.

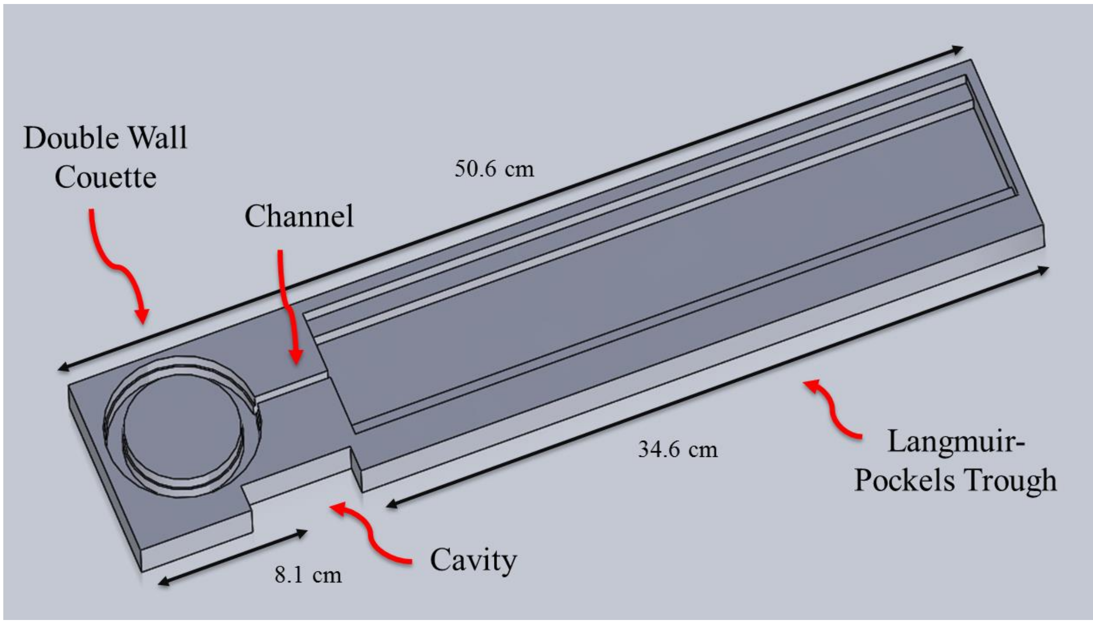


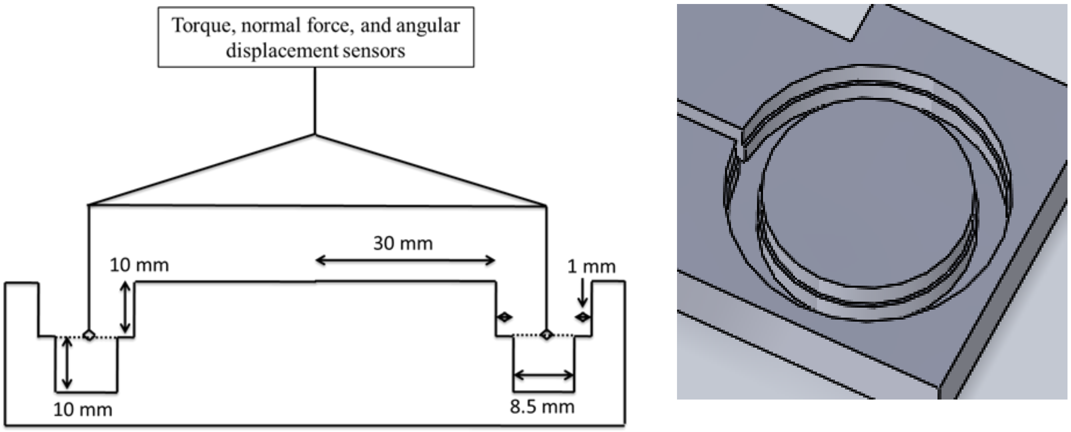
Figure 8. Langmuir-Pockels Trough with Double Wall Couette design drawing via SolidWorks software.

For experimental setup, fluid is placed in the device up to the stepwise edges, followed by surfactant. The platinum ring is positioned within the interface and the second fluid is added, if liquid. The Langmuir trough robot works by autonomously moving the barriers over the surface of the trough, shrinking the trough surface area. The ring in the Couette oscillates in a shear, two-dimensional manner to measure surface rheological properties like the dynamic viscosity and the surface viscous modulus by varying phase angle and angular frequency [20].

In the following sections, the design specification and reasoning of each portion of the device will be summarized.

Double Wall-Ring Couette

This double wall Couette was originally designed by Vandebril and his collegues [20]. The dimensions of the piece are displayed in Figure 9.



(b)

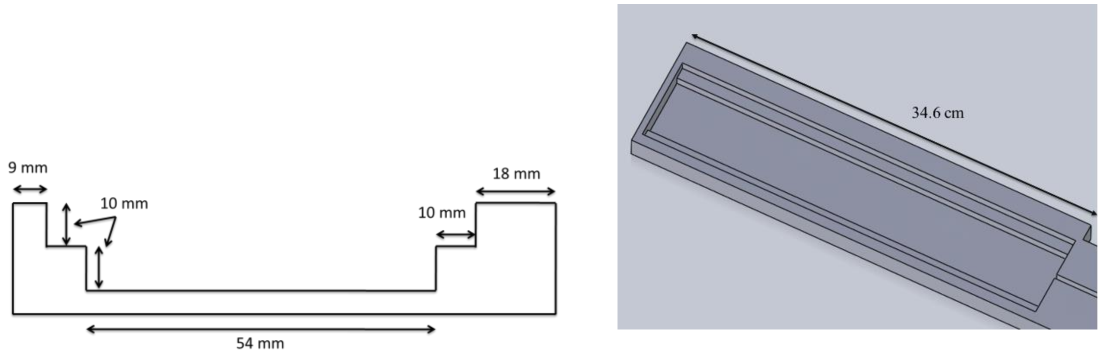
(a)

Figure 9. **(a)** Cross section of the double wall Couette setup. **(b)** Couette 3-D design drawing via SolidWorks software. [20]

When a sample is contained in the circular trough, the Du Nouy ring is positioned at the interface and connected to the DHR-3 rheometer. The interface should lie at the height of the stepwise edges to pin the interface and reduce meniscus effects where the fluid comes into contact with the sides [20]. The edges are 1-mm wide, the minimal distance for accurate manufacturing [20]. The inside circular trough has an 8.5-mm width, allowing for 3.5-mm inner and 4-mm outer gap widths, respectively. The chosen gap width values are greater than the 2.7-mm minimal air/water interface capillary length, and have proven optimal performance over a series of experiments [20]. The 1-mm wide angular ring geometry is preferred for its large contact area to interfacial perimeter, resulting in a high Boussinesq number for a given surface viscosity [20].

Langmuir-Pockels Trough

The trough was originally crafted by Pockels, and then made famous by Langmuir. The dimensions in the presented design were adapted from the medium standard Biolin Langmuir trough already in the laboratory [22]. The modified Langmuir trough dimensions are displayed in Figure 10.



(b)

(a)

Figure 10. (a) Width cross section of the modified Langmuir-Pockels trough. **(b)** Trough 3-D design drawing with a length of 364 mm via SolidWorks software [22].

All proposed dimensions match the commercial model except for the depth and outside horizontal ledges. The commercially available model is only 4 mm deep from the stepwise edge [22]. But, to accommodate the Couette depth, the trough needed to be altered to the same 10 mm depth. The depth adjustment does not change the amount of surface area present for experiments, just the liquid volume needed to match the interface to the stepwise edges. The trough has similar stepwise edges as the double wall Couette to pin the interface as well as to provide space for the barriers to slide along the length of the trough when taking measurements.

Channel

The 4-mm wide channel connects the double wall Couette and the Langmuir-Pockels trough together with the goal to provide enough space for timely interfacial equilibration, as the trough surface area decreases, while affecting data collection in the Couette as little as possible. The channel width was estimated geometry presented by Vandebril et al. [20] in Figure 11, which seemed to suggest a channel width proportional to half the Couette trough width [20]. The length of the channel is 40-mm long, to provide enough space for the Langmuir trough to sit on the ancillary equipment and still reach the rheometer sitting next to it.

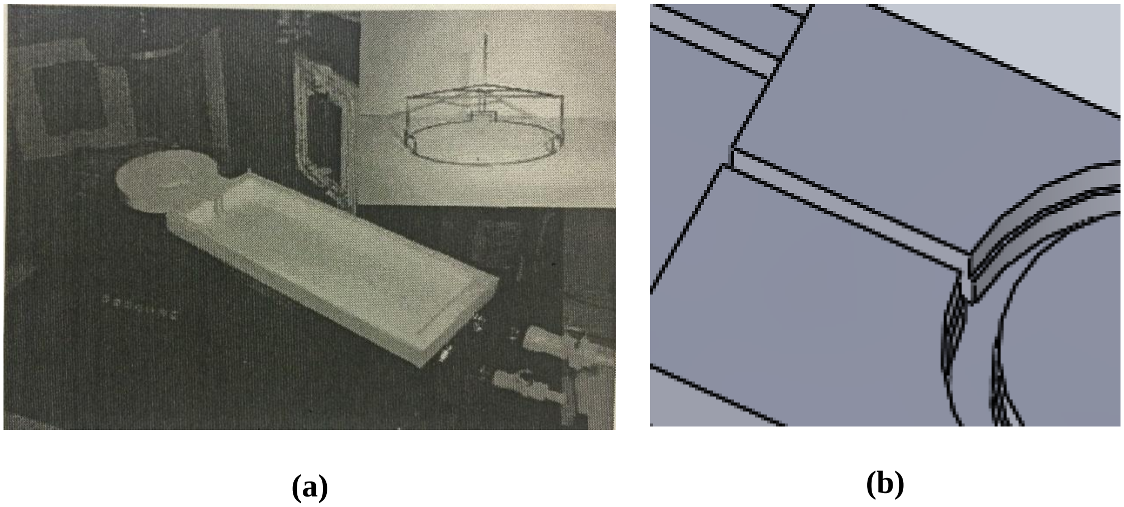

(a) **(b)**

Figure 11. (a) Vandebril et al. Teflon Langmuir trough attached to the DWR Couette [20]. **(b)** The channel 3-D design drawing with a length of 40 mm vis SolidWorks software.

Miscellaneous

The cavity on the side edge was created to make room for the ancillary equipment used to autonomously move the barriers on the Langmuir trough. The entire sketch was shifted toward the outer edge of the Teflon block to reduce the impedance of the trough robotics and maintain the ability to “lock-in” to the setup. Aligning the equipment in this manner requires a riser or shelf to lift the Langmuir trough from the lab surface, as well as an elongated Teflon beam to raise the Couette. The proposed experimental configuration is in Figure 12.

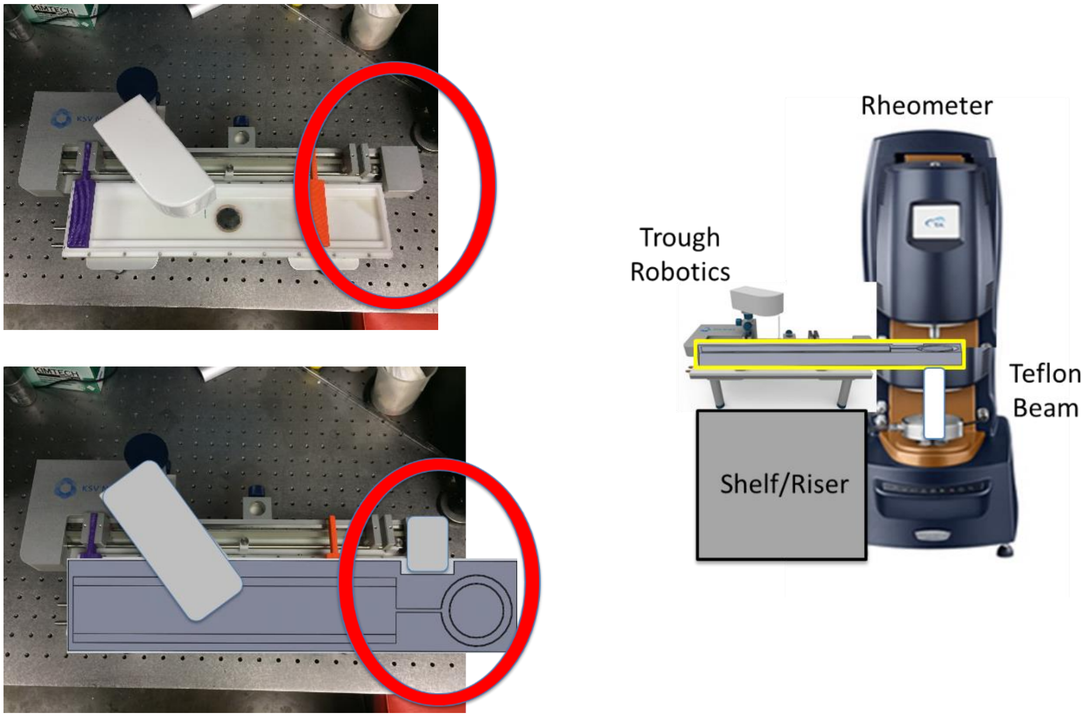


Figure 12. Left: Proposed top view of device on Langmuir trough robotics. **Right:** Proposed front view of device on the trough robotics and DHR rheometer, supported by a shelf/riser and Teflon beam, on the left and right, respectively.

FUTURE WORK

Manufacturing

A trial device is likely to be 3-D printed to confirm the design dimensions, before spending the money to have it machined immediately. Once the design has been verified, the piece will be sent offsite to be machined because of my lack of machining experience.

Testing

The device will be tested to confirm functionality and data accuracy for known Langmuir isotherms ranging from low-viscosity Newtonian oil films to viscous monolayers (e.g., PODMA) [20]. The lab will then have the ability to research the shear rheological properties of different insoluble surfactants, while controlling surface pressure.

Moving Toward Dilational Rheology

This thesis is the first stage in the device development. The proposed device was designed to allow for modifications to study compression and expansion properties, if the lab wants to move in that direction. The current design allows space for a gate to be added on, to completely close the channel gap for the capability of studying dilational rheology in the future.

CONCLUSION

Upon handing the thesis over to the Walker lab, I will have successfully designed and documented a functional Langmuir-Pockels double wall Couette and trough design to suit the lab’s needs. As a result of this project, I have gained valuable experience working in a previously unknown engineering subject, completing a device to meet research specifications. Finally, all these results were valuable for my future career and have given me additional experience to be successful in that endeavor. This project was very enjoyable for me, and I cannot wait to see how the device gets used in the future.

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