FINAL REPORT

Development of an Advanced Surface Tensiometer for Measuring Water Quality

May 2013

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Project Number: 2011HI320B

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Final Report (March 1, 2012 - February 28, 2013)

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1. Problem and Research Objectives

Characterizing the physical, chemical and biological properties of potable and recreational waters plays a vital role in assessing and controlling water quality. Direct measurements of water quality mainly rely on (1) Physical assessment, such as pH, temperature, turbidity, and total dissolved solids; (2) Chemical assessment, such as salinity, dissolved oxygen, biochemical oxygen demand; and (3) Biological assessment, such as presence and abundance of microorganisms and insects. Due to the high-cost associated with direct measurements of water quality, ongoing monitoring programs are typically conducted by government agencies. Hawaii has more than 400 public beaches stretching along nearly 300 miles of Pacific Ocean coastline. According to the 20th annual beachwater quality report released by the Natural Resources Defense Council (NRDC) on July 28, 2010, pollution continues to contaminate the water at America's beaches, causing 2,352 closing and advisory days in Hawaii last year and 18,682 nationwide. *Therefore, there is an urgent need, especially for Hawaii, to develop an inexpensive, easy-to-use, and highly sensitive technique for measuring water quality.*

Surface tension of water is a physical property highly sensitive to contamination. A trace amount of pollutants (e.g., organic chemicals and microorganisms) can adsorb to the air-water interface, thus decreasing surface tension of pure water. *Therefore, surface tension measurement can be used as a novel and sensitive physical method to detect water quality.* Dynamic surface tension measurement has long been recognized as a means of evaluating water quality.[1] The adhesion and growth of marine bacteria have been found to depend on surface tension, and therefore, potentially have a direct impact on development of some diseases.[2] Compared to other physical, chemical, and biological methods for assessing water quality, surface tension is relatively easy to measure and hence may be an useful control parameter for water quality and water-reuse systems.[2]

The **objective** of this proposed project is to develop an advanced surface tensiometer for measuring water quality. This method has the potential to be developed into a powerful screening tool for assessing water quality and other environmental impacts of water contaminants.

2. Methodology

The proposed surface tensiometer is developed based on the principle of drop shape analysis.[3] That is, in equilibrium, the shape of a drop or a bubble is determined by the balance between gravity, which tends to deform the drop (elongate a pendant drop or flatten a sessile drop), and surface tension force, which tends to hold the drop spherical. The force balance is determined by the Laplace equation of capillarity. If the shape of a drop or bubble is known (e.g., by photographing or videotaping), it is possible to determine surface tension by solving the Laplace equation. The drop shape analysis offers a number of advantages as it requires less liquid sample, is applicable to both air–liquid and liquid–liquid interfaces, and is versatile and applicable to various situations.

Specifically, the proposed surface tensiometer is called the constrained drop surfactometer (CDS). As shown in **Fig. 1**, the CDS uses a small sessile drop (~10-20 µL) to measure the surface tension of liquid sample. Any surface active pollutant, such as ocean surfactant, is expected to adsorb at the air-water of the sessile drop to decrease surface tension of pure water. The specific physicochemical properties of the pollutant can be further characterized by measuring its surface rheological properties, in which the adsorbed film will be compressed and expended by withdrawing liquid from and injecting liquid into the droplet using a motorized syringe. A key design of the CDS is a carefully machined drop holder which uses a sharp knife-edge to prevent the droplet from spreading even at very low surface tension (i.e., high surface pressure). In this case, the excess line energy of the sharp edge outweighs the weak surface tension in maintaining the integrity of the sessile drop. In addition, due to its compact design, the CDS allows accurate surface tension measurements with a controlled environment using a drop chamber.

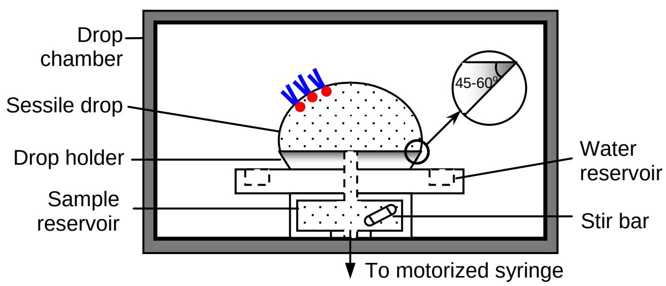

Figure 1. Schematic of the constrained drop surfactometer (CDS).

The surface tension of the liquid sample will be determined from the shape of the sessile drop using Axisymmetric Drop Shape Analysis (ADSA). ADSA is a patent-pending software package developed by the PI.[4, 5, 6] ADSA features an optimized computational algorithm and an automatic image analysis scheme, thus permitting real-time and dynamic surface tension measurements.[4] In addition to surface tension, ADSA simultaneously outputs surface area, drop volume, and curvature at the drop apex. All this information is valuable for characterizing properties of water samples. ADSA is superior to all existing commercial software packages in terms of rapid and highly accurate calculation, which is a key requirement for high-throughput screening. Meanwhile, ADSA features a user-friendly PC interface which allows surface tension measurement on one-click without the need of pre-training and knowledge of surface science. The applicability and accuracy of ADSA for measuring dynamic surface tension have been clearly demonstrated.[4, 5, 6]

3. Principal Findings and Significance

3.1. Prototype Development

During the past 12-month period, we have successfully developed the prototype of the CDS. As shown in **Fig. 2**, the prototypes consists of three primary modules: the optical module, the liquid handling module, and the environmental control module. The optical module, which consists of a high resolution CMOS camera and a high-performance LED backlight, was developed with a separate grant. The liquid handling and the environmental control modules were developed in this project.

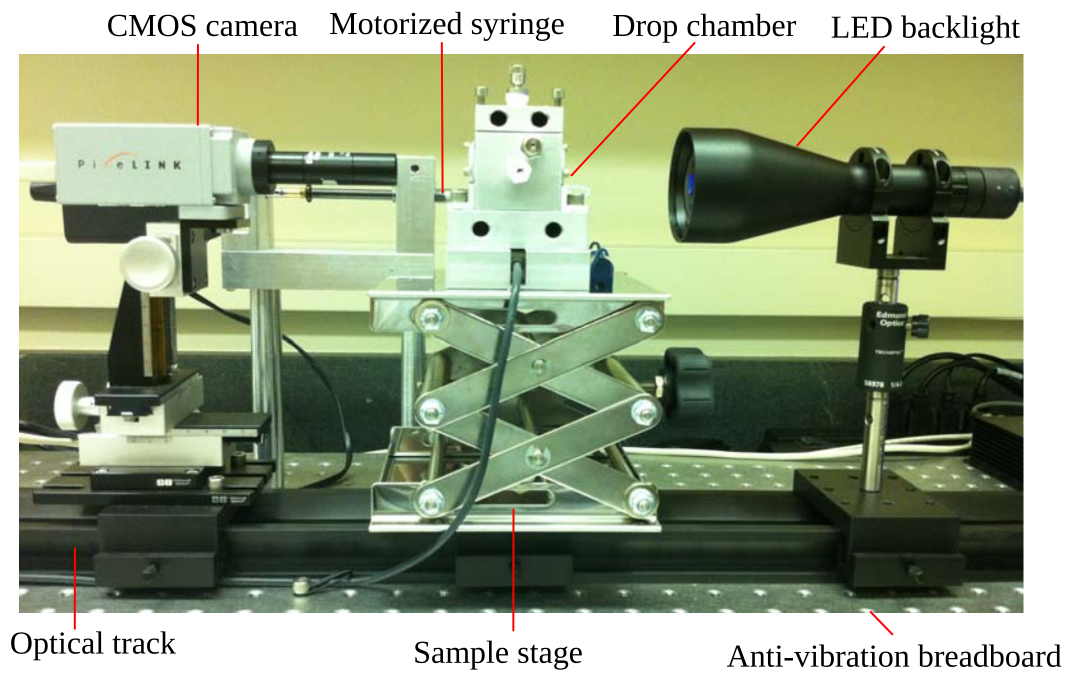

Figure 2. Prototype overview of the constrained drop surfactometer (CDS).

3.1.1. Liquid Handling Module

The liquid handling module was developed based on a motorized syringe. We have developed a LabVIEW program (**Fig. 3**) to precisely control movement of the motor, including the travel distance, rate, and fashion of movement (forward, backward, and cycling). This will allow us to automatically pump the liquid sample, form the droplet, and study the rheological properties of the liquid sample.

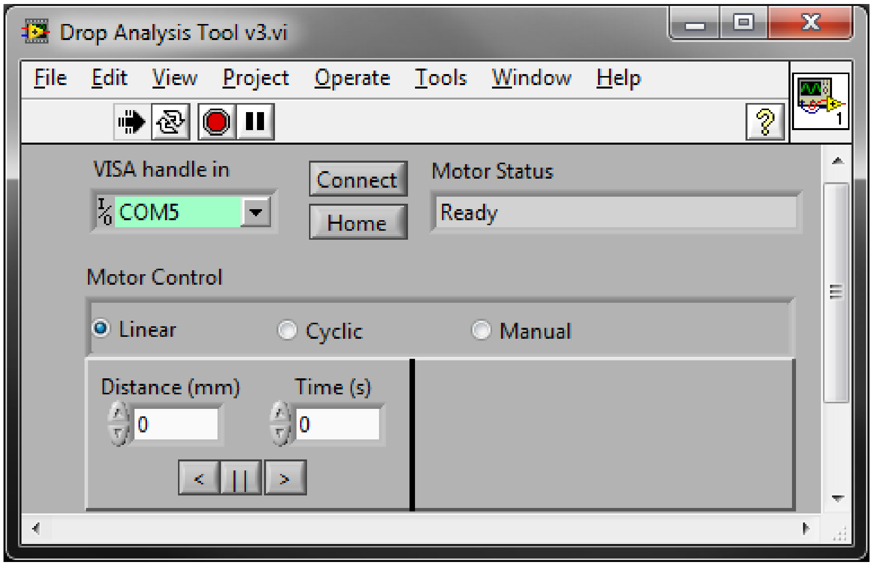

Figure 3. LabVIEW program to control the motorized syringe.

3.1.2. Environmental Control module

The environmental control module was developed based on a drop chamber (**Fig. 4**), designed and machined in the machine shop of the Department of Mechanical & Industrial Engineering at the University of Toronto. The temperature is controlled within ± 1 ^{o}C externally by a circulating water bath.

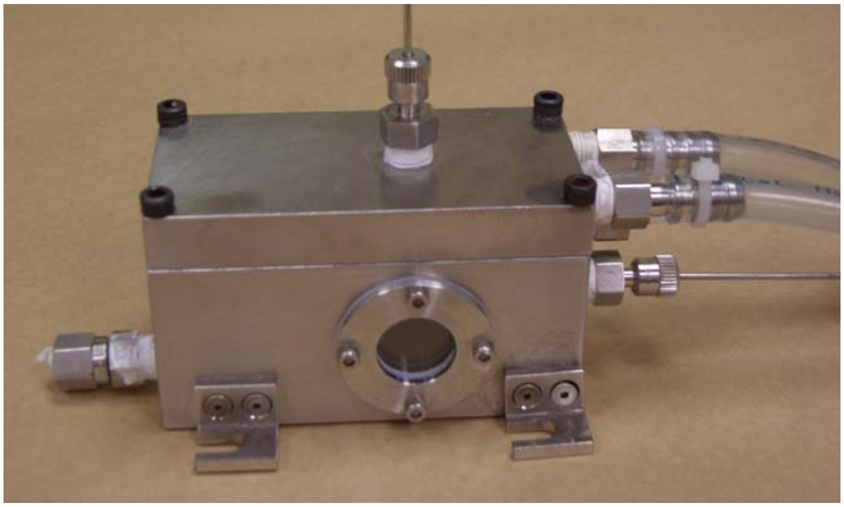

Figure 4. Drop chamber of the constrained drop surfactometer (CDS).

3.2. Test Results

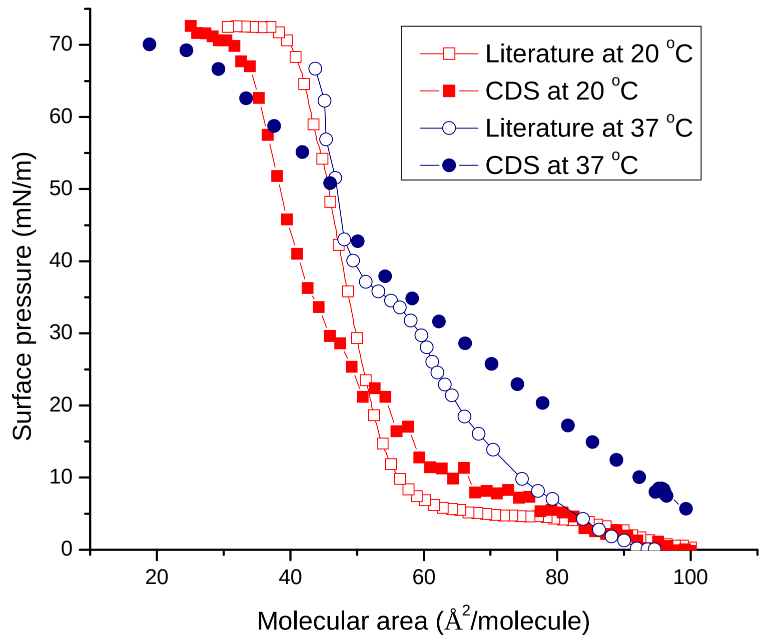

Figure 5. Comparison of DPPC isotherms at 20 °C and 37 °C obtained from the CDS to literature values obtained with established methods.

To test the CDS prototype, we have measured the surface pressure - surface area isotherms of dipalmitoyl phosphatidylcholine (DPPC) monolayers at the room and body temperatures. Surface pressure is define to be the difference between the surface tension of pure water (~72 mN/m at room temperature) and the surface tension of film-covered (i.e., contaminated) water surface. Therefore, increasing surface pressure corresponds to decreasing surface tension. To verify our measurements, we have compared the isotherms obtained from the CDS prototype to those obtained with established methods. The standard DPPC isotherm at room temperature (20 °C) was obtained by the classical Langmuir balance.[7, 8, 9] The DPPC isotherm at body temperature (37 °C) was produced by Crane and Hall using the captive bubble surfactometer (CBS).[10] As shown in **Fig. 5**, at both temperatures, our measurements show some agreement with the literature values produced with the established methods. We will further develop our technique to increase its accuracy.

4. Publications Cited in Synopsis

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