A TECHNIQUE TO MEASURE THE REAL SURFACE TENSION ON A BUBBLE WALL

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Abstract: *The surface tension of water is a key parameter for assessing the degree of contamination of harbours, ports and open waters. However standard methods of measuring surface tension do so at the flat air/water interface at the top of a body of water, whereas in for many important processes, this is not the manifestation of surface tension that is most important. For biogenic decomposition, air/sea gas exchange, the production of aerosols (all three of which are known to be important for climate on a global scale), as well as the behaviour of ship wakes and their effects (in distributing contaminants in the water column, affecting the local sound field or the ship's acoustic signature), and in the harvesting and transportation of petrochemicals, it is the surface tension on the wall of bubbles within the water column that matters. This paper explores a technique that can measure the surface tension on a bubble wall, and compares it with the surface tension measured at the air/water interface. Any difference would mean that modelling of the above effects, based on measurements of surface tension on the flat air/water interface, would contain systematic errors with global implications.*

Keywords: *bubble, surface tension, air/sea gas flux, pollution, wake*

1. INTRODUCTION

The question 'what is the surface tension on a bubble wall' is key to many environmental processes, including: the dynamics of bubble clouds under breaking waves and in ships wakes and their effect on sonar and air/sea gas transfer; and the formation of aerosols at the sea surface and their subsequent effect on climate; and the transport of pollutants.

However the actual meaning of the question 'what is the surface tension on a bubble wall' is less straightforward than might first be thought. There is a parameter (σ) that we call 'surface tension', that enters formulations the idealized physics of a range of processes. These include the balance of forces when a liquid film breaks, the formation of liquid droplets when such films break, the coalescence and fragmentation of liquid drops and or gas bubbles in liquids, the motion of capillary waves on a gas/liquid interface, and many more. They enter these formulations because the 'surface tension' can be incorporated into the idealized physical model of the process through its twin abilities to equal the energy required to form a unit surface area of new interface, and to equal the force per unit length perpendicular to an imaginary line drawn in a flat interface. However these simple equalities leave out a wealth of detail that escapes the current physical models of these process, the most obvious being whether the process is done in static conditions (i.e. so slowly as to an equilibrium state to be established in the surface), or in dynamic conditions (i.e. so rapidly as to prevent equilibrium conditions from being established).

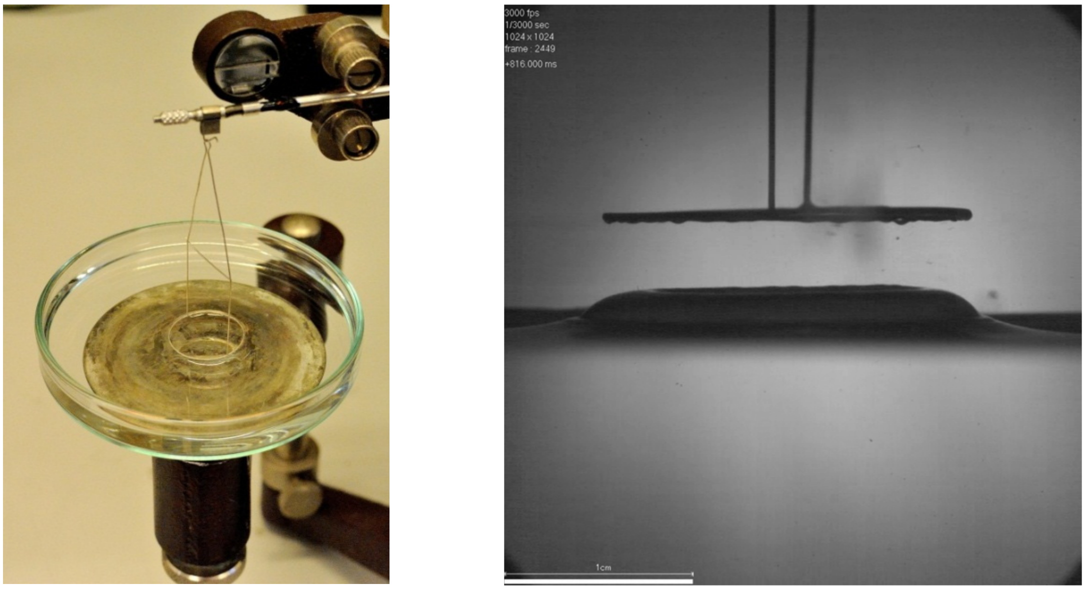
This difference means that a measurement of the 'value of the surface tension' undertaken by one accepted technique, may not be transferrable to another process. The implication is that textbook values of surface tension, or values of the surface tension of a particular water sample measured using accepted techniques in the field or the laboratory, may not be accurate to extrapolate to predict how that same water sample will behave when it participates in environmentally- and climatically-important processes.

This paper will report on the preliminary measurements made to explore these issues by comparison of single 'look-see' measurements (repetitions and statistical analysis will be made when enough data have been compiled) of the value of surface tension on a bubble wall using the threshold for the formation of Faraday waves, and measurement of the value of surface tension in the same liquid sample using a standard method.

2. BACKGROUND

The well-known du Noüy ring tension meter method is used in this paper to obtain values of surface tension that an accepted example laboratory method would produce. A ring is immersed in the liquid [Fig. 1(a)], and then the vertical separation between the ring and the liquid is increased, and the force on the ring measured, until the ring separates from the liquid [Fig. 1(b)]. The vertical separation is increased sufficiently slowly that equilibrium conditions exist on the surface.

To compare with this, we obtain an estimate of the surface tension that pertains to the threshold for the excitation of Faraday waves on the bubble wall [1, 2]. Once the acceleration of a pulsating bubble exceeds a threshold value (which usually means that the amplitude or frequency of the sound field driving the bubble to pulsate has passed some critical value [3]), after a short transient period [4, 5] that then leads to a steady-state pattern being formed on the bubbles wall [6, 7], a perturbation is superimposed on the bubble wall motion which corresponds to that spherical harmonic which (i) had non-zero order and (ii) has a natural frequency that is closest to half of the driving frequency. This is called the Faraday wave, first characterised by Faraday for flat air/liquid interfaces [8-10] and since studied on liquid drops [11]. If, say, the amplitude of the driving sound field continues to increase, additional spherical harmonic perturbations will be excited, and superimposed on the bubble wall motion [12].



(a) *(b)*

Fig. 1: (a): Photograph of the well-known du Noüy ring tension meter method used for comparisons in this paper. (b): Frame showing the moment as the liquid film breaks away from the ring of the du Noüy ring tension meter (the white line at the bottom left of the frame is a 1 cm long scale bar).

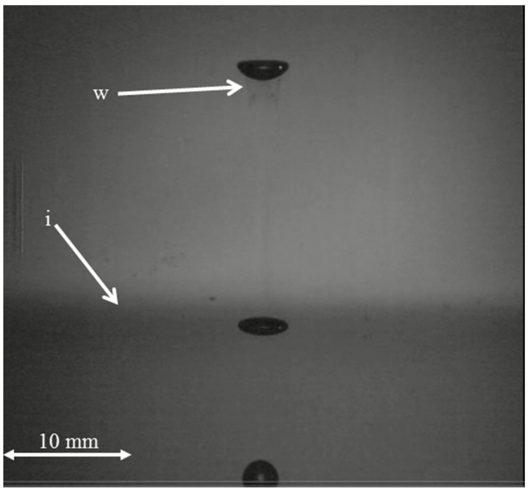


Fig. 2: A series of air bubbles rise through a layer of salt water, 5% (w/v), coloured by food dye, to then rise through the interface (labelled 'i') into an upper layer of pure water. The wake (labelled 'w') is visible because the upper bubble has carried with it material from the coloured salt water layer.

The generation of a Faraday wave can be detected by electrochemical techniques [13-15], and by acoustical [16-24] and optical imaging [25], and it was proposed that these measurement points could be inverted to infer the value of surface tension, as it pertains to the threshold for Faraday waves. The environment around a bubble wall is known to be dynamic. Bubble growth, through coalescence, or fragmentation/dissolution mechanisms, which reduce the bubble size, are likely. In addition the exact conditions at an individual bubble wall may differ significantly to those at the gas/liquid interface of the bulk fluid which is determined by the du Noüy ring tension meter. Hence the ability to determine the surface tension on a bubble within the bulk of the fluid is highly advantageous particularly because a bubble can collect surface active agents (and indeed particulate matter) on its wall as it moves through a liquid (Fig. 2).

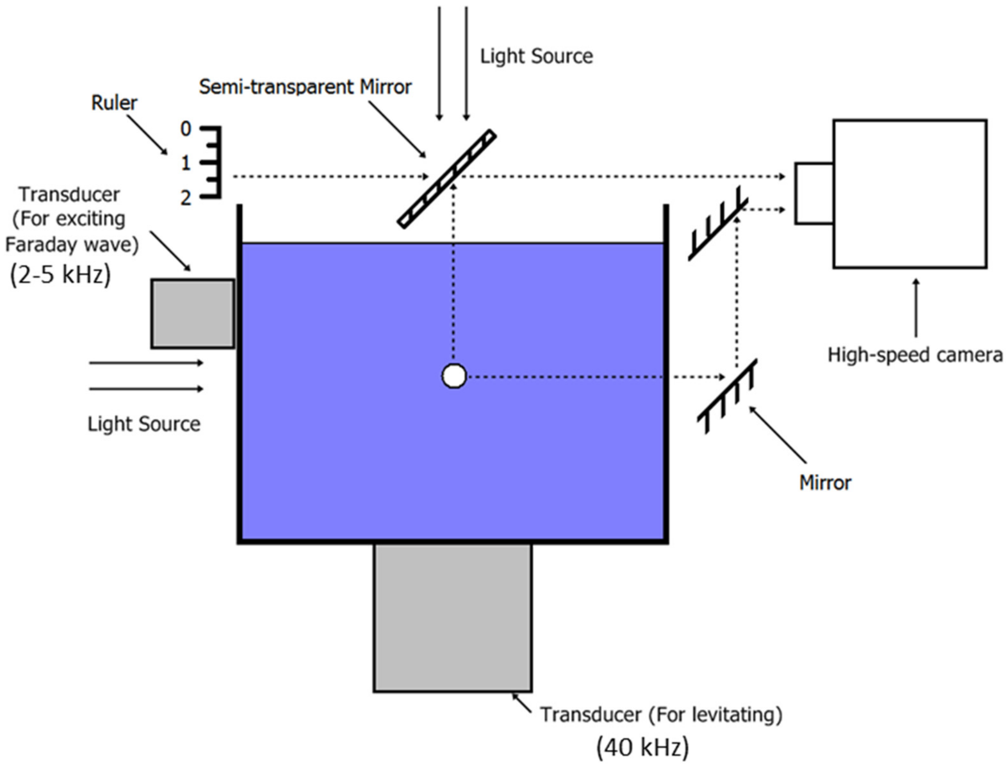


Fig. 3: The apparatus used for measuring the Faraday wave threshold.

3. EXPERIMENTAL PROCEDURES

The apparatus shown in Fig. 3 uses a 40 kHz sound field. It is assumed for the moment that this levitating field is sufficiently far from the bubble resonance that it does not contribute to the acceleration of the bubble wall sufficiently to affect the threshold for Faraday waves. Unless resources are available to conduct these experiments in a microgravity environment [26-28], the bubble must be held at the focus (and in the field of view) of the camera, and the levitation method [29-35] is less invasive than tethering under glass bodies, or with hoops of fine wire to thread [36, 37].

The use of mirrors ensures that the bubble is properly illuminated and that images of it from top and side are simultaneously in focus in each frame of a high speed camera (as is the ruler). The experiments must be done quickly to avoid rectified diffusion, and so a preprogrammed increments of increasing drive field amplitude are run until the faraday wave is detected, and then the frequency is increased and the process repeated.

A monolayer of decane ($CH_3(CH_2)_8CH_3$) was placed on the surface of the previously fresh, purified water, and the value of the surface tension was measured in three ways: (i) using the du Noüy ring tensiometer meter; (ii) using the Faraday wave technique on a bubble injected into the body of the water; and (iii) using the Faraday wave technique on a bubble entrained into the body of the water through the upper liquid/air interface (and the decane monolayer) by a water droplet impacting the water body from above.

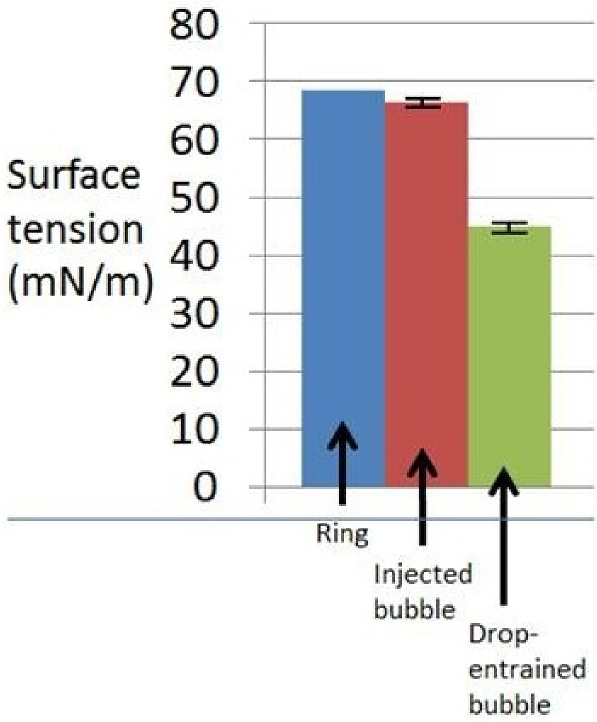


Fig. 4: The results of measuring the value of the surface tension using the du Noüy ring tension meter (blue column); and using the Faraday wave technique on a bubble injected into the body of the water (red column) and a bubble entrained through the decane layer by a water droplet. These represent the preliminary findings from a single experiment and have yet to be repeated. The error bars reflect the estimated limits of precision of the measurement technique. As such these can only be treated as preliminary 'look-see' data.

4. RESULTS

According to the preliminary data of Fig. 4, the ring method sees barely any reduction in the surface tension (from the ideal value for a pure air water interface of 72.8 mN/m at 20ºC) resulting from the presence of the decane monolayer. The injected bubble appears to be best described by a marginally lower surface tension, though more data are required. The bubble entrained by a drop through the decane layer has a significantly lower surface tension.

5. DISCUSSION AND CONCLUSIONS

The du Noüy ring technique appears not to be affected by the presence of a monolayer of decane on the water interface(see Fig. 4).. The surface tension measured is slightly higher than that measured using Faraday waves on the injected bubble, which could be said to be 'clean' as the injection apparatus was immersed prior to the addition of the decane. However, the entrained bubble using the drop method is significantly altered compared to the bubble injected into the bulk liquid. This implies that a proportion of the entrained bubble has been loaded with decance which reduces the surface tension that best describes Faraday wave motion in that case.

6. CONCLUSIONS

If a value of surface tension is to be used in a model to predict, say, the formation of bubble clouds or the injection of aerosol droplets into the atmosphere, and used as input to predict the contribution these processes have to weather or climate, it is important that the value of the surface tension that is used is critically assessed to ensure that it is derived from a measurement process in which the same properties of surface tension are characterised, as are relevant to the physical mechanisms in play at sea. This extends to measurement of 'surface tension' for biomedical contrast agents, food and pharmaceutical manufacturing etc.

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