

NOTE

MEASUREMENT OF SURFACE TENSION BY THE FORMING BUBBLE METHOD

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(Received 5 September 1989 • accepted 18 January 1990)

Abstract—The present work proposed a modified technique of the forming bubble method for measuring surface tension, and compared surface tension data by this method with other reported data. This method shows an applicability to the study of surface aging effect in a surfactant system.

INTRODUCTION

A number of methods for measuring surface tension of liquids or solutions have been utilized, such as capillary pull methods, capillary rise method, drop weight method, maximum bubble pressure method, and ripple method [1]. Each of these methods has merits but its own drawbacks, so there is need for more simple and reliable method of measuring surface tension. In a recent paper, Rao and Baird [2] measured the surface tensions of various liquids continuously so that the slug of air is held stationary in a vertical tube by controlling the liquid flow, but this method gave a higher value than that founded on equilibrium techniques, so the method is not recommended for surfactant solutions. Ohsawa and Ozaki [3] reported on adaptability of bubble forming method for measuring surface tension of liquid or solution. The usefulness of the bubble forming method for measuring surface tension has been already reported in the literature [4]. This method enabled us to measure the surface tension of a fresh surface of a liquid or solution rapidly and precisely. Thus one can eliminate the serious problem of the formation of a film-like surface layer by the rapid drying of the surface of solution. The present work proposed a modified technique of the bubble forming method for measuring surface tension, and compared surface tension data by this method with other reported data.

BASIC PRINCIPLE

Many models were proposed to describe bubble formation in liquids, and all were based on some forms of force balance for predicting stages of bubble growth period [4,5]. At very low flow rates the bubble is formed uniformly and attached to the orifice at the end of the capillary. Orifice submergence does not influence the bubble volume at the tip as far as the depth is larger than approximately twice of the bubble diameter [4]. At the extremely small flow rates (less than $0.1 \times 10^{-6} \text{ m}^3/\text{sec}$), the effect of viscosity is presumably negligible, and the upward force due to the buoyancy of bubble volume is balanced by the downward force of surface tension, which is widely known as "Tate's law" [6,7]. The volume of a single bubble can be calculated by dividing gas flow rate by the frequency of bubble formation with the assumption of bubbles formed in the same size. Therefore, the surface tension can be determined by measuring the period of bubble formation at a constant flow rate and the following relationship.

$$\sigma = \frac{T_{\text{gq}} \Delta p}{d_o \pi} \quad (1)$$

EXPERIMENTAL

The experimental apparatus used in this work was slightly modified in gas feeding and data analysing system from those described previously [3,8,9]. Therefore, it gave an advantages of uniform and wider range

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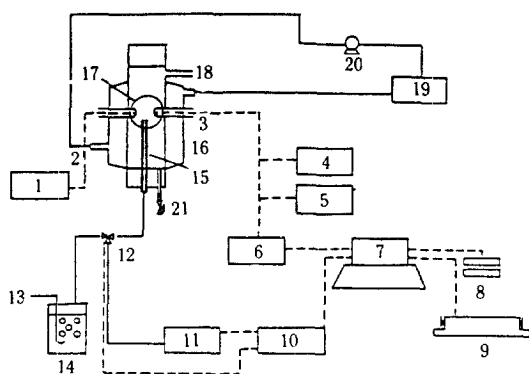


Fig. 1. Experimental setup for surface tension measurement of liquid.

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|-------------------------|-------------------|
| 1. Light source | 2. Optical fiber |
| 3. Sensor | 4. Recorder |
| 5. Oscilloscope | 6. A/D Converter |
| 7. Microprocessor | 8. Disk Drive |
| 9. Printer | 10. Motor driver |
| 11. Syringe pump | 12. 3 Way valve |
| 13. Air | 14. Pre-saturator |
| 15. Orifice | 16. Bubbler |
| 17. Sight glass | 18. Purge |
| 19. Constant water bath | 20. Pump |
| 21. Drain | |

of bubble formation rate with stepping motor control, and enabled one to measure an elapsed time between bubble growth and detachment as shown in Fig. 1. The air was fed to syringe pump after pre-saturated with distilled water and filtered. The flow rate of air to nozzles was controlled by a gas tight syringe pump, which was manipulated by microprocessor. Since the syringe (Hamilton #1010) barrel had a constant cross section, a constant linear velocity of the plunger corresponded to a uniform volumetric flow rate with a reliable accuracy. Various sizes of orifices (0.35, 0.5 and 1.3 mm ID, glass capillary) were used for bubbler, and the effect of temperature fluctuation on the surface tension was eliminated by a thermostatic water jacket controlled within $20 \pm 1^\circ\text{C}$. The capillary tips were located about 50 mm beneath the surface of the liquid. In order to maintain accurate pressure drop for slow bubble forming at the end of the tip, the volume of air in the supply system to the capillary was reduced by connecting to the syringe with silicon tubing of 0.03 m length and 0.8 mm ID. In order to find an elapsed time between bubble growth and detachment, light from a 60W tungsten halogen lamp was guided by an optical fiber, and it was passed just above the orifice tip and through the column onto a photo-darlington (PT-IMLA, Kodenishi Corp.), which was connected to a DC power supply. The light intensity varied with the

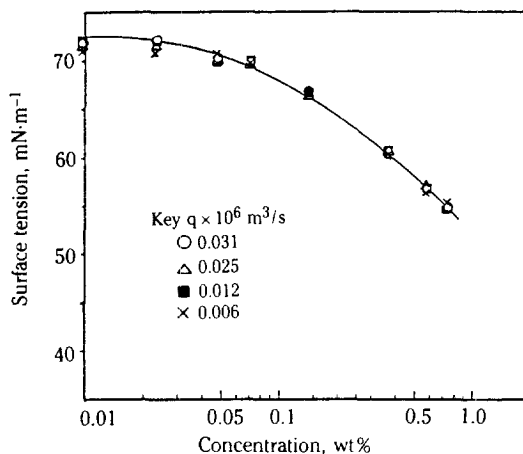


Fig. 2. Surface tensions of n-butyl alcohol solutions.

bubble formation and was converted to voltage signal. After the bubbling frequency is reached to steady state, the analog signal from the photo-darlington was sent to high-speed A/D converter for digitizing and finally to a microprocessor for storage and data analysis. The mean period of bubble formation was evaluated from the stored data of about 800 samples for each operation. The measurement procedure at each concentration was carried out within 1 hour.

RESULTS AND DISCUSSION

The surface tension of distilled water, whose conductivity was always lower than 10^{-4} S/m, was measured using various sizes of orifice. In case of 0.35 mm and 0.5 mm ID orifice, measured values were nearly about the same as those in literature [10] without regard to bubbling rate in the feed range of this experiment ($0.12 \times 10^{-6} - 0.006 \times 10^{-6} \text{ m}^3/\text{sec}$). But the value with 1.3 mm ID orifice was a slightly lower (about 3%) than that in the literature [10]. This means that larger orifice than 1 mm ID produces smaller size of bubble than predicted by Tate's law. It can be explained that the system with larger tip does not give sufficiently high flow resistance to satisfy constant flow condition, although the largest tip used in this work was only 1.3 mm ID. Ohsawa and Ozaki [3] also reported that the bubble diameter can be treated as statistically uniform when the nozzle diameter is 0.1 cm or less.

In aqueous solutions of lower alcohols (up to n-hexanol), adsorption equilibrium is established within a few msec [11], therefore the effect of the dynamic surface tension on the bubble growth would be small and could be ignored. This view was supported by the

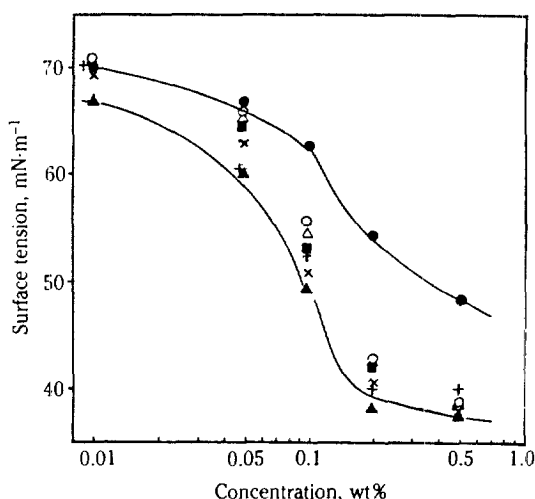


Fig. 3. Comparison of surface tensions of aqueous sodium lauryl sulfate solutions with other data.

- Continuous apparatus: Rao & Baird (1983)
- ▲— Tapered tube apparatus: Rao & Baird (1983)
- △ × This work (symbols are same as in Fig. 2)
- + Ring method: Vijayan et al. (1980)

values of surface tension at various gas feed rates, which were as shown in Fig. 2.

The surface tensions of sodium lauryl sulfate (SLS) solutions in this work were measured by controlling the gas flow rates, and compared with other data [2,12] as shown in Fig. 3. In tapered tube method [2], the equilibrium meniscus position after several hours was measured, so static (equilibrium) surface tension can be determined. But the data by continuous apparatus [2] are higher than values found by static technique because of the surface tension gradient methods. Strongly surface active material such as SLS requires a finite time to reach surface equilibrium, and Owens [13] found that the time was in order of 10-100 msec with increasing as the concentration of SLS was reduced. Therefore the surface tension of surfactant solution could be measured if the concentration was enough to give rapid orientation. For low concentrations less than 0.1 wt% SLS, longer orientation times are required, which shows the surface aging and relaxation effect of surfactant. Static surface tension cannot be determined except at low bubbling frequencies. This method is called a quasi-dynamic method in

which freshly formed liquid-air interfaces are involved. And as Tate's law is good for static, the bubble forming frequency should be maintained in order to hold the quasi-static balance assumption in deriving Eq. (1). One can measure the elapsed time for a bubble formation in this system. Therefore, the surface aging effect in a surfactant system will be able to be studied for various bubble forming frequencies.

NOMENCLATURE

- d_o : orifice diameter [m]
- g : gravitational acceleration [m sec^{-2}]
- q : gas flow rate [$\text{m}^3 \text{sec}^{-1}$]
- T : period of bubble formation [sec]
- $\Delta\rho$: density difference between the gas and the liquid [kg m^{-3}]
- σ : surface tension [Nm^{-1}]

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