Measurement of the Charge on Small Gas Bubble

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It is of importance to measure the electromobility of a gas bubble in flotation studies because the rate of flotation deeply depends on the electromobility or the zeta-potential of particle and bubble.

When one would intend to determine the zeta-potential, one has to pay attention to those as follows:

1. The electroosmotic flow of the solution in the closed system
2. The vertical movement of bubble due to buoyancy force so that bubble travels not only horizontally due to the electric potential between electrodes but vertically during the measurement.

Collins et al. (1978) modified the vertical microelectrophoresis cell by drilling the small holes (about 0.5 mm) at shorter side walls and measured the zeta-potential of generated small gas bubble by electrolysis which was kept to the stationary level to compensate the electroosmotic streaming. Their method has solved the problems noted above beautifully but is not handy because the operation to chase the bubble to be measured within the field of view of a microscope by eyes is troublesome.

Moreover, since the ratio of the width to the depth, k, of their cell with internal dimensions of 1 × 10 × 40 mm was 10, the effect of the shorter side walls is not negligible according to the calculation of Mori et al. (1980).

Also, 10 separate bubbles measured at one side of stationary level are not sufficient because the velocity distribution in the cell is plausibly asymmetric with respect to the center line of the cell.

Although larger bubble of about 75 μm in dia. is possibly generated in the low concentration of sodium sulfate according to their method, the upper limit of the diameter of the bubble which could be pursued by a microscope in their work was about 35 μm and so they could not measure the potential of the bubble generated at the concentration of Na_2SO_4 lower than 5×10^{-4}M.

Then, we have improved these points to measure the electromobility of bubble by using a monitor T.V., T.V. camera, Video Tape Recorder, etc. and have made the operation easier. Our method has also made it possible to determine the zeta-potential of bubble in wide range of the bubble size compared with the one of Collins et al.

EXPERIMENTAL METHOD

The schematic diagram of the experimental setup is depicted in Figure 1. A micro-electrophoresis apparatus (Mitamura Riken Kogyo, Tokyo, Japan) was modified by using an order-made quartz cell of rectangular cross section with internal dimensions of 1.1 × 23 × 73 mm shown in Figure 2 mounted horizontally with its broadest side vertical. Small holes of about 0.5 mm in dia. were drilled in the shorter side walls of the quartz cell and two thin platinum wires were sealed in them with an epoxy resin (Rapid Araldite, Ciba-Geigy, Switzerland).

To minimize heating of the cell contents or to avoid thermal convection problems, a transparent vessel filled with solution of copper sulfate was laid between a source of light and the reflecting mirror of a microscope.

The other details of the method are similar to those of the method of Collins et al.

A flotation solution to be tested was poured into the cell, while a microscope was focussed on the stationary level in the cell. The flotation solution under test contained the cetyltrimethylammonium bromide(CTAB), in concentration 5×10^{-5} M, and ethanol as a frother at 0.5% (v/v) as in the work of Collins et al. An oxygen bubble was liberated and rose under gravity by a short controlled burst of current at 12 V via the platinum wires. The bottom wire was connected to earth to avoid the bubble to be charged by the circuit. The operator kept the bubble in the center part of the screen of a monitor T.V., turning the microscope screw by a hand, and recorded the figure of the clearly focussed rising bubble on V.T.R. After recording, the videotape was slowly rerecorded on a monitor television. The horizontal distance and the time were measured required for the bubble to rise between the lines on the stationary level 1.5 mm above and below the center of the cell. Since the magnification depends on the curvature of the T.V. screen, the magnification for each division (20 × 20 mm) of the center screen was examined with standard scale. The magnification was about 1,000.

The electromobility was measured in such a way as:

a. Changing the polarity by normal and reverse switch
b. For two different kinds of currents
c. At two stationary levels

At least 10 separate bubbles were pursued for each case. Therefore, the zeta-potential of at least 80 separate bubbles was determined for the each concentration of Na_2SO_4.

The position of stationary level is given by Komagata (1933) as follows:

$$y_S = \pm b\sqrt{\frac{1}{3}\left(1 + \frac{384}{\pi^5 k}\right)} \tag{1}$$

where coordinates are taken as shown in Figure 3, the longer and shorter sides of the cell are 2a and 2b respectively, and k is equal to a/b.

Equation 1 has been derived under the following assumptions:

1. a is much greater than b, that is to say, k is much greater than 1.0.
2. The distance between the electrodes is so long that the various effects produced near the electrodes may be neglected. Namely, the problem can be treated as that of two-dimension.
3. The electroosmotic velocity on the surface of the longer side wall and that on the surface of the shorter side wall are constant.
4. The solution under consideration is incompressible and viscous, so that the stream is laminar.

RESULT AND DISCUSSION

The following Helmholtz-Smoluchowski's formula (1905) is used to calculate the zeta-potential.

$$\zeta = \frac{4\pi\mu}{\epsilon} \cdot V \cdot \frac{S}{i} \cdot \frac{1}{R} \times 9.0 \times 10^{10} \tag{2}$$

where ζ is the zeta-potential (mV); μ is the coefficient of viscosity of liquid (poise); ϵ is the dielectric constant (−); v is the horizontal velocity of bubble (cm/s); S is the cross sectional area of the cell (cm^2); i is the current (mA); and R is the specific resistance (Ω cm) measured with a conduct meter (Model CM-1F, TDA Co., Japan).

When the solution is water at 25°C, Eq. 2 is rewritten as follows:

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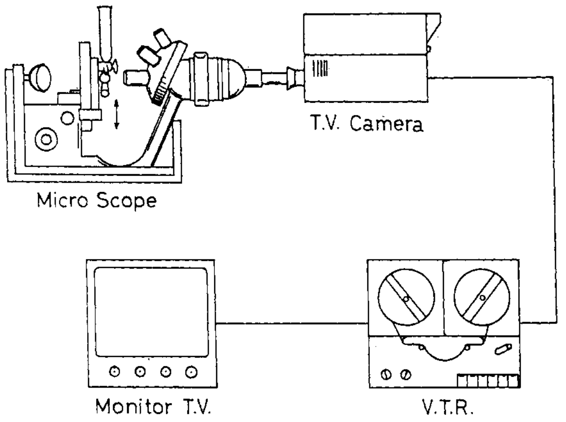

Figure 1. Schematic diagram of experimental setup.

$$\zeta = 12.82\ U_E \tag{3}$$

where U_E is mobility (μm/s/mV/cm).

The experimental results of the zeta-potentials of bubble for the various concentrations of sodium sulfate are given in Figure 4 along with the results of Collins et al. Our results plotted in Figure 4 are the average values of at least 80 measured values as noted above. The average diameter of bubbles measured in our work was about 40 μm, while that was about 35 μm in the work of Collins et al.

The depth of viewfield of the microscope used in our work with ×20 objective lenz and ×20 eyepiece (Olympass Kogaku Co., Japan) was found to be about 4.4 μm by calculation. The bubble to be measured has also actual size. Therefore, the plane, in which the center of the bubble passed, did not exactly coincide with the stationary level, even when the figure of bubble was clearly observed on the T.V. screen. Moreover, the experimental errors inherent in any electromobility determination were included so that the considerable spread of our experimental values with the typical standard deviation which was 20% of the mean of individual mobilities is rather natural. Incidentally, this deviation was 10% of the mean value in the work of Collins et al., which seems too good considering their troublesome operation and the number of bubbles to be measured to determine the each electromobility.

Mori et al. have reported that when k of the cell is smaller than 20, the effect of shorter side walls is not negligible by their analysis of electrophoretic velocity in the rectangular cell. Collins et al. estimated the systematic error to be within 8% in their case that $k = 10$. This effect in our work was negligible since $k = 20.9$.

Also, Mori et al. pointed out that the observed velocities at both sides of stationary level are quite different due to the asymmetry of electroosmotic stream with respect to the center line of the cell. However, the conventional Komagata's method which we followed such that the average of the experimental values at both sides of stationary level is considered as the electromobility is acceptable. Collins et al. seems to have measured the electromobility only at one side of stationary level.

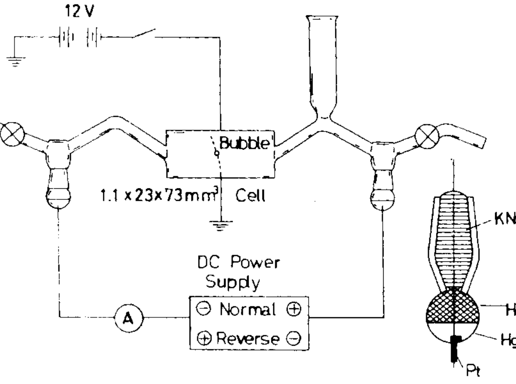

Figure 2. Schematic diagram of a micro-electrophoresis cell and an electrode.

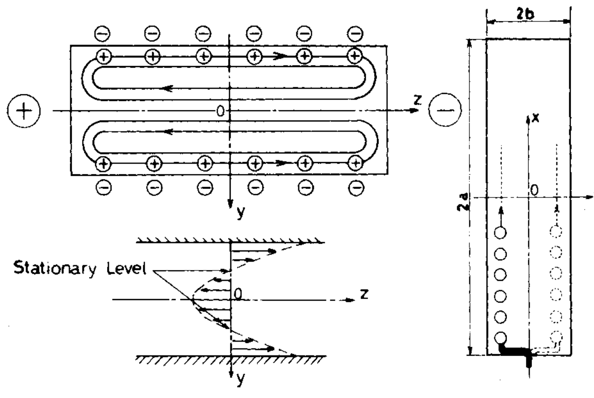

Figure 3. Coordinates of a micro-electrophoresis.

Our method could widen the range of bubble size to be measurable up to about 75 μm in dia. which was possibly generated at the concentration of Na_2SO_4 10^{-4}M. The larger bubble than about 35 μm rose too quickly to follow by their method.

It is of interest to get the experimental equation for the best curve for the measured values.

$$\zeta = \sqrt{1{,}000\ ln\left(\frac{1}{C}\right) - 1{,}753} \tag{4}$$

where C is the concentration of Na_2SO_4 in the range between 10^{-4}M and 0.2M with 5×10^{-5}M of CTAB and 0.5% (v/v) of ethanol.

Our results of the bubble mobility follow the general trend that addition of sodium sulfate reduces the bubble charge by collapsing the double layers and represent the trend more clearly than their results.

NOTATION

a = longer side or width of cell
b = shorter side or depth of cell
C = concentration of Na_2SO_4
i = electric current
k = ratio of width to depth of cell
R = specific resistance
S = cross-sectional area of cell
v = horizontal velocity of bubble

Greek Letters

ζ = zeta-potential
ϵ = dielectric constant
μ = liquid viscosity

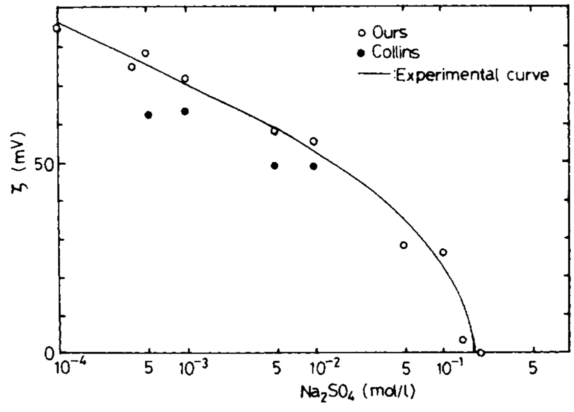

Figure 4. Experimental results.

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BOOKS

Physical Chemistry of High Temperature Technology, E. T. Turkdogan, Academic Press, April 1980, 447 pages, $49.50.

The author of this work is the elder statesman of industrial process metallurgy. The volume therefore contains a wealth of factual information that he has acquired over the years. Because most of these years have covered a period when physical chemistry, rather than process engineering, was dominant in process metallurgy, the book is canted in the direction of the former topic, as the title implies. The work is divided into two parts: "Fundamentals" and "Applications." The division is arbitrary since there is much in the second part, for example, the chapter on rate phenomena, that this reviewer would regard as fundamental. It is in the first part that the reader will find the most valuable material, a critical review of physicochemical data together with predictive and correlative techniques for physical properties.

The book is not likely to find use as a text since its approach is encyclopedic, rather than heuristic. Turkdogan's lack of exposure to an audience of uncomprehending students is evident from his frequent failure to provide full explanations or derivations. An example would be the author's mention, in a section on diffusion in metals and alloys, of a "backscatter effect" without further elaboration concerning the nature of this effect. A second example, in connection with the work of Chatterjee and Bradshaw on the impact of a gas jet impinging on a liquid surface, is Turkdogan's presentation of the relationship between the depth of the depression formed at the liquid surface and the onset splashing, without providing the relationship (present in the original work) between the depression depth and jet momentum.

It is regretable that the opportunity to present physical property data in SI units was not seized. Equally regretable is the failure to provide a list of symbols, particularly since some symbols are not even defined when they are first used! The index is rather scant for a work of this nature; for instance "Fick's law," "flames," "refractory" and "thermocouple" do not appear therein.

Most of the work will be comprehensible to those with a batchelor's degree in chemistry or metallurgy. The subject matter is treated with sufficient depth in the first part, but the second part is occasionally superficial, for example, in its treatment of heat transfer by radiation. There is little presentation of experimental technique despite the author's substantial reputation as an experimentalist.

The fundamentals part of the book will be of great interest to those working in any field of high temperature technology. The second half is mainly concerned with iron and steel, and those oriented towards such technologies as nuclear energy, aluminum smelting, geothermal energy and the incineration of wastes must look elsewhere for their applications.

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Chemical Engineering Communications (an International Journal for Communications of Research), Edited by: Standard and Ulbrecht, Published by: Gordon and Breach, Price: Individual $43.00 Library $83.00.

Chemical Communications actually started publication in 1973. The original intent was to publish full length research papers, short letters and review papers à la the now defunct, but well remembered *Industrial and Engineering Chemistry* reviews. The then editors—Pings and Seinfeld published twice in 1973, four times in 1974, once in 1975, twice in 1976. Three reviews appeared and four letters along with numerous research articles in a broad spectrum of topics (approximately 20% of the papers were in the area of fluids, 20% in control and optimization, 20% in kinetics and catalysis, 20% in transport and the remaining 20% were in areas such as diffusion, numerical analysis, thermo dynamics and heat transfer). With the January, 1978 edition, the current editors, Standard and Ulbrecht, began publication. The most recent edition was the May, 1978 volume which is somewhat disappointing with two major articles and one letter. One of the major articles is a review and the other a research publication.

Problems with this journal might be the fact that the audience was not well defined and its objectives too broad for a non society publication. The purpose of the journal is "an international journal devoted to the publication of full length research articles covering significant completed research, short letters giving preliminary announcements of results and occasional papers in chemical engineering, applied chemistry and related fields." The editors are hoping for rapid publication of papers enabling prompt and a lively exchange of ideas.

In the past, the quality of the research articles has been good and we can hope with new leadership that this journal can be an interesting forum for the serious chemical engineering researcher.

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Liquids and Their Properties: A molecular and macroscopic treatise with applications, by H. N. V. Temperley and D. H. Trevena, Published by John Wiley & Sons, Inc., 274 pages, $37.50 (1978).

This book is a useful survey of liquids that combines molecular and macroscopic approaches. It is designed to be of use to students in the pure and applied sciences, and also to research workers in other fields who require a basic knowledge of the liquid phase. As is the case with other recent books on liquid state, this one seems to emphasize new insights into the structure and properties of liquids at the molecular level that have resulted from computer simulations, beginning about 1957, and the parallel developments in theory and experimental methods. It differs from other recent books in that it covers a wider variety of topics, including hydrodynamics, acoustics, liquids under tension, and other specialized or applied topics that are specialties of one or both authors.