Paper

Relation between Streaming Potential and Streaming Electrification Generated by Streaming of Water through a Sandwich-type Cell

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Both streaming potential and accumulated charge of water flowed out were measured simultaneously using a sandwich-type cell. The voltages generated in divided sections along flow direction satisfied additivity. The sign of streaming potential agreed with that of streaming electrification. The relation between streaming potential and streaming electrification was explained from a viewpoint of electrical double layer in glass-water interface.

***Key Words**: streaming potential, streaming electrification, electrical double layer*

1. Introduction

The generation of both streaming potential and streaming electrification has been said to be originated from the friction between mobile liquid and solid wall[1), 2)]. However, they have been often argued independently. Streaming potential of liquid has been investigated in relation to ζ potential of electrical double layer on solid surface in scientific field[3)]. On the other hand, streaming electrification has been recognized in a practical field such as maintenance of pipeline of oils to avoid explosion by some spark. Electrospray ionization in an electric field draws recently much attention in the application to mass spectroscopy[4)]. However, there has been few report on the quantitative analysis of streaming electrification without an electric field. Under an expectation to find some relation between streaming potential and streaming electrification, both streaming potential and accumulated charge of water flowed out were measured simultaneously.

2. Experimental

2. 1 Apparatus

The schematic apparatus used in this experiment is shown in **Fig. 1.** A sandwich-type cell for the measurement of streaming potential was built up using parallel two plates of quartz glass (optical glass grinding grade, 13×29×6 mm^3). The space between two plates was about 2 μm. Both sides of the cell were fixed by epoxy resin and the cell was held between copper holders to avoid the distortion of the plates. The cell was also held between inlet adapter and outlet adapter made by acryl resin. Four platinum wires were placed as electrodes with interval of 1 cm. Two of them were placed at the inlet and outlet adapters, other two Pt wires were inserted through two holes bored through the quarts

glass. Super pure water ($1.7\pm0.6\times10^{-6}$ S cm^{-1} of electric resistivity, pH=5.7±0.3) stored in a water box made by quartz glass was forced to flow through teflon tube, the sandwich-type cell, and then teflon tube under a pressure of 10 kg cm^{-2} nitrogen gas. The charge of droplet water flowed out from the outlet teflon tube was collected in a Faraday-cage, which was connected with an electrometer. They are insulated from other equipment electrically. All of above equipment was set in an electrically shielded box maintained at 30±0.3 ℃. Streaming potential was measured using an electrometer TAKEDA RIKEN TR-8000, in which the negative terminal was connected to Pt wire placed nearer to the inlet adapter than another Pt wire.

2. 2 Method of measurements

Step 1: The charge of water stored in the quarts water box before streaming experiment was estimated by the charge of droplet water flowed out from bi-path teflon tube without an additional pressure. The droplet water was collected in the Faraday-cage and the accumulated charge was followed by the electrometer. This charge was estimated to be background.

Step 2: The water in the water box was forced to flow into the sandwich-type cell under a pressure of 10 kg cm^{-2}. The streaming potential generated was recorded and the droplet water flowed out from the end of the teflon tube was collected in the Faraday-cage and their accumulated charge was recorded.

Step 3: After finishing the measurement of the streaming potential, the charge of water remained in the source water box was estimated by droplet water flowed out through bi-path teflon tube without an additional pressure. The droplet water was collected in the Faraday-cage and their charge was followed by the electrometer.

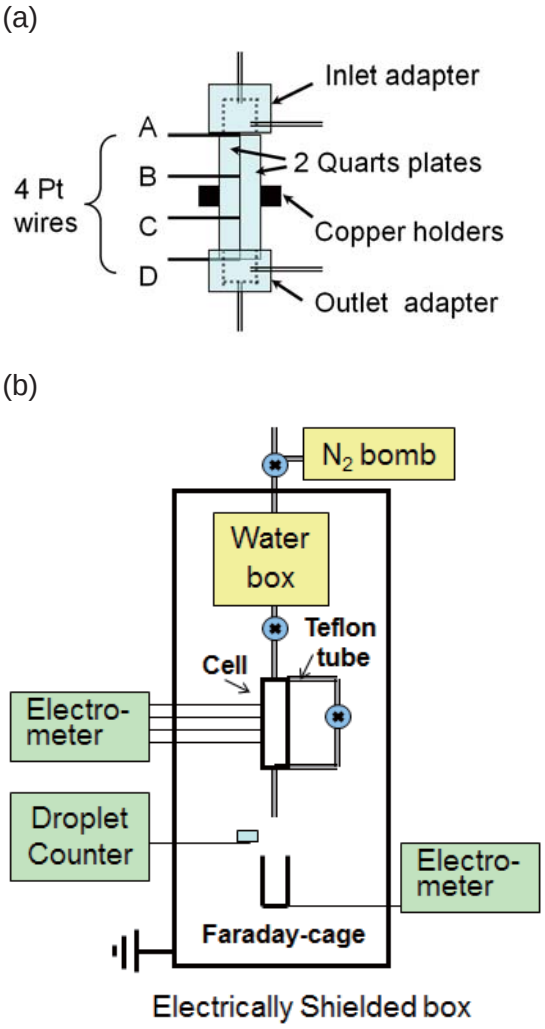

Fig. 1 Experimental apparatus: (a) sandwich-type cell, (b) assembly.

3. Results and Discussion

Figure 2 shows the variation of streaming potential (*Vs*) generated between Pt wires A and B (denoted as $Vs_{(A\text{-}B)}$), B and C ($Vs_{(B\text{-}C)}$), C and D ($Vs_{(C\text{-}D)}$), and A and D ($Vs_{(A\text{-}D)}$) as a function of time, where the negative terminal of the electrometer was connected to each Pt wire placed near to the inlet adapter. As soon as water flows, *Vs* suddenly jumps

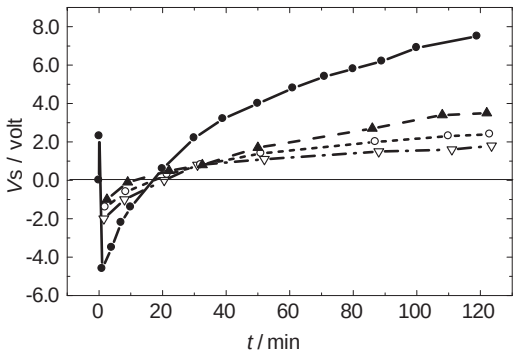

Fig. 2 Streaming potential *Vs* as a function of flow time: ●$Vs_{(A\text{-}D)}$, ▲ $Vs_{(C\text{-}D)}$, ○ $Vs_{(B\text{-}C)}$, ▽ $Vs_{(A\text{-}B)}$. Cell material: quartz glass.

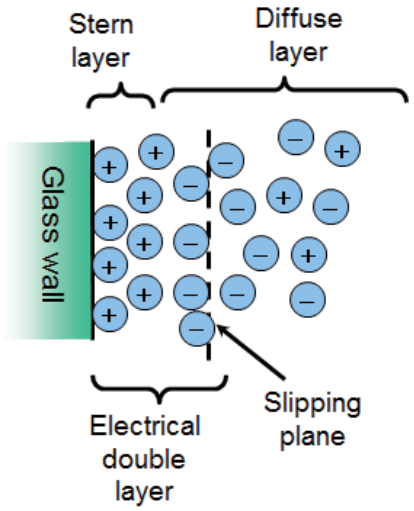

Fig. 3 Interface structure.

to some positive voltage, and quickly falls down to negative voltage and then it increases gradually.

The liquid layer attached to solid surface exists as two parts called electrical double layer as shown in **Fig. 3**[1), 2)]. An inner region is called the Stern layer, where the ions are strongly bound to solid surface. In an outer diffuse region, the ions are less firmly attached. Within the diffuse layer there is a notional boundary inside which the ions and particles form a stable entity. When fluid moves, ions contained in the boundary region do not move with it, but any ions beyond the boundary move with water. This boundary is called slipping plane shown in **Fig. 3**. Using glass capillary cell, protonic conductivity is reported to be the predominant of surface charge[5)]. This means that the Stern layer attached to glass surface is covered with positive charge.

In the case of an electronic circuit, a decrease in voltage is owing to the collision of electrons with lattice structure and they lose energy. The direction of electric current in electronic circuit is from higher potential to lower potential. In this circuit, if a negative terminal of voltmeter is connected to higher potential, voltge is observed to be negative. In the case of streaming potential at this experiment, flow ions do not lose their energy. They are merely carried by the flow of water. Then the potential of ions in the flow does not decrease. On the basis of this consideration, if negative ions flow with water, negative charge will increase at outlet position, and counter positive charge will be accumulated at the opposite side that is inlet position. Therefore the electrometer indicates the generation of negative voltage contrary to the case of electronic circuit.

Initial jumping to positive voltage in **Fig. 2** may be induced by sudden stream of water. The place of slipping plane exists in the electrical double layer as shown in **Fig. 3**. Then negative ions travel with flow of water to give the generation of negative voltage. Subsequently, all inner ions in the electrical double layer are involved by the flow of mobile phase little by little. At the same time, the positively charged interface retaine the negative ions in the fresh water flowed into the cell from the inlet adapter to give them delay. This function is the same as that appeared in a liquid column chromatography. Then the voltage generated gradually increase and change to positive and finally it shows some constant positive voltage at the stationary state.

The longer the standing time before measurement, the less the initial decrement in voltage. This implies that some time is needed to construct stable and stationary double layer. The each distance of adjacent Pt wires is 1 cm, however, the streaming potentials of them are not same; $Vs_{(C\text{-}D)} > Vs_{(B\text{-}C)} > Vs_{(A\text{-}B)}$. The concentration of ions contained in fluid water near to the slipping plane are accumulated and increased according as water travels. Then the voltage generated near to the outlet adapter, $Vs_{(C\text{-}D)}$, is highest among above three potentials. In addition, the potential $Vs_{(A\text{-}D)}$ is the same as the sum of $Vs_{(A\text{-}B)}$, $Vs_{(B\text{-}C)}$, $Vs_{(C\text{-}D)}$, i.e. additivity is satisfied.

If positive charge moved with the flow of water, the droplet water from the outlet is expected to be charged positive. **Figure 4** shows both streaming

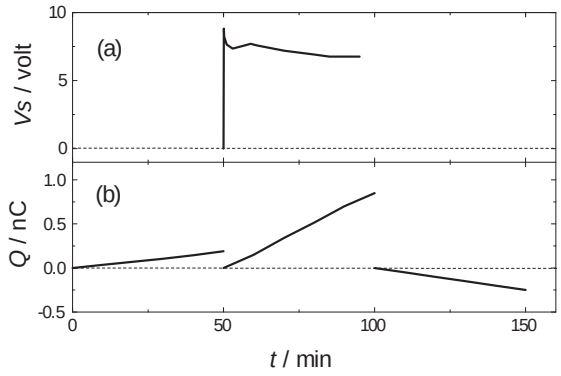

Fig. 4 Streaming potential (a) and charge accumulated in Faraday-cage (b) as a function of flow time. Cell material: quartz glass.

potential and collected charge accumulated in the Faraday-cage. Before application of the pressure, the droplets slightly charged to be positive (2.5pC/cm^3). After applying the pressure to make water flow through the cell, streaming potential shows positive value and droplets are charged to be positive as expected. In this case, the structure of electrical double layer is not built up enough to show negative voltage. After stopping the flow through the cell, droplet water traveled through bi-path are charged to be negative (-4.8 pC/cm^3). This means that the negative charge is accumulated in the source water box according as water travels through the sandwich-type cell.

Figure 5 shows the results using another cell, which was built up using borosilicate glass (Na_2O-B_2O_3-SiO_2). Before application of the pressure, the droplets slightly charged to be positive (2.3pC/cm^3). After applying the pressure to make water flow through the cell, streaming potential shows negative voltage and droplets are charged to be negative as expected. In this case, the structure of electrical double layer may be different from that of quarts glass and, in addition, it was left for longer time before the experiment. The long time standing is favorable condition to construct a stable electrical double layer. After stopping the streaming of water through the cell, water droplets through bi-path show relatively large positive charge (12.5 pC/cm^3) as expected. The charge collected in the Faraday-cage decreases and then shows slight increase according as negative streaming potential turn to positive.

In order to estimate the charge of the cell after streaming of water, another small glass cell was constructed using borosilicate glass (Na_2O-B_2O_3-SiO_2) and placed in the Faraday-cage. Water was flowed through above small cell and the charge of it was followed. The cell became slightly charged to be positive gradually. But the charge was +0.1-0.2 pC after 60 min water streaming. It is low enough to be trivial to take into consideration compared with about -0.6 nC shown in **Fig. 5**.

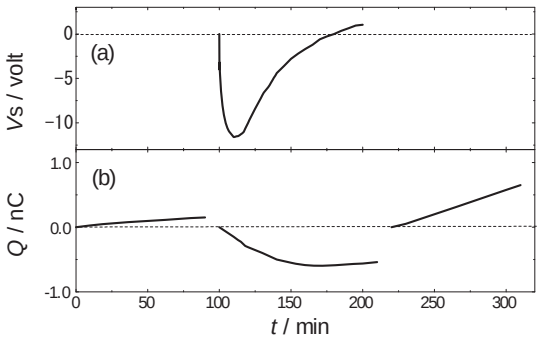

Fig. 5 Streaming potential (a) and charge accumulated in Faraday-cage (b) as a function of flow time.
Cell material: borosilicate glass.

4. Conclusions

Flow of pure water through the sandwich-type cell gives rise to generation of both streaming potential and streaming electrification. The voltages generated in divided sections in the sandwich-type cell satisfied additivity. The sign of streaming potential agreed with that of streaming electrification. The relation of streaming potential and streaming electrification can be explained from a viewpoint of electrical double layer in glass-water interface.

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