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An Investigation on The Mechanism of EHD Phenomena in High Intensity and Asymmetric Electric Field

Seiichi Suzuki, Tadashi Nakasone and Keiji Ishikawa

Seikei Univ., Faculty of Eng., Dept. of Electrical Eng. And Electronics
3-3-1 Kichijojikitamachi, Musashinoshi, Tokyo 180-8633, Japan
Phone: +81-422-37-3733 E-mail: seiichi@ee.seikei.ac.jp

1. Introduction

The effects of high intensity electric field in conductive fluid is, in general, difficult to study because of the Joule heat production and resulting boiling, bubble formation and destruction of electrodes. However, in smaller scale of environment, the effects of Joule heat are reduced because of the high efficiency in heat radiation. In the micrometer scaled electrode system, EHD phenomena produced by the electro-chemical reaction can be observed at the field intensity of 10^5-10^6[V/m]. If the electric field is uneven, local swirl of the solution can be seen. In a electrode system of symmetric geometry, these local EHD flows are canceled each other and no flow can be observed in larger scale. So we developed an asymmetric electrode system to produce total translational flow in one direction. The EHD flow rate was slow but continuous, without pulse or fluctuation and easy to control. These characteristics are suitable for a micro pump used in precision analysis by a micro-scaled column, even though further refinements are required.

For improvement of the micro pump, understanding of the mechanism of this EHD flow is essential. However available data and theory for analysis are not enough now. In a few cases, the mechanisms of EHD effects are studied intensively and well analyzed. The ion injection in insulating oil[1], dielectrophoretic flow in thermal gradient[2,3] and electro-osmotic flow are among them. However, the mechanism of EHD flow by the electro-chemical reaction is still in question. In this study, we measured the EHD flow rate in relation with the parameters related to the electro-chemical characteristics.

2. Micropump system

The schematic view of the micro pump and electrodes is shown in Fig.1. A pair of comb shaped electrodes is interdigtated to make narrow gaps. One finger of the electrode has flat and pointed edge on each side. The sharp points on one edge and flat edge make asymmetric electric field. The high intensity field around the point causes EHD flow. Application of AC electric field, 100k-1MHz and 1-2MV/m, produces swirls of EHD flow. In the experiments, fluorescent-labeled latex beads were added to the fluid to visualize the EHD flow. The movement of the beads in the micro channel was observed by fluorescent microscopy and recorded by video camera at a point far from the electrodes. The flow velocity was calculated by averaging the position shift of three beads in a unit time.

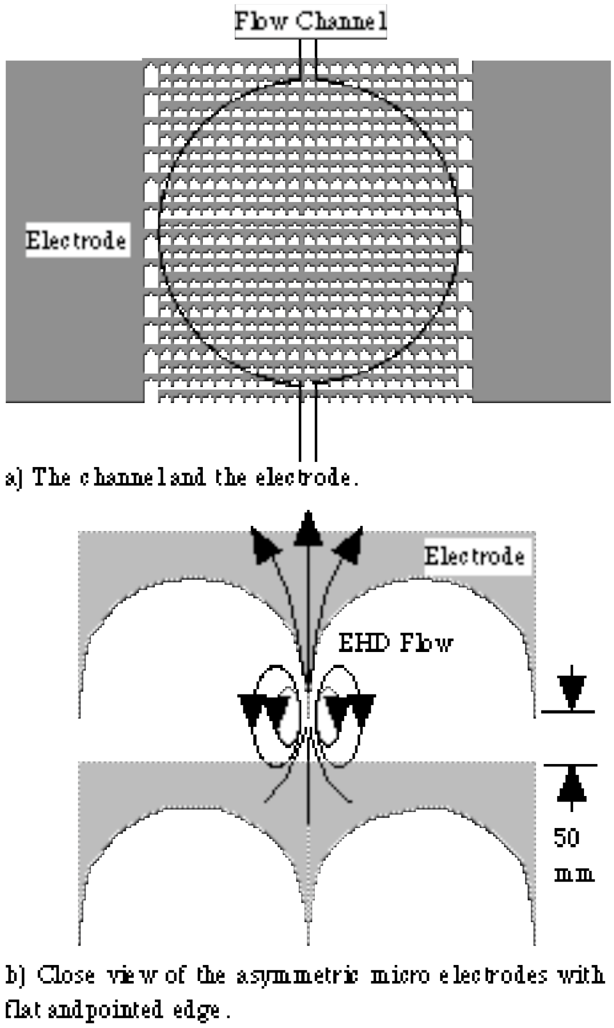

Fig.1 Schematic view of the micro fabricated electrodes and the flow channel.

3.Results

We measured flow rate of the EHD pump in relation with some parameters.

Field intensity dependence

The flow rate as a function of square ot field intensity is shouwn in Fig. 2. It shows rather linear curve. This quadratic dependency can be seen in dielectrophoresis and some other physical phenomena but not in Coulombic effects such as elecroosmotic flow.

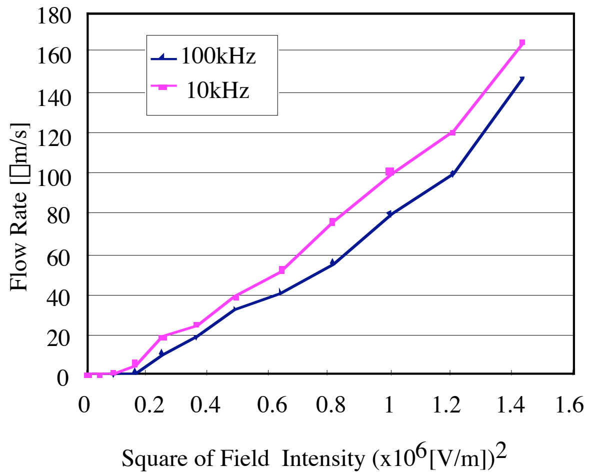

Fig.2 The flow rate of the EHD pump as the function of square of the field intensity.

Conductivity dependence

The flow rate dependence on the fluid conductivity is shown in Fig. 3. The flow rate is higher in rather conductive solution. This is controversial to electrostatic effects such as electro- or dielectrophoresis, because the increased electric current in the solution reduces the effective field intensity.

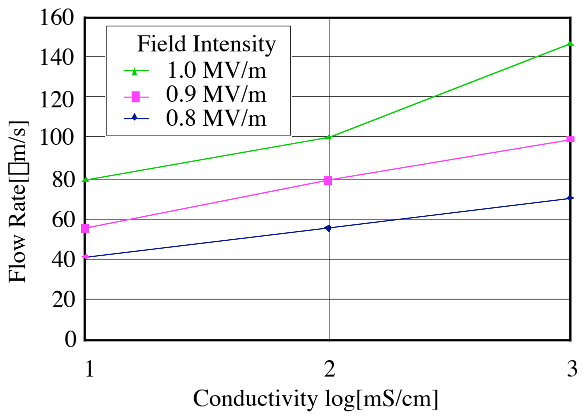

Fig.3 The fluid conductivity dependence of the EHD pump flow rate.

Temperature dependence

The EHD flow rate was measured in some different ambient temperature conditions, and the results are shown in Fig.4. The flow rate increases exponentially as the ambient temperature increases. This tendency suggests the contribution of chemical reaction to the EHD phenomena. Further increase of temperature will promote the chamical reaction but, at the same time, produces large amount of heat and disturb the flow itself.

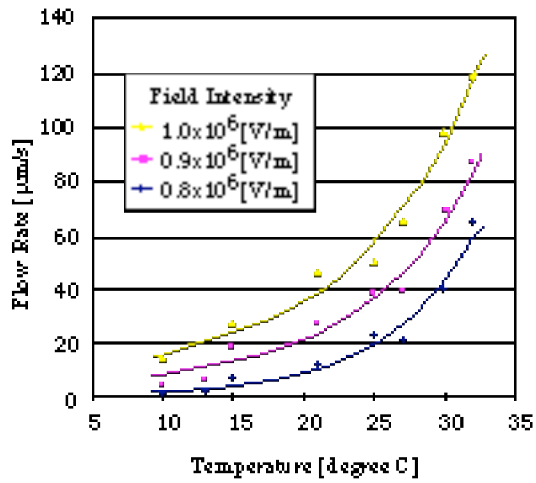

Fig.4, The EHD flow rate in various ambient temperature.

4. Discussions and Conclusions

The quadratic dependency of the EHD flow rate on the field intensity gives us some clue to understanding the mechanism of the EHD effects. Simple Coulombic force, such as electroosmotic flow should has linear dependency. This characteristic suggests participation of induced charge to the EHD phenomena. On the other hand, dependency on the fluid conductivity denies the major contribution of dielectrophoretic force. In highly conductive solution, enhanced electric current produces large potential drop at the electrode surface, and the field intensity in the bulk fluid is attenuated. The enhanced flow rate in the conductive solution means that the current or potential drop may have some function in this EHD process. The results in the temperature dependency support this speculation. Electro-chemical reaction at the electrode-solution interface is linearly proportional to the electric current and chemical reaction is exponentially enhanced by the ambient temperature.

These results suggest the participation of electrochemical reaction to the EHD flow mechanism in conductive fluid. However, electrode reaction is a complex process and further investigation is needed to establish the EHD mechanism.

References

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