The Seventh JSME-KSME Thermal and Fluids Engineering Conference,
Oct. 13-16, 2008, Sapporo, Japan

I123

# Measurements of Electroosmotic Flow and Electric Field in Micro-channels using Micro-PIV

Keisuke Fukuda, Kazuya Tatsumi, Yoichi Katsumoto & Kazuyoshi Nakabe

Department of Mechanical Engineering and Science, Kyoto University, Japan
Corresponding e-mail address: tatsumi@mbox.kudpc.kyoto-u.ac.jp

**Keywords**: Electroosmotic flow, Electric field, Micro-PIV, Two particles correlation

**Abstract**: The authors have proposed a method that can measure the electroosmotic flow velocity and electric field in micro-channels using the μPIV measurement technique. Two kinds of tracer particles with different electrical surface properties were used in the measurement. The correlation function between the electric field charged in the channel and the velocities of these particles were firstly obtained from a calibration experiment. Measurements of the electroosmotic flow and electric field in two types of micro-channels, i.e. straight and U-bend channels, were, then, carried out by applied this correlation function to the μPIV measurements. These results were compared with those obtained from the experiment using fluorescent dye and numerical simulation. In both comparisons, an excellent agreement was achieved in the flow velocity and electric field distributions indicating the validity of the method.

Measurements of the flow and electric fields in micro-channel are important and challenging issues in terms of developing micro-devices with fluid containing components, such as μ-TAS and Lab-on-a-chip. μPIV is regarded as an effective measurement technique to obtain the flow field in such micro-channels (Meinhart et al. (1999)). Many problems, however, are incurred when an electric field is applied to the channel, particularly due to the electrophoretic force appearing in the tracer particles (Sato & Hishida (2006)).

In the present study, a method, which can measure the electroosmotic flow and electric field using the μPIV measurement technique, is proposed. In this measurement, two kinds of particles with different electrical surface properties were used as tracer particles. If the apparent velocity of the particles can be regarded as a superposition of the components induced by hydraulic and electrophoresis forces (Yan et al. (2006)), then, the electric and flow fields can be obtained by analyzing the velocities of the two particles when the relation between the electric field and electrophoretic velocities of the each particle is known.

A calibration experiment was first conducted using a straight channel made of PDMS (polydimethylsiloxane) as shown in Fig. 1. Height and width of the channel were 50μm and 200μm respectively. DC electric field was applying to the channel by platinum electrodes inserted in each reservoir. The working fluid was a buffer fluid of pH=6.86 (nacalai tesque Co. 37220-35). Measurements were conducted in the area located at $z/H$=0.5 and at the streamwise center of the channel.

The capsule-type fluorescent tracer particles employed in the experiment were made of polystyrene with carboxylate-layer (Molecular Probes Co. F8819: referred to as particle A) and melamine (Sigma-Aldrich Co. 90518: referred to as particle B) respectively. The nominal diameter of both particles was 1μm. The particles were excited by a light of wave length 530nm, and the fluorescent images of the particles were recorded by a high-speed camera. PIV analysis was applied to these images to calculate the velocity field. In addition to this, electroosmotic flow velocity, $u_{eof}$, was obtained by injecting fluorescent dye (Rhodamine B) into the channel, and measuring the velocity of the interface between the fluids with/without dye using a high-speed camera.

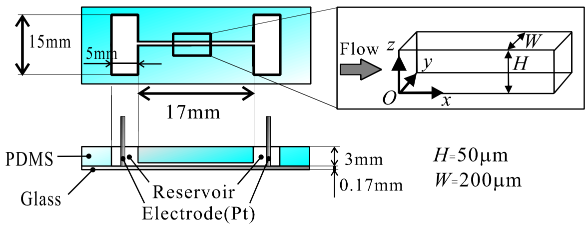



Fig. 1: Schematic of the straight micro-channel.

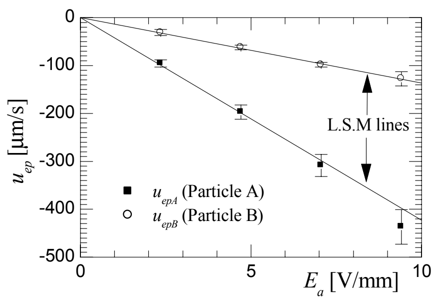



Fig. 2: Correlation between $u_{epA}$, $u_{epB}$ and $E_a$.

Figure 2 shows the correlation between the electrophoretic velocity, $u_{ep}$, of each particle and the

Copyright © 2008 by the Japan Society of Mechanical Engineers

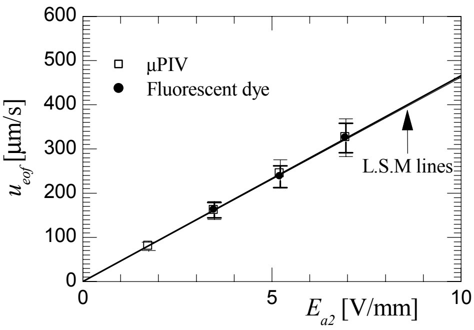



Fig. 3: Relation between $u_{eof}$ and $E_{a2}$.

intensity of the electric field, $E_a$. $u_{ep}$ was obtained by subtracting $u_{eof}$ from the apparent velocities, $u_A$ and $u_B$, which were obtained respectively from the measurements using fluorescent dye and μPIV. As shown in the figure, $u_{epA}$ and $u_{epB}$ linearly decreases as $E_a$ increases. From this relation, a correlation function of $u_{ep}$ and $u_{eof}$ against $u_A$ and $u_B$ were derived respectively.

Two types of channels have been investigated to evaluate the present method. One was a straight channel made of a material SU-8 (MicroChem Co.), which differs from that of the channel used in the calibration. The channel shape, size and measuring location were set to be identical to those of the calibration experiment.

The velocity distributions of the two tracer particles were first obtained by μPIV measurement. The correlation functions obtained from the aforementioned calibration experiment was, then, applied to the results to calculate the electroosmotic flow velocity, $u_{eof}$. The results are shown in Fig. 3 presented by the □ symbols. The abscissa axis, $E_{a2}$, is the intensity of the electric field obtained from the DC voltage applied to the electrodes. Addition to this, $u_{eof}$ obtained by conducting an experiment using fluorescent dye is also plotted in the figure presented by the ● symbols. Both results show an excellent agreement under all $E_{a2}$ conditions, indicating the validity of the present method.

The other experiment to evaluate the present method was a U-bend channel as shown in Fig. 4. In this case, due to the existence of the singular point generated at the corner, two-dimensional forms of not only the velocity field but also the electric field are expected to be produced. The results obtained from the experiment applying the present method are compared with those obtained from a numerical simulation.

The height and width of the channel were 50μm and 200μm respectively, and other dimensions of the channel are described in the figure. The channel material was PDMS and the electric field was produced in the same way as in the above cases. Numerical simulation of the electric field was conducted using a commercial code ANSYS Multiphysics v11.0 (ANSYS Inc.). Symmetric boundary condition was applied at the streamwise center of the channel, and the electric fields of the fluid and solid parts were both solved.

Figure 5 shows the contour distributions of electric field intensity, $E_a$, in the area illustrated by the square in Fig. 4 (bend section). The results obtained respectively from the experiment and simulation are shown in Figs. (a) and (b). Here, $E_a$ is normalized by $E_m$, which is the averaged value of $E_a$ within the area.

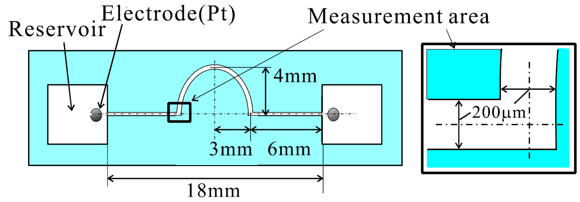
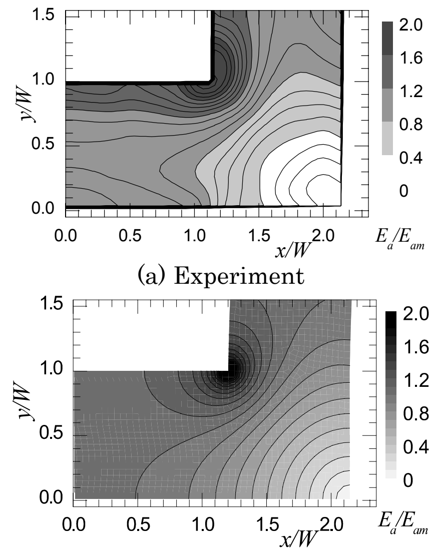



Fig. 4: Schematic of the U-bend channel.




(a) Experiment

(b) Simulation

Fig. 5: Electric field intensity distributions.

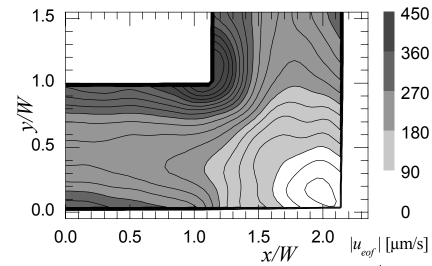



Fig. 6: Flow velocity distributions (Exp.).

In Fig. 5 (a), $E_a/E_m$ takes a maximum peak at the inner corner of the bend section, and is minimum at the outer corner. In the numerical results shown in Fig. 5 (b), a similar tendency is observed indicating the validity of the present method in measuring the two-dimensional distributions of the electric field.

Figure 6 shows the distributions of the absolute value of the flow velocity, $|u_{eof}|$, obtained from the experiment. $|u_{eof}|$ takes maximum and minimum values at the locations of the inner and outer corners respectively. The reason for this is believed to be the relatively small electric field intensity appearing at the outer corner resulting in the reduction of the electroosmotic flow velocity, and the flow stagnation produced in the area adjacent to the outer corner.


Meinhart, C.D. Werely, S.T. & Santiago, J.G. 1999, *Experiments in Fluids*, Vol. 27, pp. 414-419.

Sato, Y. & Hishida, K. 2006, *Fluid dynamics Research*, Vol. 38, pp. 787-802.

Yan, D., Yang, C., Nguyen, N.T. & Huang, X. 2006, *Electrophoresis*, Vol. 27, pp. 620-627.