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The application of μPIV technique in the study of magnetic flows in a micro-channel

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Abstract

In this preliminary experimental study, micro-scale particle image velocimetry (μPIV) was adopted for the first time to get the quantitative information of magnetic flows in a micro-channel. The μPIV consists of an inverted florescent microscope, a Q-switch Nd:YAG laser and a CCD camera. The florescent liquid with particles of 3 μm diameter was blended homogeneously with the prepared magnetic fluid. A permanent magnet approached and left one end of the micro-channel. The response of the magnetic fluid was recorded with the μPIV simultaneously. The flow features validate the feasibility of using μPIV technique in the study of magnetic flows in a micro-channel. μPIV provides a promising experimental tool for visualization and quantitative measurement of magnetic micro-flows.

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Keywords: Micro-PIV; Magnetic fluids; Micro-channel

1. Introduction

Magnetic fluids with both magnetic and flow properties have been attracting increasing attention with the promise of applications in areas as diverse as high-speed silent printing, heat transfer enhancement in the thermo-fluid engineering and drug-delivery to a target site in the body in the field of medicine [1,2]. There exist wide and nearly unlimited areas of application open for exploration. Along with the foreseeable increasing demand for micro-fluidic devices in the biomedical applications [3], magnetic force driven flows may represent another potential application to the micro-scale flow fields where traditional driving forces, such as pressure gradient, cannot be easily accessed.

However, due to the opaqueness and selectivity of wavelength of the light source of the magnetic fluids [4] and micro-scale effects, visualization and quantitative measurement of magnetic micro-flows becomes one of the key challenges. The motivation of this study is then to develop a suitable experimental technique to get the quantitative information of magnetic micro-flows. A florescent micro-scale particle image velocimetry (μPIV), which can measure velocity profiles accurately in the electro-kinetic micro-channel flows [5,6], was adopted to study a simple magnetic micro-channel flow. The flow features are presented and the feasibility of using μPIV technique in the study of magnetic flows in a micro-channel is justified.

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2. Experimental setup

The test device is composed of a micro-channel and a large permanent magnet and is shown in Fig. 1. The dimensions of the micro-channel are 2 mm in width, 50 μm in height and 6 cm in length, which is enclosed between two transparent PMMA plates. Both ends of the channel are open with a well of about 1 mm in diameter and 1.5 mm in depth.

The magnetic fluid used in the current experiment was the light mineral oil based ferrofluid (Ferrotech Corp. EMG 911, viscosity = 4 cp at 27 °C, $M_s = 100$ gauss). The ferrofluid was mixed with the diluting base liquid in the ratio 1:1. The florescent liquid with particles of 3 μm diameter was then blended homogeneously with the prepared ferrofluid in the ratio 1:7. The channel and both wells were filled fully with this prepared liquid. Capillary force automatically filled the channel and the surface tension kept the drops of equal size in the two wells in place.

The subsequent experiment started only if no flow could be observed. A large permanent magnet was placed and taken away from one end of the test cell (Fig. 1). The flow features were recorded with the movement of the magnet by a florescent μPIV. The experimental apparatus of μPIV shown in Fig. 2 consists of an inverted florescent microscope (Nikon ECLIPSE TE2000-S), a Q-switch Nd:YAG laser and a CCD camera of 640 pixels × 480 pixels (Sony ICX 084). The system is synchronized by a personal computer. The green laser with a wavelength of 532 nm excites the 3 μm particles, which emit red light with a wavelength of 610 nm. An optical filter allows the image of the red particles to be recorded with the CCD camera. The measurement reported in this study was carried out with 4× objectives. The image window is 1.2 mm × 1.6 mm. Two 30 mJ laser pulses with delay times ranging from 3 to 4 ms were used to illuminate the flow fields. PIVview (PivTec GmbH, Germany) program was chosen to calculate the velocity fields. The interrogation area is 32 pixels × 32 pixels.

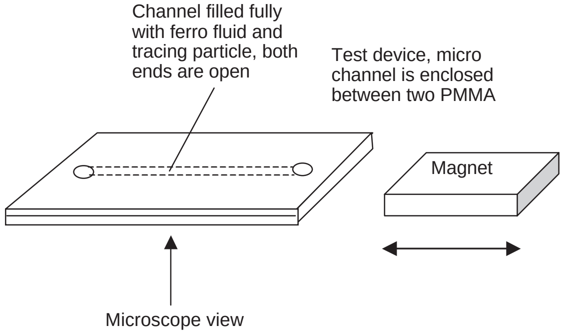

Fig. 1. Schematics of the test device of the magnetic micro-channel flow.

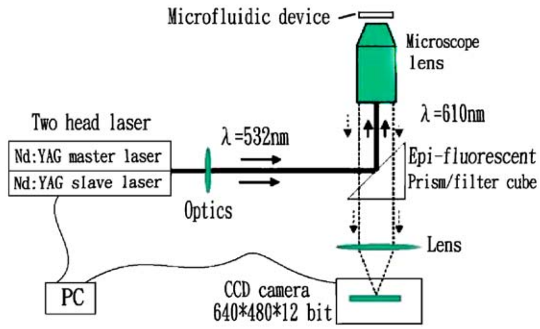

Fig. 2. Experimental setup of the florescent μPIV.

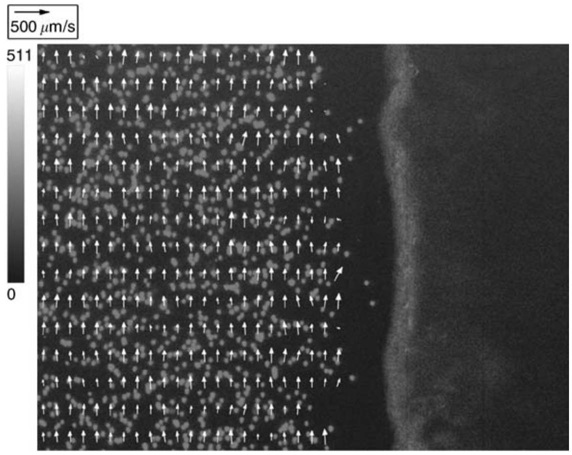

Fig. 3. μPIV image and superimposed velocity vectors at the channel wall at the beginning when a permanent magnet approaches the end wall from the top.

3. Results and discussion

Figs. 3,4 and Figs. 5, 6 show the florescent μPIV images and superimposed velocity vectors at channel wall and in the middle of the channel, respectively, while the magnet was approaching and leaving an end of the test cell (from the top of the image). Magnetic fluid inside the micro-channel moved quickly toward the magnet initially with the velocity of the order of 500 μm/s when the magnet was approaching (Figs. 3 and 5) and slowed down to a full stop after the magnet was halted at the end wall. When the magnet was taken away from the end wall (Figs. 4 and 6), magnetic fluid reversed its moving direction quickly with the velocity of the same order of 500 μm/s and slowed down to a full stop over time.

The approaching magnet polarized and attracted the ferroparticles, which dragged the fluid. While the

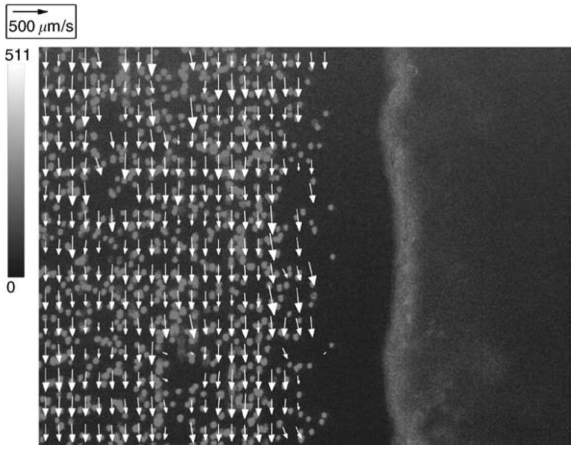

Fig. 4. μPIV image and superimposed velocity vectors at the channel wall at the beginning when a permanent magnet leaves the end wall from the top.

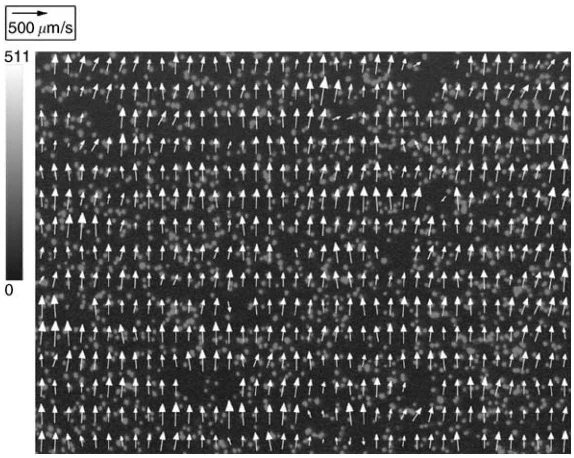

Fig. 5. μPIV image and superimposed velocity vectors in the middle of the channel at the beginning when a permanent magnet approaches the end wall from the top.

magnet was leaving the end wall, the surface tension difference of the two air–liquid interfaces around the two wells (one drop at the top in Figs. 4 and 6 was overfilled with smaller surface tension, the other interface at the bottom was inside the well initially) then caused the reverse flow. The fast reverse flow indicates that the surface tension difference in this case is quite large.

Interesting effects were observed. Florescent particles seemed to align to the magnetic field. Some ferroparticles may stick on the surface of the florescent particle.

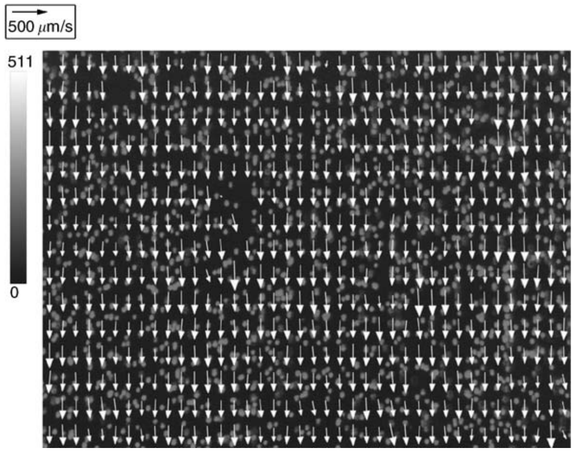

Fig. 6. μPIV image and superimposed velocity vectors in the middle of the channel at the beginning when a permanent magnet leaves the end wall from the top.

The test did not work well with a silicon/glass channel of $100\,\mu m \times 100\,\mu m$. Further study will be conducted to verify these points. As shown in Figs. 3 and 4, near the channel wall, the seeding of the florescent particles posed the other challenge.

4. Conclusion

A florescent micro-scale particle image velocimetry (μPIV) was developed for future experimental studies of magnetic micro-flows. A simple magnetic micro-channel flow was set up for the first benchmark test. The preliminary results validate the feasibility of using μPIV technique in the study of magnetic micro-flows. μPIV provides a promising tool for flow visualization and velocity measurement of magnetic micro-flows.

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