A method for measuring simultaneously the fluid and particle mobilities under strong DC and low-frequency AC fields

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Recently, electrokinetic phenomena have gained considerable attention as a means of separating charged species and for the transport of suspensions in microdevices. The application of these phenomena in various “lab-on-a-chip” devices requires the quantification of the motion of both the fluid and the suspended species. We have developed a method in which the fluid electroosmotic velocity and the particle “apparent” velocity inside a capillary are measured simultaneously under strong DC fields. The particle electrophoretic velocity is then computed from their difference and is found to remain independent of the surface properties of the channel.

The experiments were conducted by employing strong DC fields (upto ~1kV/cm) along a capillary (50 micron inside diameter) initially filled with a dilute suspension (c~0.00025v/v) consisting of 4 micron diameter polystyrene particles uniformly dispersed in deionized water. The results of our DC field experiments showed that the fluid electroosmotic and particle electrophoretic velocities remained proportional to the applied field strength over the whole range from 100V/cm to 1kV/cm. We also obtained the apparent particle velocity under low-frequency AC field (frequency 5-50Hz) by measuring the amplitude of the particle oscillations which, as expected, was found to be proportional to the field strength (at fixed frequency), and inversely proportional to the frequency of the applied field (at fixed field strength). Close agreement was found between the values for the apparent mobilities as obtained from the DC and AC field experiments.

Experimental Setup

The experiments were conducted in the setup [1] shown schematically in Fig. 1. A dilute aqueous suspension is transported from an upstream reservoir (marked as 1) to a downstream reservoir (marked as 2) by applying a voltage difference along a capillary microchannel connecting the two reservoirs. The downstream reservoir, serving as ground, is connected to a calibrated microsyringe via a needle. The ends of reservoir 1 and the microsyringe are open to the atmosphere (Fig. 1). At the beginning of an experiment, some suspension is pumped into the microsyringe so that a liquid meniscus can be observed. The whole assembly is kept horizontal to eliminate the effects of gravity. The details of the experimental setup and the experimental results are presented in Ref. [2].

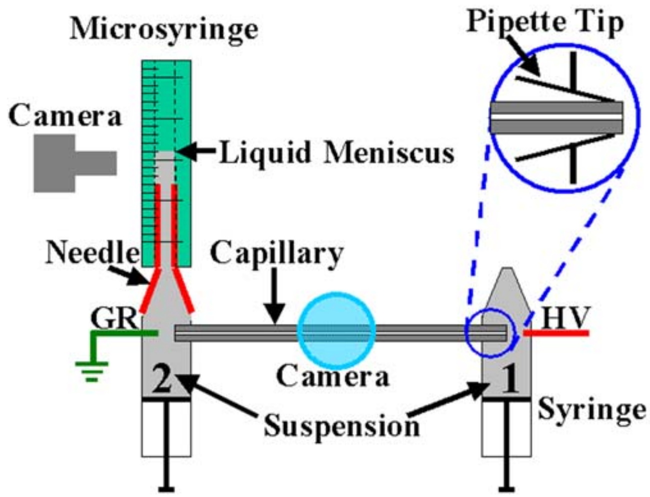

Figure 1. Schematic of the experimental setup. Syringe 1 is connected to the high-voltage output of the power supply while Syringe 2 is connected to the ground. The volume of the fluid flowing through the capillary is measured by observing the displacement of the meniscus position as the fluid enters into the microsyringe. The particle motion in the capillary is recorded by a camera connected to a microscope. The whole assembly is fixed onto a stage and is kept horizontal. The inset shows the airtight connection between the capillary and the syringe reservoirs.

DC-Field Experiments

Following the application of a DC field, the electroosmotic flow generated within the capillary causes a net motion of the liquid meniscus in the calibrated microsyringe. The slope of the fluid volume collected in the microsyringe as a function of time gives the electroosmotic flow rate of the fluid and thereby the electroosmotic fluid velocity, v_{eof}, provided that the velocity profile within the capillary is uniform. On the other hand, the apparent particle velocity, v_{obs}, observed within the capillary, is also measured simultaneously by tracking their motion in the field of view of a microscope. Once both, v_{eof} and v_{obs}, are available from an experiment, the electrophoretic particle velocity, v_{eff}, is then calculated from their difference, $v_{obs} - v_{eof}$.

In a typical set of experimental data, we observed a linear increase of the meniscus displacement with time for over 45 minutes which demonstrates that extraneous effects, such as heating as well as evaporation losses from the ends exposed to the atmosphere, were insignificant under our experimental conditions. Next, from the linear slope of the fluid volume vs. time, we computed the fluid electroosmotic velocity, v_{eof}, and from the data on the velocities of ~ 100 particles, we computed the apparent particle velocity, v_{obs}. Thereafter, the particle electrophoretic velocity, v_{eff}, was computed from their difference, $v_{obs} - v_{eof}$. The dependence of v_{obs}, v_{eof}, and v_{eff} on the field strength is linear and from a linear fit (within a 95% confidence level), we obtain for the fluid electroosmotic mobility $\mu_{eof} = (3.5 \pm 0.3) \cdot 10^{-8} \mathrm{m}^2/\mathrm{V} \cdot \mathrm{s}$, for the apparent particle mobility $\mu_{obs} = (1.4 \pm 0.2) \cdot 10^{-8} \mathrm{m}^2/\mathrm{V} \cdot \mathrm{s}$ and for the particle electrophoretic mobility $\mu_{eff} = (2.1 \pm 0.4) \cdot 10^{-8} \mathrm{m}^2/\mathrm{V} \cdot \mathrm{s}$. In contrast to studies of strong-field electrophoresis in Refs. [3-5], our experiments did not discern any non-linear effects of electrophoresis and electroosmosis within the accuracy of our measurements.

AC-Field Experiments

When an AC field was applied across the two ends of the capillary, the particles exhibit an oscillatory motion about their mean position. For these experiments, we measured the particle oscillatory amplitude on an enlarged screen by projecting the computer screen via an LCD projector. We limited our measurements to 50Hz. The particle amplitudes were found to be proportional to the field strength, E_{rms}, and inversely proportional to the field frequency. We did not observe any nonlinear behavior in our AC-field experiments, consistent with the results of our DC experiments discussed earlier. A linear fit (within 95% confidence level) of the data indicates that the ratio A/E_{rms} is inversely proportional to the field angular frequency, hence: $A = \sqrt{2}\mu_{AC}E_{rms}/\omega$ with $\mu_{AC} = (2.1 \pm 0.1)\cdot 10^{-8}\,m^2/V\cdot s$. This value is close to the apparent mobility μ_{obs} found in the DC-field experiments, thereby confirming the quasistatic nature of the oscillatory motion of the fluid and of the particles.

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