STREAMING POTENTIAL EFFECTS IN FLOWS ON BIO CHIPS

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ABSTRACT

Microfluidic flow is important in miniaturized bioscience applications including chemical analysis, biological and chemical sensing and drug delivery. Miniaturization of these processes provides benefits in reduced size, weight and cost, and better performance. Microfluidic flow characteristics differ from more familiar macroscale flows due to the complex interactions between the wall of the microchannel and fluid flow through the channel. Our research focuses on the **streaming potential** in pressure driven flow. A theoretical model of the electrical double layer (EDL) combined with a flow model allows prediction of the streamwise electrical potential (streaming potential) generated when an electrolyte flows through a channel with a surface charge. We have conducted preliminary experiments in capillaries with a diameter range of 25 to 400 µm.

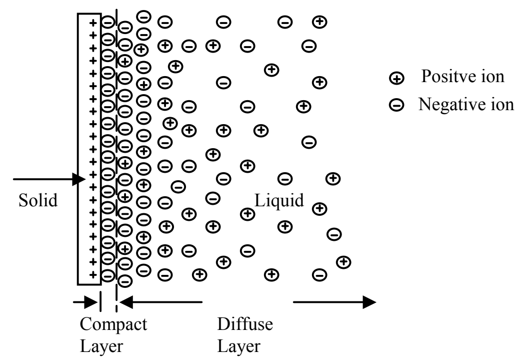
Dielectrics typically exhibit surface activity due to the unbalanced electrostatic forces on the molecules near the surface. When an electrolyte is contained by a dielectric wall, one polarity of ion tends to adsorb on the wall and the resulting charge concentration exerts an electrostatic influence on the ions that remain in the liquid. This is the so-called electrical double layer (EDL). Helmholtz[1] is credited with the EDL model illustrated in Figure 1. The electrical potential distribution is computed from the Poisson-Boltzmann equation which balances the electrostatic forces of all the ions in the system

$$\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} = -2zen_o \sinh \Psi$$

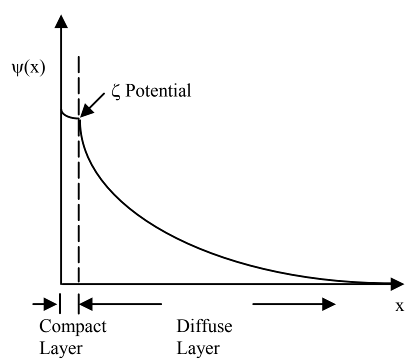
where ψ is the electrical potential, z is the number of charges on each ion, e is the charge on an electron and n_o is the nominal concentration of ions. This can be solved to yield a charge distribution near the wall (1D) as

$$\psi = 2\ln\left(\frac{e^{\psi_0/2} + 1 + (e^{\psi_0/2} - 1)e^{-x}}{e^{\psi_0/2} + 1 - (e^{\psi_0/2} - 1)e^{-x}}\right)$$

This charge distribution near the wall is the source of the electro-kinetic effects[2-5] including electroosmotic flow and the streaming effects described here.



a) Ion distribution in electrolyte



b) Electrical potential distribution

Figure 1. Electrical Double Layer in the Interface between solid and liquid

Pressure driven flow of an electrolyte past a charged surface carries an unbalanced mix of ions and results in a streaming current. The transport of ions leads to the separation of charge axially along the channel and produces an electric field called the streaming potential as shown in Figure 2. The streaming potential exerts an electrostatic force on all the ions in the system and drives a "conventional" electric

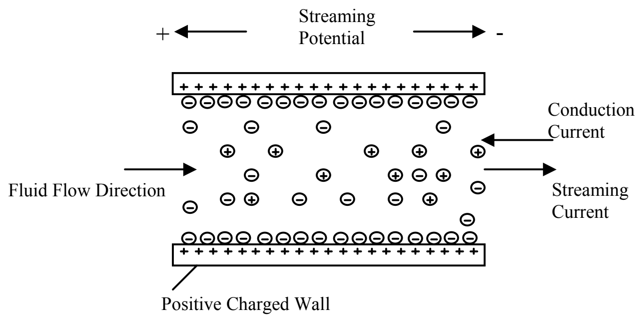


Figure 2. Streaming Potential and Current in Microfluidic Channel

current in the electrolyte. This conduction current, due to ion migration, is in the opposite direction to the streaming current. The steady-state streaming potential represents the case where the streaming current and the conduction current are equal and opposite. The streaming potential also interacts with the fluid flow to create an electroosmotic flow in the direction opposite to the pressure driven flow. This effect is interesting but is found to be insignificant for the capillary diameter range of interest in this study.

A model of pressure driven flow of an electrolyte through a tube (the cross section can be trapezoidal, rectangular or circular) was written. A simplified form of the Navier-Stokes equation which accounts for pressure drop, the electrical body force due to the streaming potential and the viscous shear forces can be written as

$$\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}=\frac{1}{\mu}\frac{dP}{dz}-\frac{\rho_e E}{\mu}$$

Here, net charge density ρ_e is obtained by solution of potential distribution.

The calculated streaming potential due to aqueous KCl flowing through a rectangular channel as a function of zeta potential and pressure drop is plotted in Figure 3. It is seen that the streaming potential is proportional to both zeta potential and pressure drop.

An experiment was set up to measure the streaming potential. Bottled nitrogen was used to control the pressure. A series of capillary tubes with different diameters were tested. A digital multimeter, with standard electrodes, was used to measure the streaming potential at steady state by immersing the electrodes in the solution at each end of the capillary.

Preliminary measurements have been completed and results with data from the literature are shown in Figure 4 along with simulation results. The experimental data matches well with the data from the literature and also with the numerical simulation. Further work will be focused on obtaining more data on streaming potential focusing on small channels where the effect of streaming potential on flow rate is not negligible.

In summary:

- The streaming potential is a streamwise voltage resulting from the bulk transport of ions in a flowing electrolyte due to the charge separation that occurs near a wall that has a surface charge.
- The magnitude of the streaming potential depends on the flow rate, the surface charge of the capillary and the conductivity of the electrolyte
- The streaming potential is largely independent of radius in the range of radii of interest in this study.
- The streaming potential is important in macroscopic systems when low voltage measurement systems are in use but is usually not

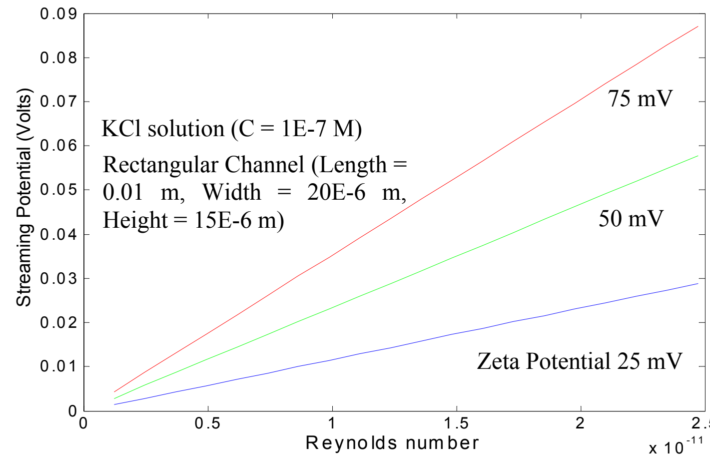


Figure 3. Calculated Streaming Potential

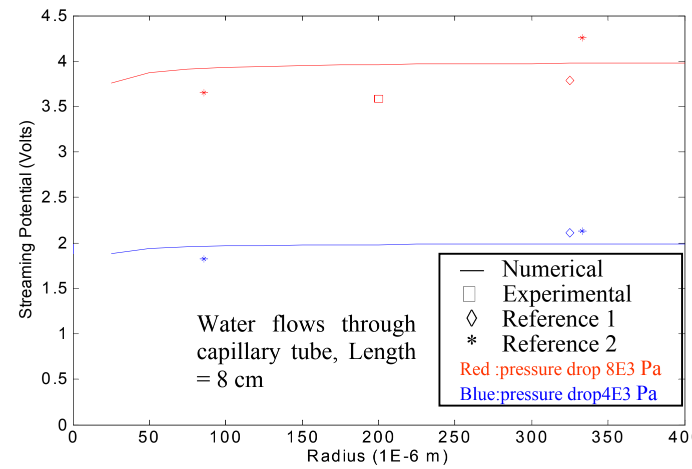


Figure 4. Experimental Data

observed since most flow systems are metal which provides a parallel path for the conduction current and thus minimizes the streaming potential

- The streaming potential tends to retard the velocity near the wall but the effect is negligible unless the Debye length is a significant fraction of the cross section of the flow.

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