Numerical Analysis of Electroosmotic Flow Through Capillaries

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Abstract

In the last decades, the topic of microfluidic electroosmotic pumps (EOP) gained the attention of scientists all over the world. One of the greatest advantages of electroosmotic pumps is that there are no moving parts. With the effect of electroosmosis it is possible to generate a continuous, bi-directional, impulse-free stream of electrolyte fluids. This effect leads to a high pressure inside the capillaries of the Electroosmotic Pump. The simple construction of this type of pumps opens a wide range of applications. The small size is very attractive for lab-on-a-chip (LOC) experiments. These are cheap and easy to integrate.

The focus is on the numeric analysis of DC-EOP with COMSOL Multiphysics® software. The scope of the investigation is on the performance of a volumetric flowrate of a DC-EOP by the influence of fluid-parameters and boundary conditions.

An Electroosmotic Flow (EOF) is the flow in a capillary, which is induced by an electric field and a charged capillary wall [2].

Creating a constant balance, the cations of the electrolyte move nearby the capillary wall (Fig. 1).

This effect causes the forming of a double layer which produces a potential difference, i.e. the so called Zeta-Potential ζ.

The Zeta-Potential decreases with the wall distance. This phenomenon is shown in Fig 2.

The electric field pulls the cations of the diffuse double layer straight to the cathode [1]. The impulse of the cations diffuses through the fluid. So the Electroosmotic Pump transports the electrolytes from the anode to the cathode [3].

A big advantage of the EOF is the homogeneous velocity profile. In the middle of the capillary the fluid gains round about 95% of its stationary value [4]. The evolution of the flow profile is illustrated in Fig. 3.

The COMSOL Multiphysics® model is quite simple: the capillary is simplified as a 2D rotation and axis symmetric rectangle.

For the stationary simulation of a flow under influence of an electric field it is necessary to implement two physics interfaces, i.e. "Electric Currents" and "Creeping Flow".
The interface "Electric Currents" is used to calculate the electric potential distribution. For flows in a microfluidic regime the interface "Creeping Flow" is needed: It calculates flows with low Reynolds numbers, the so called Stokes-flows. Beside of the EOF-part there is one input and one outtake area.

Different parameter studies were performed. One of the results is, that a smaller capillary leads to higher pressure. High pressure differences cause a better efficiency rate of the flow.

The results show a non-linear influence of the geometry on the pressure. Different parameter studies showed a linear influence of viscosity, density and voltage on the pressure.
For an optimized efficiency the geometry configuration should be investigated further.
The simplified model has some limits, since there are no losses included. For a complete a correct model it is absolutely necessary to implement an equation for the fluid friction.

Reference

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Figures used in the abstract

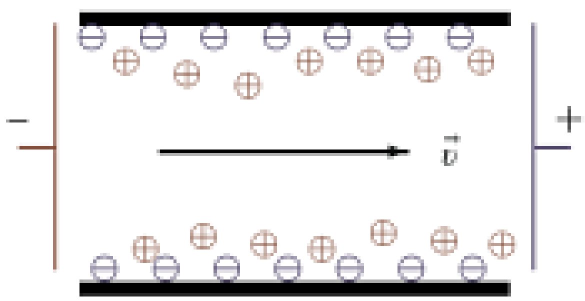

Figure 1: Evolution of electroosmosis [3].

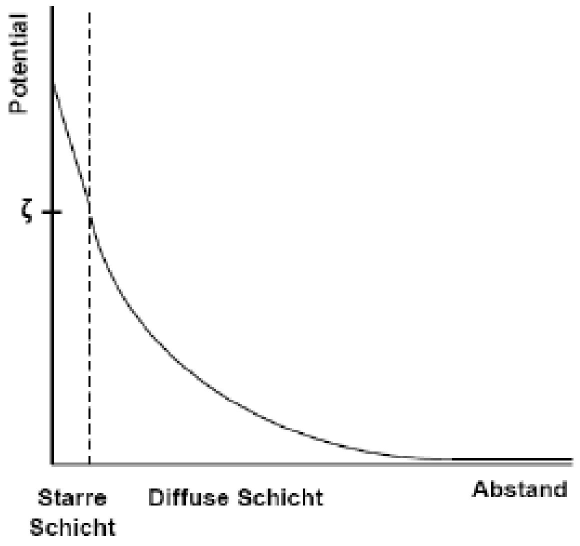

Figure 2: Trend of the Zeta-Potentials [2].

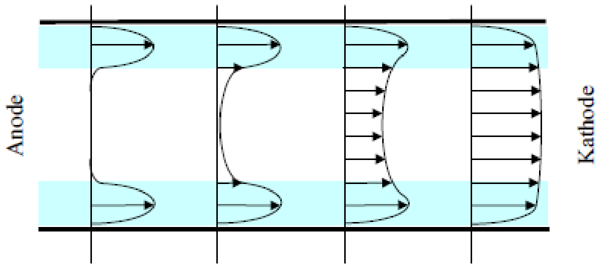

Figure 3: Evolution of a EOF [4].

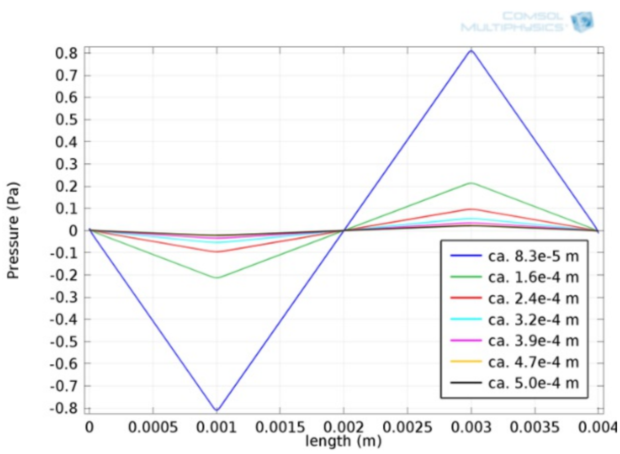

Figure 4: Diameter vs. pressure.