Variable Physical Properties Effect on Velocity and Potential Distribution in a Nanotube with Large Zeta Potential

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In recent decades, after introducing micro- and nano-fabrication technologies, several possibilities in the case of micro- and nano-fluidic devices have been invented. This idea has been followed by some modern technologies such as Lab-on-a-Chip.

One of the most important subsystems of the micro- and nano-fluidic devices is their passage or "Micro- and nano-channel". Nano-channel term is referred to channels with hydraulic diameter below 100 nm. [1]. By decrease in size and hydraulic diameter some of the physical parameters such as surface tension will be more significant while they are negligible in normal sizes.

Concentrating surface loads in liquid – solid interface makes the EDL to be existed. If the loads are concentrated in the end of nano-channels, a potential difference will be generated that forces the ions in the nano-channel. However, induced electric field is discharged by electric conduction of the electrolyte.

Rice and Whitehead [2], Lu and Chan [3] and Ke and Liu [4] studied the flow in capillary tube. None of them solved the problem based on the curvilinear coordinates system. Also, all of them studied the problem with existence of the pressure gradient while in the modern applications, the pressure gradient can be eliminated and consequently, solving the problem considering this fact is necessary. In this paper, velocity profiles for large zeta potentials without pressure gradient will be studied based on the curvilinear coordinates in a capillary tube.

Governing equations in electroosmotic phenomena are species and mass conservation, Navier-Stokes and Poisson-Boltzmann equations [5]. By some simplifications, set of nonlinear differential equations will be identified for bulk fluid:

In this paper, it is assumed that, zeta potential is large enough that, we must numerically solve the following Problem:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial \varphi}{\partial r}\right)=\frac{-\beta}{\varepsilon^2}\left(X_p-X_m\right) \tag{1}$$

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u}{\partial r}\right)=\frac{-\beta}{\varepsilon^2}\frac{\varepsilon_e E_0 RT}{F\,\mu U_0}\left(X_p-X_m\right) \tag{2}$$

According to [5], we can explore the following assumption for nano-tube bulk fluid:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial \varphi}{\partial r}\right)=\frac{\sinh(\varphi)}{\varepsilon^2} \tag{2}$$

In small amount of zeta potential, we can assume $\sinh\varphi=\varphi$ and consequently, problem will be solved analytically, but in this paper, this assumption is no longer valid. As a result, numerical simulation has been employed. By using finite difference method powered by Newton-Raphson algorithm, flow and velocity fields have been obtained through nano-tube. Figure 1 shows the results of simulation for potential distribution. Furthermore, in Figure 2, velocity profile is investigated [8]. In addition, a comparison has been made in order to find out the difference of two assumptions (linear and nonlinear ones). It is shown in Figure 3.

Next, the main part of the paper contribution starts. Temperature assumed to be variable in the range of liquid water (0 to 100oC). In this case, some of the electrolyte (water) properties will be variable such as viscosity μ and dielectric constant ε_e. In addition, zeta potential is affected by temperature variations. In this paper, we use the exact definition or interpolation for temperature effect on zeta potential, dynamic viscosity and dielectric constant according to data shown in [5,6,7] respectively. About dielectric constant variation over temperature, it is noted that, It is assumed that, all phenomena are in standard pressure (p = 100 kPa constant).

By these considerations, simulations are done. In Figure 4, potential distribution in four specific temperatures is investigated. As it can be considered, no very significant effect is made due to temperature variation in potential distribution (around 20% from 20^oC to 80^oC). As it can be inferred in Figure 5, considerable variations will be made according to temperature and consequently, physical properties variation (more than three times from 20^oC to 80^oC). Another achievement of this investigation is that, if water electrolyte can safely works in temperatures near boiling point, Reynolds number significantly increases. This fact can be employed in nano-electromechanical devices (Figure 6).

References

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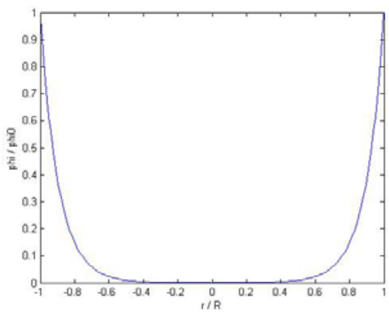

Figure 1. Normalized distribution of potential as a function of normalized radius

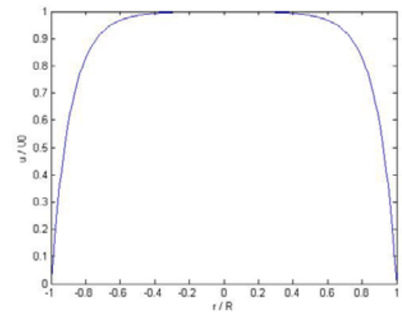

Figure 2. Normalized velocity profile as a function of normalized radius

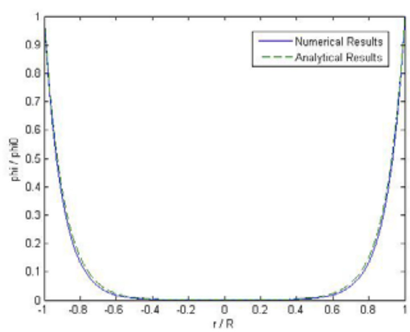

Figure 3. Comparison of results obtained from numerical and analytical simulations

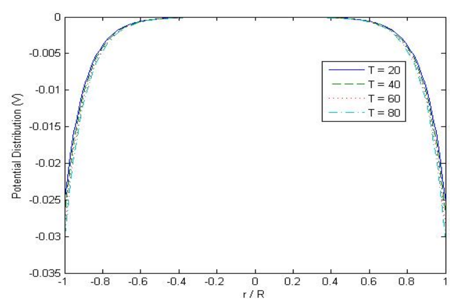

Figure 4. Potential distribution over nano-tube in different temperatures

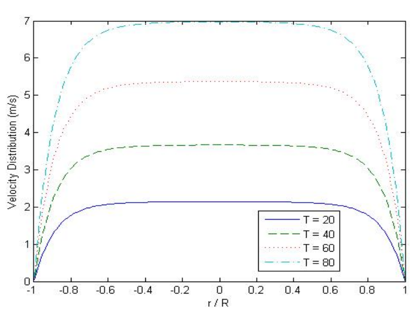

Figure 5. Velocity distribution over nano-tube in different temperatures

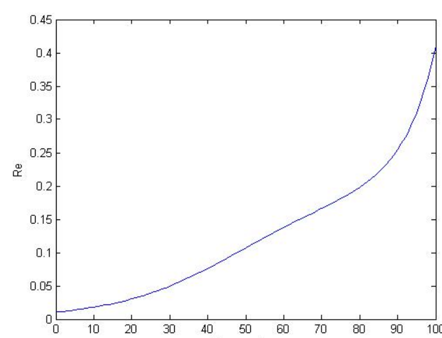

Figure 6. Temperature variations effect on Reynolds number in nano-tube