

Electrokinetic flow in a pH-regulated, cylindrical nanochannel containing multiple ionic species

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Abstract Considering the wide applications of the electrokinetic flow regulated by pH, we model the flow of an electrolyte solution containing multiple ionic species in a charge-regulated cylindrical nanochannel. This extends previous analyses, where only two kinds of ionic species are usually considered, and a charged surface assumed to maintain at either constant potential or constant charge density, to a case closer to reality. Adopting a fused silica channel containing an aqueous NaCl background salt solution with its pH adjusted by HCl and NaOH as an example, we show that if the density of the functional groups on the channel surface increases (decreases), it approaches a constant potential (charge density) surface; if that density is low, the channel behavior is similar to that of a constant charge density channel at high salt concentration and large channel radius. Several interesting results are observed, for example, the volumetric flow rate of a small channel has a local maximum as salt concentration varies, which is not seen in a constant potential or charge density channel.

Keywords Electrokinetic flow · pH-regulated cylindrical nanochannel · Multiple ionic species

1 Introduction

Electrokinetic flow has been applied extensively in separation devices, micropumps, and biochemomedical analyses (Daiguji et al. 2004a, b; Mei et al. 2008; Karenga and El Rassi 2010; Karnik et al. 2005; Wang et al. 2009). The fast advances in micro- and nano-scaled channel (Gasparac et al. 2004; Tas et al. 2002; Campbell et al. 2004; Mao and Han 2005) and pore (Li et al. 2001; Storm et al. 2003; Krapf et al. 2006) fabrication techniques make it highly necessary to establish a general theoretical approach for the analysis of the associated electrokinetic phenomena such as electroosmotic flow. For a narrow channel, since the thickness of electrical double layer (EDL) can be comparable with its radius, EDL overlapping might occur, yielding several interesting phenomena, such as ion enrichment (Pu et al. 2004) and concentration polarization (Kim et al. 2007; Nischang et al. 2006). As pointed out by Schoch et al. (2006), due to EDL overlapping, the behavior of the electroosmotic flow in a nanochannel deviates appreciably from that in a microchannel.

Both the direction and the magnitude of the electroosmotic flow in a narrow channel can affect strongly the associated applications; both of them depend upon its charged conditions, the strength of the applied electrical field and the physicochemical properties of the liquid phase. In practice, many narrow channels have ionizable functional groups and, therefore, are charged when in contact with liquid such as water. For example, pure silica channels have silanol groups (Nawrocki 1997; Liu and Maciel 1996), and titanium oxide (Hirst et al. 2005) channels bring hydroxide groups. When immersed in an aqueous environment, these functional groups dissociate or absorb ions, yielding a channel charged. In these cases, because the charged conditions depend upon the solution

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