# DESIGN OF SUPER-EFFICIENT MIXER BASED ON INDUCED CHARGE ELECTROOSMOTIC

by

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Short paper
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*The super-efficient sample mixing induced by the induced-charge electrokinetic flow around conducting/Janus cylinder was numerically studied in a confined |U-shaped microchannel with suddenly applied DC weak electric filed. It's found that there are four large circulations around the conducting cylinder and two smaller circulations around the Janus cylinder. The results show that samples can still be well mixed with high flux due to the induced electroosmosis. It is demonstrated that the local flow circulations provide effective means to enhance the flow mixing between different solutions. The dependence of the degree of mixing enhancement on the electric field is also predicted.*

Key words: *microchip, induced-charge electroosmosis, mixer*

## Introduction

The advent of microfluidic technology raises the fundamental question of how mix fluids at micron scales, where pressure-driven flows and inertial instabilities are suppressed by viscosity. In general, the manners of sample mixing are classified into two categories: diffusion and convection. Though a longer mixing length and does not mean a sufficient mixing [1], it is still usually used as a method to adding to sample mixing, and curved part is often introduced into a narrow microchannel [2]. Then, it is very important to have a study on sample mixing in curved microchannel, in fact, a lot of work has already been done on the mixing in pressure-driven microchannel [3-5]. From the works of some researchers [6, 7], it have been found that the instability of flow field and circulation regions induced by electroosmosis with high Reynolds number can be utilized to adding to sample mixing in some degree, but for a microchannel, there is a tradeoff between the capability of sample mixing and transport [8]. Wang *et al*. [9, 10] indicated that a step change in zeta potential will cause a significant variation in the velocity profile and pressure distribution of the flow, the barriers periodically embedded in the microchannel are beneficial to the chaotic mixing. The impetus of this paper is to advance the understanding of induce charge electroosmosis (ICEOF) around a conducting/Janus cylinder in a confined U-shaped microchannel, and it is mostly concerned with the design of module of pump and mixer separately, then they are integrated into the U-shaped microchannel to get super-efficient mixer owing to the high flux induced by ICEOF.

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## Computational model

The continuum approximation is not valid if the Knudsen number is larger than 0.1, then other equations instead of Navier-Stokes equation should be used, for example, the Burnett equations [11]. In the present study the Navier-Stokes equation can be used, so the governing equations are:

$$\rho(\boldsymbol{V}.\nabla)\boldsymbol{V} = -\nabla p + \mu\nabla^2\boldsymbol{V} + 2n_\infty ze\sinh\left(\frac{ze\varphi}{k_\mathrm{b}T}\right)\nabla\phi \tag{1}$$

$$\nabla^2\varphi = \frac{-\rho_e}{\varepsilon\varepsilon_0}, \quad \nabla^2\phi = 0 \quad (\boldsymbol{V}\cdot\nabla)C = D(\nabla^2 C) \tag{2}$$

where $\boldsymbol{V}$ is the velocity, $p$ – the pressure, $\rho$ and $\mu$ denote the density and the viscosity, respectively, $\varphi$ – the EDL potential which is associated with the electrical double layer (with the surface potential $\zeta$), and $\phi$ represents the externally applied potential. $\rho_e$ is the charge density, $\varepsilon$ – the dielectric constant of the electrolyte solution, $\varepsilon_0$ – the permittivity of vacuum, $z$ – the valence of ions, $e$ – the fundamental electric charge, $n_\infty$ – the ionic number concentration in the bulk solution, $T$ – the absolute temperature, $k_\mathrm{b}$ – the the Boltzmann's constant, $C$ and $D$ are the sample concentration and diffusivity, respectively. Electroosmotic velocity is on the order of 1 mm/s and the diffusion coefficient is approximately $10^{-10}$ m$^2$/s. Atmospheric pressure is specified at the inlet and outlet. For EDL potential, its normal-differential value on the inlet and outlet is zero. For sample mixing, a constant value for concentration (zero at the inlet 1 and one at inlet 2 ) is specified, while its normal-differential value is zero at other boundaries. The design of mixer with the module of pump and mixing is shown in fig. 1(a), the modules are magnified in fig. 1(b) and 1(c) is the mesh of the computational domain.

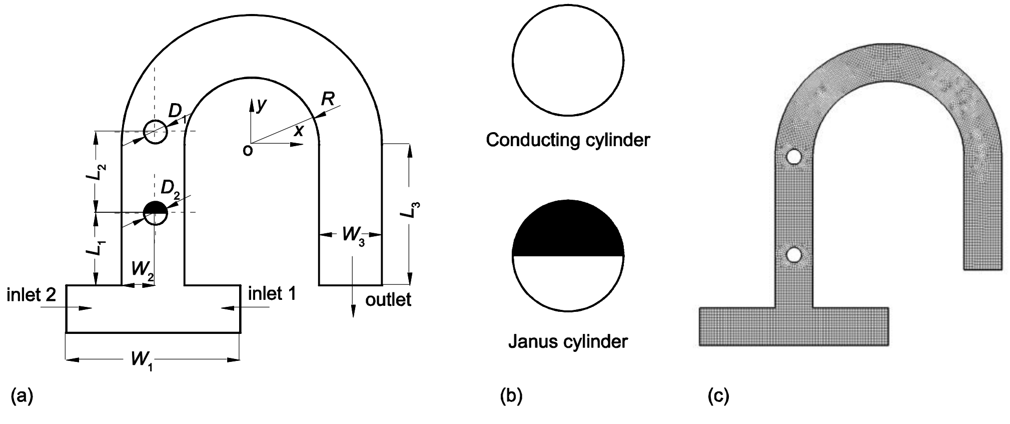

**Figure 1. Schematic diagram of (a) the U-shaped microchannel with conducting/Janus cylinders; (b) the property of cylinders and (c) the mesh used in numerical simulation**

## Results and discussions

The geometric parameters $W_1$ = 25 μm, $W_2$ = 2.5 μm, $W_3$ = 5 μm, $L_1$ = 7 μm, $L_2$ = = 13 μm, $L_3$ = 15 μm, $R$ = 10 μm, $D_1$ = 2 μm, and $D_2$ = 2 μm. Water-liquid is used as the working fluid and with $\varepsilon$ = 80, $\varepsilon_0 = 8.85 \cdot 10^{-12}$C/Vm, $\mu = 1.003 \cdot 10^{-3}$kg/ms, $\rho$ = 998.2 kg/m$^3$, $D = 10^{-10}$ m$^2$/s. The control-volume-based method was used to solve these equations, and specified discretization method was used to get the secondary order accuracy. The microchannel has an external electric potential of $\phi_{in} = 10$ V while $\phi_{out}$ is changeable. Zeta potential at the microchannel wall is zero. The mixing efficiency α is used to quantify the mixing enhancement by ICEKF,

$$\alpha = 1 - \frac{2\int_L |C - C_{\text{ideal}}|\,\mathrm{d}l}{L} \tag{3}$$

where $C_{\text{ideal}} = 0.5$ corresponds with perfect mixing on a normalized scale, $C$ is the concentration distribution at outlet. A fully mixed state therefore would have a 100% mixing efficiency while the unmixed state would have a 0% mixing efficiency. When the conducting cylinders are immersed in the electric field, a non-uniform distribution of zeta potential will be induced on the conducting surfaces, causing a varying driving force of the electroosmotic flow. Consequently, the slipping velocity on the conducting surfaces changes with position, resulting in a non-uniform flow field. Due to the oppositely charged surfaces, flow circulations are generated near the embedded cylinders in the channel. We examined two streams entering the

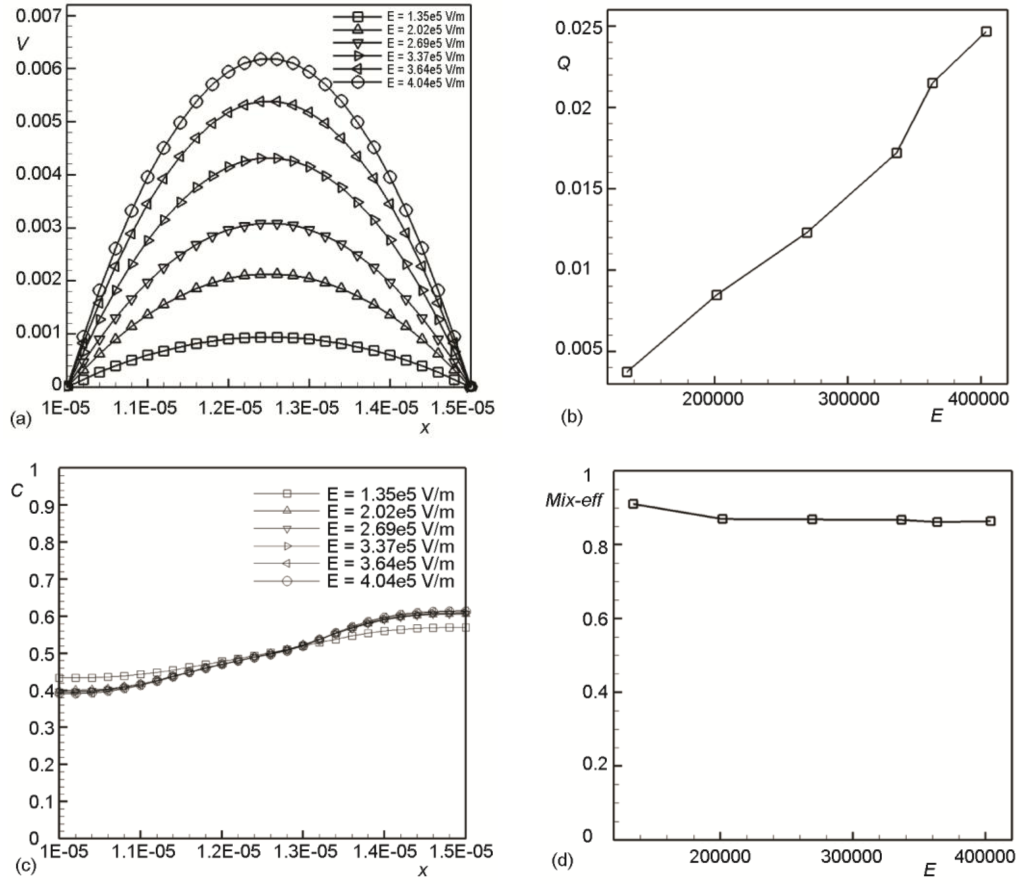

**Figure 2. Under different applied electric field; (a) the velocity magnitude profiles, (b) the flux, (c) the concentration profiles, and (d) the mixing efficiency at the outlet of the microchannel**

channel from the "inlet 1" and "inlet 2", with a non-dimensional normalized concentration of 0 and 1, respectively. The two parallel streams enter the inlet and initially separated by the channel center line. As shown in fig. 2(a), at the outlet of the microchannel, the velocity gradient increase with the increasing of the electrical field strength. As shown in fig. 2(c), at the outlet of microchannel, the concentration profile under lower electric filed is much closer to the ideal concentration, and there is no obvious difference among the concentration profiles under higher electric field. As shown in fig. 2(d), under a low applied electric field, this mixer gives high mixing efficiencies. That is because the molecular diffusion is the dominant mixing mechanism at a low applied field. Thus, as long as the microchannel has a sufficient length, the species in the microchannel can always be well mixed after a certain distance. However, if the electric field is increased, the fluid convection becomes dominant over the diffusion and the mixing efficiency is decreasing rapidly if there is no flow circulation in the channel. Higher electric field will induce stronger surface charges and thus stronger local flow vortices, tending to increase mixing efficiency. As shown in fig. 2(d), at high electric strengths, the conducting hurdles yield quite stable high mixing efficiencies. This is an effective way for fast fluid delivery with high effective species mixing. The mixer shows the highest mixing ability, with stable mixing efficiency of 92% at electric field of 135 kV/m. Combining fig. 2(b) with fig. 2(d), this mixer's capability of transport increases rapidly with electric field while its capability of mixing is almost stable.

## Conclusions

It is found there are four large circulations around the conducting cylinder and two smaller circulations around the Janus cylinder, and they can be used to mix samples with high flux. The dependence of the degree of mixing enhancement on the electric field is also predicted. The conclusions above can be utilized for the optimization of the design of microfluidic devices.

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