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Mixing of two different electrolyte solutions in electromagnetic rectangular mixers*

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Abstract: This study proposes a new electromagnetic rectangular mixer, and numerically examines the mixing characteristics of two different electrolyte solutions in the device under a uniform magnetic field. The mixer consists of a conduit with electrodes equipped on its top and bottom walls. The difference in the electric potentials applied to the sets of electrodes induces the current. The combination of the induced current and magnetic field yields Lorentz force, resulting in the fluid motion for pumping and mixing of the two different fluids. The numerical simulation is carried out with the use of commercial software CFX. The present numerical model is validated by an existing numerical work. The effect of different variables on mixing efficiency is investigated in many different cases with two different heights of the duct and various input voltages of the electrodes. The current simulation results indicate that the mixing performance can be enhanced by using multiple sets of electrodes and applying higher input voltages (absolute values) to the electrodes.

Key words: CFX, electrolyte solution, Lorentz force, mixer, mixing efficiency

Introduction

In recent years, there has been a growing interest in microfluidic devices, which are widely used in biodetection, biotechnology, chemical reactors, medical and environmental monitors. In order to facilitate chemical and biological reactions, the mixing and pumping of various reagents and chemicals are often necessary. Since the characteristic length of microdevices is usually very small, the effective mixing is too slow to be achieved with low diffusivity. Meanwhile, the Reynolds number of liquid flows in such micro-channels is usually very small, thus turbulence that may enhance mixing is not available[1]. Therefore, more efficient microdevice is required for higher mixing efficiency.

Generally speaking, microfluidic mixers can be categorized as passive or active micromixers. The passive microfluidic mixers perform the mixing by increasing the contact area and contact time of the mixing species[2]. Many investigators have performed various researches on passive microfluidic mixers. For example, Buchegger et al.[3] presented a multi-lamination micromixer with four wedge-shaped inlet channels for fast and highly uniform fluid mixing in the low-millisecond range. The four-layer laminar flow was created by a fluidic distribution network. Due to the optimized wedge-shaped inlet channels, this micromixer could be applicable in a situation with very low flow rate and could reduce reagent consumption. Liu et al.[4] fabricated a three-dimensional serpentine microchannel with a "C-shaped" repeating unit in silicon wafer, where the mixing was enhanced passively by implementing chaotic advection. Yi and Bau[5] designed a two-dimensional serpentine conduit in low-temperature co-fired ceramic tapes. They took advantage of bend-induced vortices to stir the fluids and enhance the mixing process. Wang and Lin[6] constructed a passive chaotic micromixer with helical microchannels, which achieved higher mixing efficiency

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compared to those of straight and serpentine microchannels when Reynolds number was low. Wang et al.[7] numerically investigated the electromagnetic features and mixing performance of diffusing species in the passive micromixer embedded with barriers. They found that the specially embedded periodic barriers could shift the flow pattern and produce blinking flow, which could facilitate the mixing process.

The active microfluidic mixers enhance the mixing performance by applying some external forces to accelerate the transport process[8]. Typically, active mixers use acoustic (or ultrasonic), dielectrophoretic, electrokinetic time-pulse, pressure perturbation, electro-hydrodynamic, magnetic and thermal techniques[2]. The magneto-hydrodynamic (MHD) effect has been used by many researchers to realize active micromixers. For example, Bau et al.[9] designed an active micromixer equipped with arrays of electrodes on the conduit's bottom wall. By applying alternating potential differences across the pairs of electrodes, the current was induced. In the presence of a magnetic field, the combination of the current and magnetic field induced Lorentz force, which could be used for mixing. Yi et al.[10] developed a micromixer which consisted of a circular cavity. An electrode (denoted by C) was deposited on the side wall of the cavity, and two copper-wire electrodes (denoted by A and B) were placed eccentrically inside the cavity. By alternately activating two pairs of electrodes AC and BC over a period, the complicated fluid motions could be generated. In addition, the complexity of the motion increased with the increasing of the alternation period. La et al.[11] designed an MHD mixer, in which a pair of electrodes (for pumping) were positioned on the side walls and many pairs (for mixing) on the bottom wall repeatedly. The Lorentz force, a driving force for the flow, could be variously induced in the microchannel by changing the applied voltages of the electrodes. Three-dimensional CFD simulations under steady-state condition were carried out to examine the mixing performance of the device.

The Lorentz force can be used not only for mixing, but also for pumping. In previous studies about microfluidic systems, Jang and Lee[12] presented a micropump where pumping mechanism was based upon MHD principles. Lorentz force was used as the pumping source of the micropump. The performance of the micropump was obtained by measuring the pressure head difference and flow rate with different voltages. Lemoff and Lee[13] constructed an AC MHD micropump in which the Lorentz force was used to propel the electrolyte solutions. The micropump produced a continuous (not pulsatile) flow and was compatible with solutions containing biological specimens. Their results demonstrated that multiple, independently-controlled pumps could be integrated on a single chip through the design of the AC MHD micropump. Zhong et al.[14] fabricated a micropump with co-fired ceramic tapes at low temperature. The shape of the conduit in the device was of a toroidal loop with the rectangular cross-section. They showed that the Lorentz force could be utilized to propel liquids such as saline solution and deionized water in minute conduits. Bau et al.[15] presented the feasibility of the use of Lorentz force to control fluid flow in microfluidic networks. By prescribing either the potential or the current across electrode pairs, the liquid flow could be controlled in a programmable way, without the need for mechanical pumps or stirrers.

In view of the above-mentioned previous works, several studies[9-11] have been performed for MHD mixers, but numerical works on MHD mixers have rarely been conducted. Bau et al.[9] presented the theoretical and experimental investigation of the electrolyte solutions in a rectangular MHD micromixer. Here, the electrodes positioned on the bottom wall of the microchannel can be used for mixing only. But, in the present study, the electrodes positioned on the top and bottom walls of the microchannel can be used for simultaneous mixing and pumping, thus the time for well mixing can be shortened. A two-dimensional, time-periodic flow of saline solutions in a circular MHD mixer is theoretically and experimentally studied by Yi et al.[10], while a three-dimensional, steady-state, incompressible, constant-property, laminar flow of electrolyte solutions in a rectangular MHD mixer is numerically considered in this study. In the works of Bau et al.[9] and Yi et al.[10], the mixers have the function of mixing only. Though the microdevice in La's work[11] can serve both as a pump and a mixer, a pair of side-walled electrodes for pumping and many pairs of bottom-walled electrodes for mixing are used.

In the present study, a new electromagnetic rectangular mixer for electrolyte solutions with pumping function is proposed. An arrangement of electrodes quite different from those of Refs.[9-11] is devised, so that an electrode can be used for generating the current flow for simultaneous pumping and mixing. By applying different electric potentials to different electrodes, the Lorentz force with different intensity is generated, which induces the fluid motion. In the present work, many different cases with two different heights of the duct and various electrode voltages are numerically investigated for the comparison of the mixing performance, which are rarely studied in Refs.[9-11]. The detailed information of current density, velocity distribution, and mass fraction of one fluid, together with the value of mixing index, is obtained.

1. Problem formulation

1.1 *Geometry, magnetic field and materials*

In the current study, the flow fields with one set,