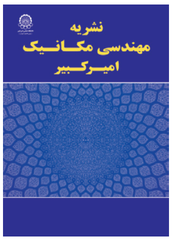

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Numerical Simulation of Mixing Two Fluids of Different Viscosities in a Microchannel with Curved Stirrer by Lattice Boltzmann Method

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ABSTRACT: In the present study, mixing of two fluids of different viscosities in a micro channel with an oscillating curved stirrer was simulated by multi relaxation time Lattice Boltzmann method and the effect of geometric shape, oscillating speed and amplitude and viscosity logarithmic ratio on mixing efficiency was analyzed. In researches in this field, the stirrer is considered as cylinder or rectangle shape and in most these researches, two fluids are same. In this study, a curved stirrer was used for mixing two fluids of different viscosities in microchannel for the first time. Calculations are performed for the dimensionless parameters of the problem including the oscillation amplitude K, viscosity logarithmic ratio R and Strouhal number St for Re=80 and Sc=10. NASA/LANGLEY LS(1)-0417 (GA(W)-1) airfoil shape was used for curved stirrer. Results showed that mixing efficiency of two fluids of same and different viscosities in microchannel with oscillating curved stirrer was higher than microchannel with oscillating rectangle stirrer. In addition, results revealed that increase in Strouhal number causes increase in mixing efficiency on studied oscillating amplitude. Optimum efficiency is on oscillating amplitude 0.5 on all studied Strouhal numbers. Also mixing efficiency decreases with increase of viscosity logarithmic ratio on studied Strouhal numbers.

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1- Introduction

Fluid mixing is an important process in the chemical industry. In mixing systems, fluid can be mixed with any of the other phases: liquid, solid, and gas. Micromixing is mixing at the smallest scale of fluid motion and molecular motion [1]. Active mixers rely on an external energy source to achieve mixing. Mixing caused by micro stirrers is in this category [2].
Shamsoddini et al. [3] numerically investigated the mixing flow in a micromixer with cross-shaped and straight stirrers using the Incompressiblesmoothed Particle Hydrodynamics (ISPH) method. It was found that the cross-shaped stirrer is more effective than the straight stirrer. Ghanbari et al. [4] studied the mixing of two fluids with different density and viscosity in a microchannel equipped with an oscillating stirrer by means of commercial code CFX. They showed the maximum mixing index changes in the case of different density and viscosity is lower than the one in case of similar fluids. Ortega-Casanova evaluated the mixing enhancement inside a straight microchannel equipped with a transversely oscillating square cylinder [5] and a rotationally oscillating square cylinder [6], using the commercial software ANSYS-Fluent. He detected oscillating square cylinder and rotationally oscillating square cylinder can improve the mixing efficiency about 10% and 15% respectively. In researches in this field, stirrer is considered as cylinder or rectangle shape and in most these researches, two fluids are same. In this study, a curved stirrer was used for mixing two fluids of different viscosities in a microchannel for the first time.

2- Methodology

2- 1- 2.1. Geometry

The schematic view of the microchannel is shown in Fig. 1. The curved stirrer is in the shape of NASA/LANGLEY LS(1)-0417 (GA(W)-1) airfoil. The stirrers forced to oscillate with the angle of $\acute{a}(t) = 2\pi K \sin(2\pi f_p t)$ where K, $f_{p,}$ and t are the dimensionless amplitude, frequency and oscillation time, respectively. Therefore, the angular velocity of the stirrer will be $\grave{u}(t) = 4\pi^2 K f_p \cos(2\pi f_p t)$

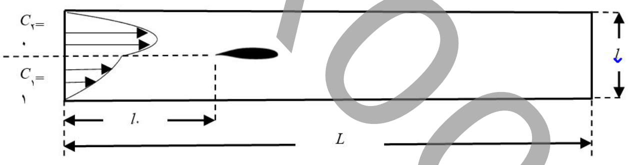

Fig. 1. Schematic view of the microchannel

In the present study, first fluid viscosity is constant and second one is changed [7].

$$R = \ln \frac{\mu_2}{\mu_1} \tag{1}$$

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To examine the mixing rate in the present problem, the time-averaged mixing index is used [1].

2- 2- 2.2. Governing equations

Governing equations are:

$$\frac{D\rho}{Dt} = -\tilde{n}\nabla \cdot \boldsymbol{V} \tag{2}$$

$$\rho\frac{D\boldsymbol{V}}{Dt} = -\nabla P + \mu\nabla^2\boldsymbol{V} \tag{3}$$

$$\frac{DC}{Dt} = Di\nabla^2 C \tag{4}$$

Where $\boldsymbol{V}$, P, C, and D_i are the velocity vector, pressure, concentration and diffusion respectively.

2- 3- 2.3. Numerical method and boundary condition

A double Multiple Relaxation Time Lattice Boltzmann Method (MRT-LBM) is employed for solving the governing equations because of the higher efficiency, accuracy, and stability than other Lattice Boltzmann Method (LBM) schemes. The D2Q9 model for the velocity field [8], while the D2Q5 model for the concentration field [9] are used in the present simulation.

For flow and concentration field, the Bounce-back boundary condition [8] is applied to the microchannel walls, while Zou and He model [10] and known concentration boundary condition [11] are used for flow and concentration field at the microchannel inlet respectively. For flow and concentration field at the microchannel outlet, Bounce-back boundary condition and constant pressure boundary condition are used respectively. Guo et al. [12] and Li et al. [9] curved boundary treatment are employed to model the velocity and concentration boundary condition on the stirrer surface respectively.

3- Results and Discussion

At the study of geometric shape, we consider a rectangle stirrer (D*0.213D) in a same microchannel. According to Fig. 2, Results showed that mixing efficiency in microchannel with oscillating curved stirrer was higher than microchannel with oscillating rectangle stirrer.

In addition, results revealed that an increase in Strouhal number causes increase in mixing efficiency on studied oscillating amplitude. Optimum efficiency is on oscillating amplitude 0.5 on all studied Strouhal numbers.

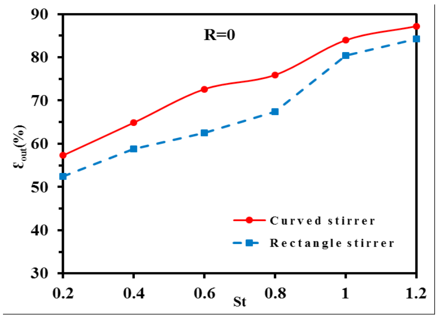

Fig. 2. Mixing efficiency variations related to various Strouhal numbers for curved and rectangle stirrer

The variations of mixing efficiency with respect to the Strouhal numbers at three viscosity logarithmic ratios showed in Fig. 3 and concentration contours for these ratios present in Fig. 4. According to Fig. 3 in each certain Strouhal number with an increase of viscosity logarithmic ratio causes decrease in mixing efficiency. According to Fig. 4 at R=0, mushroom vortexes are formed completely and affect the entire width of the microchannel so the mixing is well done. However, at R=1, mushroom vortexes aren't formed completely and the contact surface of two fluids is lower than before. At R=2, no mushroom vortexes are formed and crescent vortex is formed lower than R=1 and the fluid near the walls is less involved in the mixing process. Therefore, the greater the viscosity difference, two fluids become more resistant to deformation and less mixing takes place.

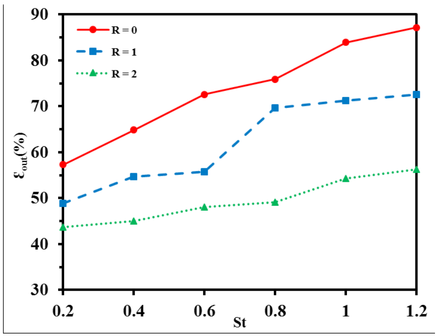

Fig. 3. Mixing efficiency changes related to Various Strouhal numbers at different viscosity logarithmic ratios

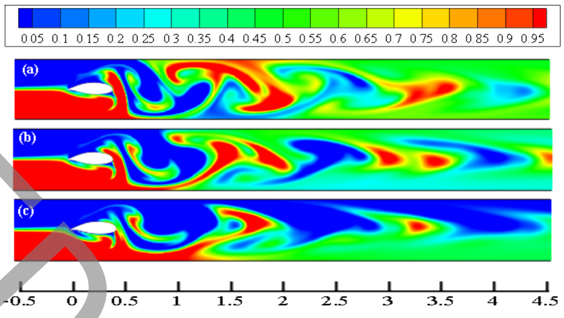

Fig. 4. Concentration contours at K=0.5 and St=1 at a) R=0 b)R=1 c)R=2

4- Conclusions

Based on the simulations, the following results can be expressed:

- The mixing efficiency of two fluids of same and different viscosities in microchannel with oscillating curved stirrer was higher than microchannel with oscillating rectangle stirrer.
- Optimum efficiency is on oscillating amplitude 0.5 on all studied Strouhal numbers.
- In each certain Strouhal number with the increase of viscosity logarithmic ratio causes decrease in mixing efficiency

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