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Flow and mixing in rotating zigzag microchannel

Yong Ren, Wallace Woon-Fong Leung *

Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hung Hom, Hong Kong, China

HIGHLIGHTS

- ▶ Rotational benefit on flow and mixing in zigzag microchannel.
- ▶ Prograde and retrograde behavior.
- ▶ Experiment and simulation confirmation.

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ABSTRACT

The flow and mixing in rotating zigzag microchannel was investigated experimentally and numerically with objective of improving mixing, which is largely due to recirculating crossflow in the cross-sectional plane of the channel and the bend connecting tilted channel segments. Unlike the conventional rotating radial channel, crossflow in the zigzag channel is highly intensified from a combination of: (a) centrifugal acceleration component in the cross-sectional plane due to the inclined channel segments, (b) centrifugal acceleration generating Görtler vortices at "channel bends", and (c) Coriolis acceleration. When the channel segment in the zigzag channel is inclined towards rotation direction (prograde), all three accelerations are aligned intensifying the crossflow; however, when it is inclined opposite to rotation (retrograde), Coriolis acceleration competes with the other two accelerations producing complex flow. Unlike a stationary zigzag channel, flow in a rotating prograde bend with outlet in the direction of rotation further induces Coriolis acceleration which adds onto the centrifugal acceleration producing enhanced crossflow and mixing, vice versa for a retrograde bend. A numerical model has been developed accurately accounting for the interactions of throughflow, crossflow and material dispersion by diffusion and convection in a rotational platform. An experimental microfluidic platform with rotating zigzag microchannel has also been developed. Experimental results on mixing quality carried out at two rotation speeds compared well with prediction from the numerical model. The overall mixing quality of a rotating zigzag channel is much improved compared with that of a stationary zigzag channel and of a rotating radial channel, due to the intensified crossflow driven by the additional acceleration components. A study on different bend angle on mixing quality in zigzag channel revealed that there is no optimal bend angle to achieve superior mixing enhancement, as a result of the complex flow pattern generated by the three competing accelerations.

1. Introduction

Achieving fast mixing in microfluidics has attracted much attention recently as it is an important task for micro total analysis systems (μTAS), or lab on a chip (LOC) systems, which have been extensively applied in biochemistry analysis and drug delivery. However, microscale flow is strictly laminar and dominated by viscous effect. In lack of large-scale convection motion in the flow, mixing of different solutions is by means of molecular diffusion between fluid regions, or fluid layers, with non-uniform solute and suspended solid concentration. The characteristic cross-sectional dimension of a micromixer d is O(100 μm). Assuming fluid regions/layers also have similar dimension, and given the molecular diffusion coefficient D is typically very small between 10^{-11} m^2/s for large macromolecules (i.e. protein) and 10^{-9} m^2/s for small molecules (i.e. sodium chloride), the time scale for diffusion, t_D ($\sim d^2/D$) ranges between 10 s and 17 min [1], which is generally much greater than the residence time t_R ($\sim L/U$) of the fluids in the channel with length L and average velocity U. Therefore, mixing by molecular diffusion is ineffective. In order to develop fast mixing, one effective means is to induce secondary or crossflow in a throughflow device, so that the mixing length ℓ_m can be much reduced by convection of the crossflow when compared to d, and

* Corresponding author. Tel.: +852 27666670; fax: +852 23654703.
E-mail address: mmwleung@polyu.edu.hk (W.W.-F. Leung).

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