11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

MIXING OF TWO-PHASE FLOW IN ROTATING MICROCHANNELS WITH A CIRCULAR CHAMBER

Jerry M. Chen [1*] and Huan-Choa Chiu [2]

[1] Department of Mechanical Engineering, National Chung Hsing University, South Dist., Taichung 402, Taiwan
jerryc@dragon.nchu.edu.tw

[2] Department of Mechanical Engineering, National Chinyi University of Technology, Tai Ping, Taichung 411, Taiwan
chc@chinyi.ncut.edu.tw

Key Words: *Rotating Microchannel, Centrifugal Force, Coriolis-Induced Vortex, Micro Mixing.*

Microfluidic technology has received great and increasing attention in the past two decades for its wide applications in chemical and biochemical analyses. Among these applications, mixing of fluids often plays a key role in the analyses. The mixing mechanism in a microscale channel, where the flow is typically laminar, relies mainly on molecular diffusion at the fluid interface and it takes a much longer time for complete mixing than in a macro system. Alternative to stationary micromixer that often utilizes high aspect ratio and multilaminated structures to induce the secondary flows [1], centrifugal microfluidics fabricated on a rotating disc offers a promising approach to mixing enhancement. Fluids in centrifugal microfluidics are pumped via the centrifugal force and the fluid mixing provides the advantages of safety as well as low-cost, easy operation and parallel detection [2]. However, much less studies have been focused on the flow patterns and the mixing mechanism taking place in the centrifuge-driven microchannels due to the rotational nature that restricts the mixing process from detailed flow visualization.

In this study, we present results of the numerical simulation using the finite volume scheme for the flow in the centrifugal microfluidics involving mixing of two fluids. The microfluidics is consisted of Y-shaped channels to bring fluids A and B into contact and an expanded-contracted circular chamber to intensify Coliosis effects for enhancement of the mixing. In the numerical simulations, the flow velocity $\mathbf{V}$ and species concentration C were computed from the Navier-Stokes equations and the diffusion convective equation on the rotating frame for spinning speeds from 300 to 1200 rpm. The numerical simulations provide detailed structure of the flow field in terms of cross-sectional distributions.

Figure 1 shows the cross-sectional concentration distributions along the channel of 300 μm×300 μm in cross section with a circular chamber of 750 μm in radius at a rotating speed Ω = 840 rpm. Fluids A (red) and B (blue) are brought to contact at the Y-junction and then the fluid A begins to mix with fluid B at the interface (y = 0). It can be seen that Coriolis force begins to influence the interface at the Y-junction. The Coriolis force, acting in the direction opposite to the tangential velocity of the rotating frame, pushes fluid B in the vicinity of the mid-plane ($z = 150$ μm) to penetrate into the fluid A territory and fluid A is driven toward the upper and lower walls to form a "C-shaped" distribution, which is referered to as interface folding. Entering the circular chamber, the fluids flip and exchange the relative position from AB to BA. In the mean time, the folded and flipped interface is stirred by the Coriolis-induced vortices in the suddenly widened region. At downstream of the circular chamber, fluids A and B appear almost mixed showing a nearly all green cross-section.

Simulations of the mixing of two-phase flow in rotating micrchannels reveal that Coriolis-induced vortices grow in strength with increasing rotational speed and develop into complex three-dimensional vortices in the suddenly expanded and contracted circular chamber. Inside the chamber, the Coriolis-induced vortices can cause folding, flipping and stirring of the interface between the two fluids. The mixing efficiency across the chamber is noticeably enhanced and the enhancement is more pronounced at higher rotational speeds. The mixing efficiencies, calcaluated based on the cross-sectional species-concentration distributions, are found to increase by 13 to 61% across the chamber ($x = -1$ to 1 mm) as indicated in Fig. 2 for $\Omega = 300$ and 1200 rpm. It is also found that mixing efficiency for the case with the circular chamber significantly exceeds the one with staight channel roatating at the same speed. At the channel exit ($x = 15$ mm), the mixing efficiency can reach more than 90%, near the completely mixed state, for the higher rotational speeds $\Omega = 840$-1200 rpm.

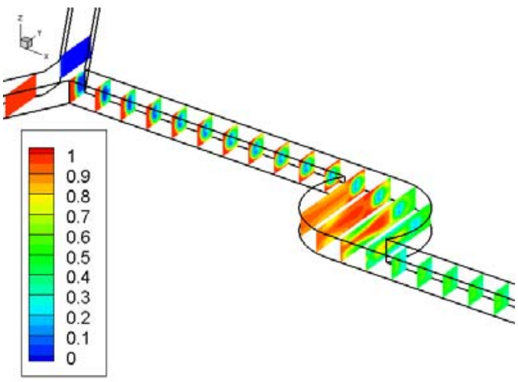

Figure 1 Cross-sectional concentration distributions along the channel with a circular chamber rotating at $\Omega = 840$ rpm. Red color represents fluid A ($C = 1.0$) and blue stands for fluid B ($C = 0$), green color denotes the complete mixed state ($C = 0.5$).

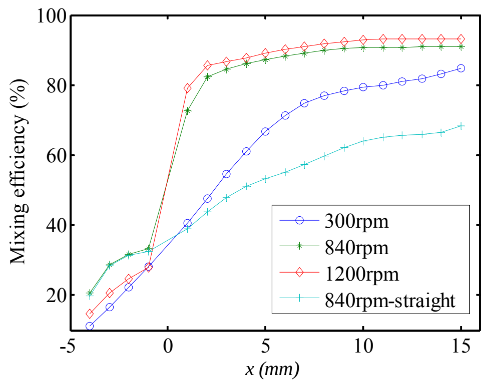

Figure 2 Variations of calculated mixing efficiency with the channel position across the expanded chamber for rotational speeds from $\Omega = 300$ to 1200 rpm and for the straight channel at $\Omega = 840$ rpm.

REFERENCES

[1] M. A. Ansari and K. Y. Kim, Shape optimization of a micromixer with staggered herringbone groove. *Chemical Engineering Science*, Vol. **62**, pp. 6687-6695, 2007.

[2] M. Madou, J. Zoval, G. Jia, H. Kido, J. Kim and N. Kim, Lab on a CD. *Annu. Rev. Biomed. Eng.*, Vol. **8**, pp. 601-628, 2006.