Two-fluid Mixing in a Microchannel

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Extended Abstract

Two-fluid mixing is an essential process in many microfluidic devices. Fluid properties such as density, viscosity and diffusivity vary with changes in variables such as temperature and mass fraction of species; hence, these variations should be taken into account when evaluating the extent to which two fluids mix. Most previous experimental studies on two-fluid mixing in microfluidic devices have used flow visualization to probe the mixing performance. Koch et al [1] used red and green inks dissolved in ethanol to test a lateral micro mixer. Liu et al. [2] and Beebe et al. [3] used solutions of phenolphthalein and sodium hydroxide dissolved in ethyl alcohol to test the mixing performance of a three-dimensional serpentine mixer. Lee et al. [4] and Stroock et al. [5] used distinct streams of a fluorescent and a clear solution to test the mixing performance of an active mixer with a pressure source/sink system and of a staggered herringbone mixer. However, few studies have been performed to elucidate the variation in mixing behavior with changes in the difference in the properties of two fluids.

In the present study we examined the influence of difference in the properties of two mixing fluids on the mixing behavior. A numerical study of the mixing of two fluids (pure water and a solution of glycerol in water) in a microchannel was carried out. By varying mass concentration (ϕ) of glycerol in the glycerol/water solution, the variation in mixing behavior with changes in the difference in the properties of the two fluids (e.g., viscosity, density and diffusivity) was investigated. Three values of ϕ were chosen in the present study, ϕ=0, 0.2 and 0.4. The mixing phenomena were tested for two typical passive micromixers: a three-dimensional serpentine mixer and a staggered herringbone mixer. The governing equations of continuity, momentum and solute mass fraction were solved numerically. To evaluate mixing performance, a criterion index of mixing uniformity, C_{mix}, was proposed. In the systems considered, the Reynolds number based on averaged properties was Re=1 and Re=10. At Re=1, the mixing performance of the serpentine mixer varied inversely with ϕ due to the dominance of molecular diffusion (Fig.1). When the Reynolds number was increased to 10, the opposite trend was observed (Fig.2). From the distributions of tracer particles at the outlet cross-section, it is clear that there is no evidence of chaos advection at low Re (Fig.3). The change in behavior of mixing performance with the increasing Re was attributed to the enhancement of chaotic advection at large ϕ (Fig.4). However, no such change was observed on increasing the Reynolds number in the herringbone mixer. Its mixing performance at both Re=1 and Re=10 shows the similar dependence on ϕ (Figs.5-6), although the curves are closer together at higher Re. The mixing performance actually deteriorated with the increasing Re. The distributions of tracer particles at the outlet cross-section are basically the same for both Reynolds numbers (Figs.7-8). Unlike the mixing inside the serpentine mixer, flow advection inside the herringbone mixer does not show the expected enhancement when the Reynolds number is increased. The residence time of the fluids inside the mixer are greatly reduced on increasing Re from 1 to 10, which diminishes the mixing performance. Moreover, inspection of mixing photographs captured at different cross-sections revealed that the breakdown of the glycerol-containing solution was largely independent of Re and ϕ.

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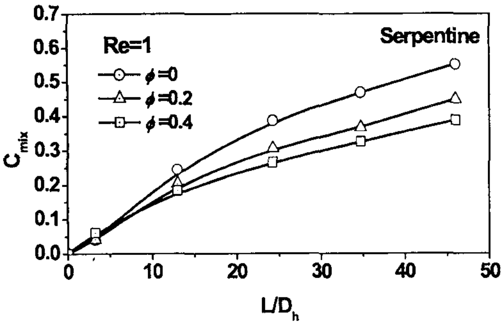

Fig.1 Mixing performance of three-dimensional serpentine mixer at Re=1

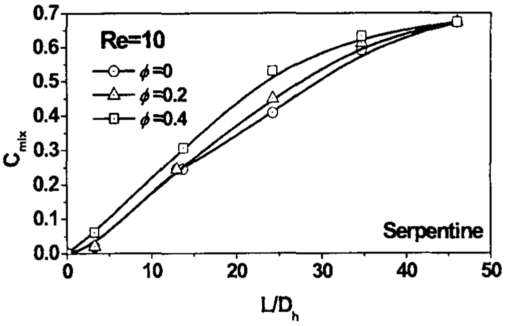

Fig.2 Mixing performance of three-dimensional serpentine mixer at Re=10

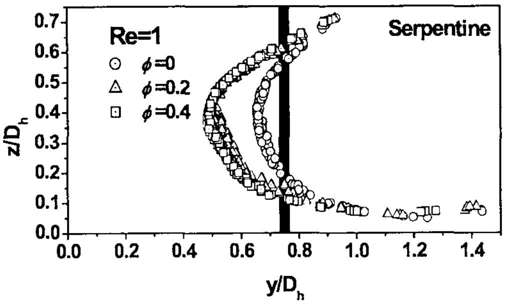

Fig.3 Particle traces at the outlet cross-section of three-dimensional serpentine mixer at Re=1

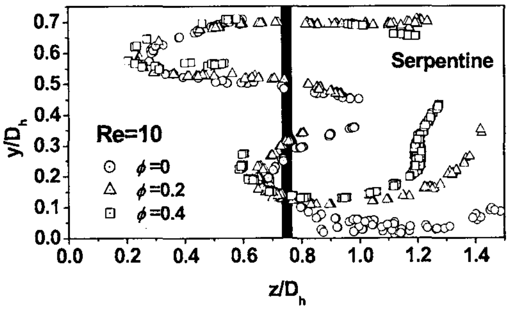

Fig.4 Particle traces at the outlet cross-section of three-dimensional serpentine mixer at Re=10

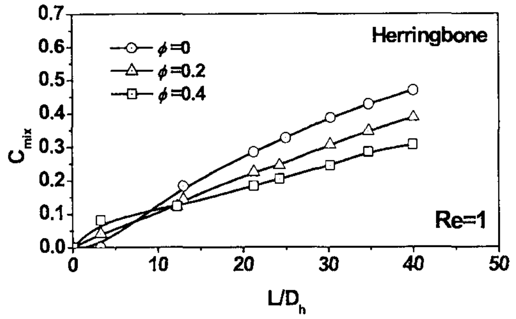

Fig.5 Mixing performance of staggered herringbone mixer at Re=1

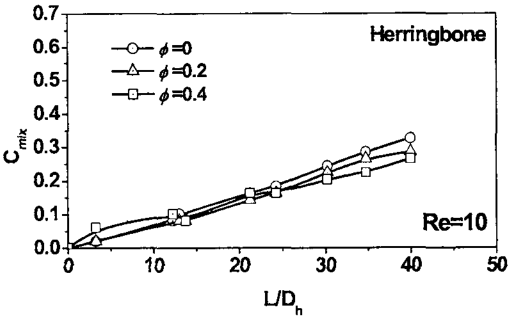

Fig. 6 Mixing performance of staggered herringbone mixer at Re=10

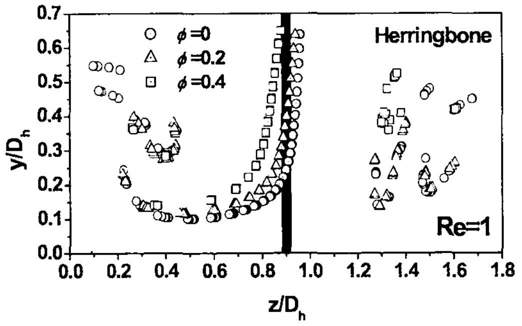

Fig.7 Particle traces at the outlet cross-section of staggered herringbone mixer at Re=1

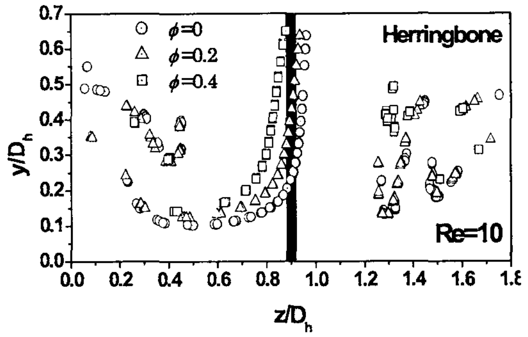

Fig.8 Particle traces at the outlet cross-section of staggered herringbone mixer at Re=10

References

[1] Koch M., Witt H., Evans A.G.R., Brunnschweiler A., "Improved characterization technique for micromixers", *Journal of Micromech. Microeng*, Vol. 9, (1999), pp.156-158

[2] Liu R. H, Mark A. S., Kendra V. S., "Passive mixing in a three-dimensional serpentine microchannel", *Journal of MEMS*, Vol. 9, (2000), pp.190-197

[3] Beebe D J., Adrian R. J., Michael G.O., Mark A.S., Hassan A., Jo B. H., "Passive mixing in microchannels: Fabrication and flow experiments", Mec.Ind. Vol. 2, (2001), pp.343-348

[4] Lee Y. K., Tabeling P., Shih C., "Characterization of a MEMS-fabricated mixing device", *Proc. ASME IMECE*, (2002), Orlando, Florida.

[5] Stroock A.D., Dertinger S.K.W., Ajdari A., Mezic I., Stone H.A., Whitesides G.M., "Chaotic mixer for microchannels", *Science*, Vol. 295, (2002), pp.647-650