Ferrofluid Mixing in A Double-Layer Magnetic Micromixer

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INTRODUCTION

In this work, a magnetic micromixer with embedded microscale magnet was developed and the simulation of mixing performance and working mechanism were conducted by COMSOL Multiphysics. The micromagnet made of neodymium powder and polydimethylsiloxane (PDMS) will generate magnetic force acting on ferrofluid so it is mixed with distilled water after flowing past the vertical magnetic bars underneath fluidic channel. The simulation of microscale mixing can be achieved by two steps. The magnetic field was calculated by AC/DC module and then coupled with the mixing phenomenon processed by laminar flow and species transport package.

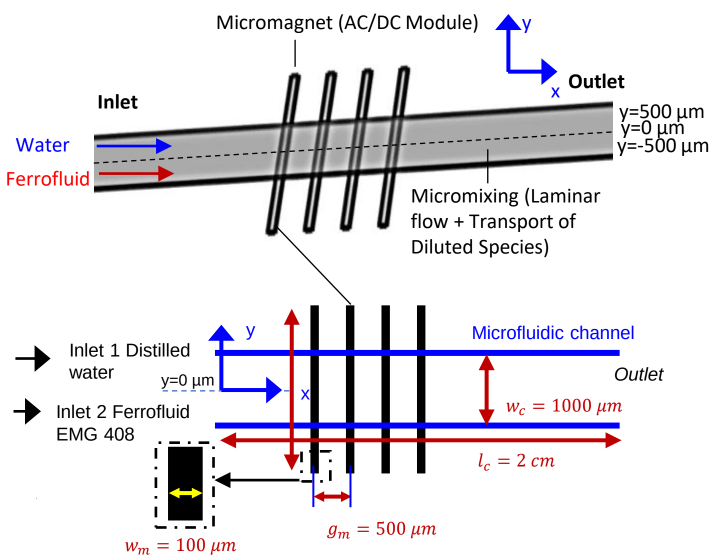


Figure 1. Schematic and dimension of double-layer magnetic micromixer. w_c and l_c are the width and length of the microfluidic channel, respectively; $\alpha = 90°$ is the angle between micromagnet and flow direction; w_m and l_m are the width and length of the micromagnet; g_m is the gap distance between each micromagnet.

COMPUTATIONAL METHOD

The Navier-Stokes equation and continuity equation for incompressible flow describe the flow in the channels:

$$\rho\frac{\partial \boldsymbol{u}}{\partial t} + \rho(\boldsymbol{u}\cdot\nabla)\boldsymbol{u} = -\nabla p + \eta(\nabla^2\boldsymbol{u}) + \boldsymbol{f_m}$$

$$\nabla\cdot\boldsymbol{u} = 0$$

where η denotes the dynamic viscosity, $\boldsymbol{u}$ is the velocity, ρ equals the fluid density, and p refers to the pressure. $\boldsymbol{f_m} = \mu_0(\boldsymbol{M}\cdot\nabla)\boldsymbol{H}$ is the magnetic force acting on ferrofluid, where μ_0 is the magnetic permeability of free space, $\boldsymbol{M}$ is the field dependent magnetization and $\boldsymbol{H}$ is the external applied magnetic field.

The mass flux is given by diffusion and convection, the resulting mass balance is

$$\nabla\cdot(-D\nabla c + c\boldsymbol{u}) = 0$$

where D denotes the denotes the diffusion coefficient and c gives the concentration of ferrofluid.

RESULTS

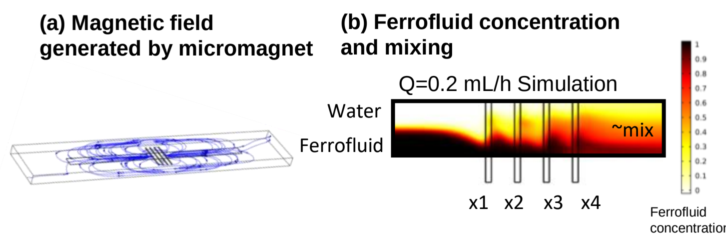
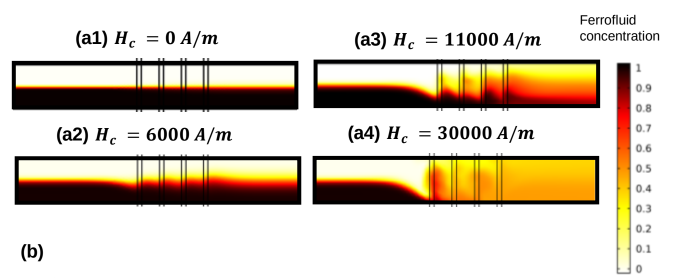


Figure 2. (a) Magnetic field generated by micromagnet; (b) Simulation results of ferrofluid concentration and mixing progress

Original Ferrofluid	Density	ρ_f	$1.07 \times 10^3\ kg/m^3$
	Saturation Magnetization	M_s	$6.6\ mT$
	Magnetic Susceptibility	χ_f	0.5
	Viscosity	η_f	$2\ mPa\cdot s$
Distilled water	Density	ρ	$1\times 10^3\ kg/m^3$
	Viscosity	η	$1\ mPa\cdot s$

Table 1. Table of fluid properties



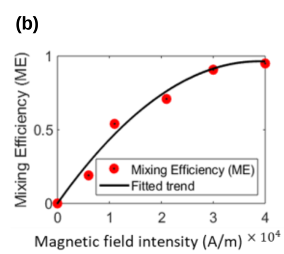


Figure 3. (a) Simulated results of ferrofluid concentration under the effect of various magnetic field intensity Hc. The total flow rate Q= 0.2 ml/h for all the groups. (b) Mixing efficiency under various magnetic field intensity.

CONCLUSION

The ferrofluid and water which were initially injected into fluidic channel had an interface but were later mixed homogeneously at the outlet of fluidic channel under the effect of the magnetic field generated by the micromagnet. The stronger magnetic field intensity is able to accelerate the mixing progress.

REFERENCES:

1. Wen, Chih-Yung, Kuok-Pong Liang, Hua Chen, and Lung-Ming Fu. "Numerical analysis of a rapid magnetic microfluidic mixer." Electrophoresis 32, no. 22 (2011): 3268-3276.
2. COMSOL Multiphysics Reference Manual