Numerical Study on the Effect of Optical Rotors on Flow and Mixing in Microfluidics Devices

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The objective of the thesis is to demonstrate the use of an optical rotor as a controllable element to enhance mixing in microfluidics devices by Computational Fluid Dynamics, and give a guideline for designing more effective optical micro rotor systems.

The optical rotor massively fabricated by photolithography is manipulated by the power of light; therefore it requires neither mechanical contact nor electrical wire. The use of a rotor to improve mixing is rarely studied, and the mixing performance of the devices is often examined by a single control parameter-rotation speed. In this thesis, the effect of numbers of control parameters-rotation speed, paddle number, and mean velocity-on the flow and mixing in microfluidics devices is investigated by non-dimensional parameters. Therefore, the obtained results promise to be widely applicable to mixing devices.

The thesis consists of 6 chapters.

Chapter 1 gives a review of the existing micromixers.

In chapter 2, the rotation mechanism, and the resulted torque and force on a rotor exposed under a laser beam are driven and analyzed. The optical torque is proportional to supplied laser power. The slope coefficient of this relation depends only on the focus point, on the ratios of refraction index of rotor and numerical aperture to refraction index of the fluid.

Chapter 3 conducts the governing equations of fluid motion the physical conservation laws on a regular mesh and on a deformed mesh. The non-dimensional form of these equations is driven to determine the characteristic velocity and length of the flow. The method to solve numerically the governing equations is also presented.

Chapter 4 studies the generated flow and mixing by the rotor in a large chamber. The rotating rotor creates a three-dimensional flow in the surrounding fluid. The numerically produced flows agree well with the experiments. Mixing in the chamber is observed by the paths of the injected massless tracers. It is observed that the tracers are moved with time averaged velocities. It implies that mixing is characterized by the time averaged velocities.

Chapter 5 investigates the flow and mixing in a Y-channel.

The flow is studied through the pressure drop, fluid forces (i.e. side force and stream force) and torque on the rotor, and transverse velocity in a cross section of the channel. The mean side force and torque are proportional to rotation speed with regardless of mean velocity in the mixer, whereas the mean stream force depends linearly on mean velocity with regardless of rotation speed. A large paddle number leads to a higher the slope of these relations. The appropriate forces and torque coefficients depend significantly on paddle number but insignificantly on rotation speed, mean velocity, and fluid. The effect of the rotor on the flow is in its vicinity, which is observed by the rapid decay of the transverse flow with distance from the rotor by a power-law.

Mixing structure in the Y-channel is visualized by particle tracking method, and mixing performance is quantified by dispersive and distributive mixing efficiency. The obtained results show that the mixing process in the channel is self-similar with the kinetic parameter, which is the ratio of the tip paddle velocity to mean velocity. Increasing the kinetic parameter significantly enhances the mixing, whereas the number of paddles has an insignificant role in the mixing

In the view of effect to mixing, the convective of the rotating rotor can be converted to an effective diffusion coefficient with a constant factor of order 10^3. It implies that the enhancing mixing by the rotating rotor is equivalent to $O(10^3)$ times of standard Frickian diffusion.

Chapter 6 gives concluding remarks the thesis.