CONTROLLED MIXING IN MICROCHANNELS USING CHEMOTACTIC BACTERIA

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In a microfluidic environment, the small scale and consequently low Reynolds number flow regime leads to diffusion-limited, viscous-dominated dynamics. This has led to several engineering challenges, for example, how to pump fluids through small system with optimum efficiency and how to enhance mixing between parallel streams of fluids. Mixing for chemical systems continues to be a challenge, although several concepts for laminar mixers have been proposed including chaotic mixers [1] based on temporal or spatial mixing of the fluid [2]. These approaches, particularly the temporal mixing, are hindered by the difficulties associated with actuating the fluid at the micrometer scale.

In the current paper, we take advantage of a natural microfluidic actuator, and demonstrate the use of E.Coli bacteria and their chemotactic characteristics to enhance mixing in a microchannel in a controlled and bi-directional manner. A unique feature of bacterial flagellar motors is that they alternate between clockwise and counterclockwise rotation in a random manner [3]. The bacteria thus provide a natural mechanism for achieving temporally chaotic mixing, and by letting them swim in the reagent soup, mixing enhancements can be achieved using random forcing at the smallest scale. Furthermore, flagellated bacteria exhibit chemotaxis, in which they swim preferentially up or down a chemical gradient [4].

In this paper, we prsent experimental results in which two streams of fluid brought together in a microchannel. Both streams contain a high molecular weight Dextran molecule, although in one of the streams, the Dextran is fluorescently labelled, enabling us to monitor the mixing by measuring the fluorescence intensity. In the absence of any intervention, the two streams mix slowly, limited by molecular diffusion. Significant enhancement of the mixing is achieved by introducing E. Coli bacteria in a third, middle, stream. The natural random swimming of the bacteria serves to enhance the mixing of the two primary lines of fluids. Furthermore, the level of mixing in each direction can be controlled by the addition of chemoattractants (positive or negative) which enhance or suppress the bacterial motion in a given direction, resulting in switchable asymmetric control of the local diffusion enhancement. Detailed results on the behavior and scaling of the chemoattractant control of mixing are presented.

References:
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Keywords: micromixing, bacteria, chemotaxis