
Product-oriented design evaluation of serpentine, sar, and bilayer passive micromixers

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Abstract

Mixing of fluids in microscale is notoriously difficult, especially in the diffusive-dominated regimes associated with laminar flow ($Re \ll 100$), which constrain processing in lab-on-chip systems, and biomedical applications. This paper numerically compares three passive micromixer geometries- serpentine channels, split-and-recombine (SAR), and bilayer lamination designs on the basis of three-dimensional COMSOL Multiphysics modelling at Reynolds number 40 in a water-water system. The serpentine mixer takes advantage of Dean vortices to instigate chaotic advection, the SAR mixer maximizes stretching at the interface by repeatedly splitting and recombining streams, and the bilayer mixer forces lamination directed vertically in order to minimize diffusion distances. The measure of mixing performance was measured with the mixing index (MI), pressure drop (ΔP), and with a performance evaluation index ($\eta = MI / \Delta P$) as a test of efficiency. Findings illustrate that SAR mixers have the most homogenization (MI > 95%) but with an almost 3-fold pressure drop of serpentine types, emphasising an energy cost-mixing intensity relationship. Bilayer mixers can boast the highest efficiency ($\eta \approx 0.12 \text{ kPa}^{-1}$) corresponding to the least ΔP with MI above 85% making it an favourable choice in portable and low power equipment. The serpentine mixer is a balanced tradeoff (MI \approx 90%, $\Delta P \approx$ 45% of SAR), with ease of manufacture, good durability characteristics. In terms of product design and development, these results reinforce the utility of geometry-based trade-offs in tailoring the design of micromixers to application-specific needs: SAR (high-precision mixing), bilayer (energy-efficient, portable diagnostics) and serpentine (general purpose systems, amenable to fabrication). The insights are applied to the design of future microfluidic devices on a lab-on-chip platform, nanoparticle synthesis and biosensing applications.