Microfluid Nanofluid (2013) 15:637–646
DOI 10.1007/s10404-013-1178-9

RESEARCH PAPER

Multi-helical micro-channels for rapid generation of drops of water in oil

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Received: 14 January 2013 / Accepted: 15 March 2013 / Published online: 4 April 2013

Abstract High throughput generation of microscopic mono-dispersed droplets of one liquid into the continuous flow of another is important for large number of engineering and biomedical applications. However, meeting conflicting demands of both uniformity of size and high rate of droplet generation have been a difficult task to be accomplished in conventional systems. We have attempted to address this problem by designing a novel multi-helical micro-channel which we have used to generate water droplets in a continuous flow of oil. The channel consists of three or more helical flow paths joined along their contour length forming a single channel with inherently asymmetric geometry. Helix angle and radius are found to be two additional geometric parameters which influence different drop break-up regimes. We have shown that both time period of generation of drops and the droplet size can be minimized by suitably altering the helix angle. A scaling law has been derived to rationalize these results.

1 Introduction

Generation of fine droplets of one fluid into the continuous stream of another is important for variety of engineering and technological applications, e.g., emulsification (Anna and Mayer 2006; Chiu 2001; Christopher and Anna 2007; Cohen et al. 1999), micro-drop reactors (Cramer et al. 2004; Dangla et al. 2010), bio-chemical synthesis and analysis (de Gans et al. 2004; Dean 1927, 1928), printing technology, printing-based lithographic processes (Eustice 1911; Feng 2002), for computing mathematical hard problems and logical control of flow systems (Fu et al. 2010; Ganneboyina and Ghatak 2012), several mass and heat transfer operations and so on. In this variety of examples, the desired mechanism of droplet generation has essentially been dictated by two conflicting demands: monodispersity of droplet size and the rate at which the droplets can be formed. For example, the conventional methods like mechanical stirring, homogenizers, static mixers, etc. generate droplets at exceedingly high rate (Garstecki et al. 2005), yet of highly poly-dispersed size because of non-uniform and spatially varying pressure and velocity field within the flow chamber; for example, viscous shear stress is different in regions at the vicinity of the stirrer from that at a distance away from it. In contrast, microfluidic devices, e.g., T-junction (Garstecki et al. 2006; Germano 1982; Germano and Oggiano 1987; Graaf et al. 2005; Gupta and Kumar 2010; Karbstein and Schubert 1995; Majumder et al. 2010; Menech et al. 2008), Y-junction, and flow focusing devices (Nisisako et al. 2001; Plateau 1849; Prakash 2007) of different types generate mono-disperse drops but at a rate, orders of magnitude smaller than the conventional systems, which renders these processes economically unviable to use in several applications baring those in biology, in which only small volume of liquid needs to be handled. Naturally, scaling up of the microfluidic-based devices has been a subject of intense research leading to several novel methodologies, e.g., parallelization, i.e., use of several closely spaced channels connected to a single manifold, extrusion of a dispersed phase or a pre-emulsified liquid through

Electronic supplementary material The online version of this article (doi:10.1007/s10404-013-1178-9) contains supplementary material, which is available to authorized users.

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