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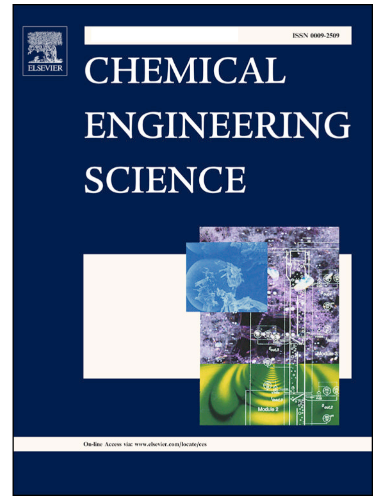

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Damping Hydrodynamic Fluctuations in Microfluidic Systems

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Abstract

In this article, we report a method to damp microfluidic hydrodynamic fluctuations caused by flow sources. We demonstrate that compliance of elastomeric off-chip tubings can be used to damp fluctuations and lead to steady flow rates. We analyze the whole microfluidic system using electrical circuit analogies, and demonstrate that off-chip compliances are significant, especially for displacement pump driven systems. We apply this hydrodynamic damping method to microfluidic droplet generation. Our results show that highly monodisperse microdroplets can be obtained by syringe pump driven systems utilizing this damping effect. We reached a coefficient of variation of 0.39% for the microdroplet area using a standard T-junction geometry. Additionally, we demonstrated that pressure pumps inherently use this effect, and have so far led the high performances found in the literature in terms of droplet monodispersity. The presented off-chip hydrodynamic damping method is not only low-cost and practical, but can also be used in elastomeric and rigid microchannels without need to introduce additional components to the fluidic circuit.

Keywords: microfluidics; fluctuation damping; compliance; droplets; monodispersity

1. Introduction

Microfluidic systems provide exquisite control on flow dynamics at microscale. Flow rate modulation and flow profile stability play a critical role in their performance. Hydrodynamic fluctuations deteriorate the performance of microfluidic systems that require steady flows. The fundamental source of such fluctuations is the flow sources. Therefore, it is necessary to develop flow sources with minimal instability or methodologies that damp the fluctuations introduced by flow sources.

Efforts have been made to analyze and minimize hydrodynamic fluctuations in order to sustain the steady state and stable fluid flow in microfluidic systems (Kang and Yang, 2012; Kim et al., 2009; Ruzicka et al., 1990). Recently, fluctuations caused by flow sources have been characterized by dimensional analysis, using the Strouhal number (Zeng et al., 2015a). It has been shown that the use of soft polydimethylsiloxane (PDMS) channels, made by increasing the base polymer / curing agent ratio, can damp fluctuations. In another work, flow rate fluctuations were suppressed using a PDMS microchannel that was designed to have a very thin layer of PDMS wall as its bottom surface. This soft wall acts as a membrane and improves the monodisperse microdroplet formation (Pang et al., 2014). Furthermore, an air compliance unit and a channel with high resistance have been applied to stabilize hydrodynamic flow in microfluidic devices (Kang and Yang, 2012). Similarly, bubble-induced mechanisms have been used to damp the fluctuations (Lee et al., 2012). Although these studies demonstrate improvements in flow stability, they have several limitations. Most of these approaches are bound to elastomeric microchannels and require modification of the microchannel design, such as incorporating membrane-like surfaces or modifying channel elasticity, which can only be varied within a tight window. Softening the PDMS channels renders them susceptible to pronounced leeching and adsorption issues. In addition, incorporating additional components to the system to damp the fluctuations is not desirable for most applications that have strict microchannel design criteria.

Here, we propose a more effective and widely applicable solution to improve flow stability, by controlling off-chip compliances to minimize fluctuations due to flow sources. We utilize the tubings used to connect the flow sources to the microfluidic channels to damp the hydrodynamic fluctuations. This method provides a passive way of damping hydrodynamic fluctuations and does not require any additional components. Tubings are already utilized in most systems, unless integrated electro-osmotic pumps or capillary-driven pumping are used to drive the fluids. Therefore, the presented method is readily

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