Simulation-Aided Optimal Microfluidic Sorting for Monodispersed Microparticles

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ABSTRACT

In order to avoid performing too many experiments by a trial-and-error approach, this study used the simulation method to investigate the optimum geometry of a microfluidic chip for sorting droplets. Under the framework of the double T-junction hybrid channel, geometry factors such as (i) the distance between the two junctions, (ii) the size of the second junction, and (iii) the size of the broadened channel were analyzed. How these factors impacted the separation process and device performance were examined and discussed to optimize the double T-junction channel design. Results indicated that the best separation performance occurred when the separation layer thickness was 8~15% of the upstream main channel width. This simulation analysis helped the optimum channel geometry design in the microfluidic chip for droplet sorting to prepare uniform microparticles.

Keywords: *Droplet, Microfluidic, Separation, Simulation, Sorting, T-Junction*

INTRODUCTION

Particulate technology has widely applied in pharmaceutical areas for drug delivery, diagnostics, and target manipulation (Arifin, 2006). Conventional methods for the preparation of microparticles, such as solvent evaporation, phase separation, and spray drying (van der Lubben, 2001), have common drawbacks. These drawbacks include a wide particle-size distribution, difficulty in precisely controlling the particle size, and poor batch-batch reproducibility of microparticles. There are many disadvantages associated with putting non-uniform microparticles to use. For example, in the field of controlled release, the target release behavior of different microparticle batches will result in poor repeatability, and the particle size and size distribution will influence the necessary drug dosage and clearance rate by the body

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(Berkland, 2001). Although sieving or sorting methods can solve the non-uniformity problem in microparticles, the additional procedures, apart from the preparation of microparticles, are tedious and uneconomical. Therefore, it is important to be able to control the particle size and size distribution for preparing microparticles for use in various applications.

Recently, microfluidic methods have received considerable attention because of their widespread use in applications such as analyses, syntheses, and microreactors (Stone, 2004; Vilkner, 2004). In order to obtain uniform microparticles, microfluidic devices are ideal for droplet formation because they have the advantage of continuous, reproducible, and scalable production (Jahn, 2004; Nie, 2006; Zhang, 2007; Yang, 2009; Huang, 2011). However, satellite droplets are common byproducts, which result from the breakup of immiscible liquids, in the droplet formation process. Therefore, there are often two or more peaks in the droplet size distribution owing to the liquid/liquid breakup. In order to obtain uniform microparticles, droplet sorting is needed for isolation and purification.

The methods for sorting droplets in microfluidic chips can be active or passive (Andersson, 2003; Teh, 2008). In general, active sorting needs an additional supplement such as an electrical, an optical, a mechanical, or a magnetic control system (MacDonald, 2003; Yi, 2006; Cho, 2007; Li, 2007; Roman, 2007; Wu, 2008), which is detrimental to the miniaturization of the system required for producing uniform droplets. Passive sorting, which is achieved by either gravity or channel geometry (Huh, 2007; Tan, 2004; Tan, 2007), usually requires a great deal of effort by a trial-and-error approach to adjust the flow conditions in order to obtain a high sorting efficiency. Recently, a double T-junction hybrid was proposed to generate uniform droplets at the 1st T-junction and to efficiently separate the desired droplets away from the byproduct droplets at the 2nd T-junction (Yang, 2009; Huang, 2011). However, how the channel geometry affects the separation efficiency was not clear.

Theoretical hydrodynamic analysis can analyze fluid dynamic problems and develop optimal designs of various components to considerably save the effort required in performing an experiment by a trial-and-error approach to tune the channel geometry and to adjust the flow conditions necessary for obtaining efficient separation. The objective of this study is to design an optimal double T-junction channel for droplet separation by using a simulation method.

METHOD

This work employed the fluid dynamic module in the finite volume simulation software, CFD-ACE+ (ESI CFD, Huntsville, USA), to study the motion of droplets in microchannels. The geometry parameters for the broadened channel and the double T-junction system were shown schematically in Figure 1, where D denoted the width of the main upstream channel, D1 was the width of the 1st broadened channel, D2 was the width of the 2nd broadened channel, L1 was the length of the 2nd T-junction in the 1st broadened channel, L2 was the length of the 2nd T-junction in the 2nd broadened channel, W was the width of the 1st T-junction channel, W1 was the width of the 2nd T-junction channel in the 1st broadened channel, W2 was the width of the 2nd T-junction channel in the 2nd broadened channel, a and b were inlets, and c and d were outlets.

The stream line in this constructed system was solved from Navier-Stokes equation. Based on previous studies (Yang, 2009; Huang, 2011), inlets a and b were fixed at constant flow velocities, and outlets c and d were fixed at a zero pressure. The boundary conditions at all channel walls were non-slip conditions. The solution was assumed to be a Newtonian fluid, with an invariable physical property. The body force and buoyancy force in the solution fluid were neglected.