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Optimal Design for Split-and-Recombine-Type Flow Distributors of Microreactors Based on Blockage Detection

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Optimal design for split-and-recombine-type flow distributors of microreactors based on blockage detection

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Abstract

In order to increase the productivity of microreactors, the parallelization of the microreactors is required. The performances of flow distributors can affect the product yield and fault detection ability when blockage happens. In this research, an optimal design method to calculate the channel diameters and to determine the flow sensor location is derived based on mass balance and pressure balance models of split-and-recombine-type flow distributors (SRFDs). The model accuracy is verified by experiment data. The proposed method is applied to optimal design of SRFDs under constant flow rate operation conditions. The maximum angle difference between normal and blockage conditions at one sensor to those at the other sensors are set to be objective function and the uniformity of flow distribution in microreactors under normal condition is also required. The diameters of each pipe in SRFDs are selected as the design variables. Simulated annealing algorithm is used to solve the optimization problem. The effectiveness of the optimal design results is demonstrated by fluid dynamics simulations. The results show that using the optimal channel diameters of SRFDs, the pressure drop in SRFDs section is lower than that of in microreactors section. Meanwhile, in the case studies, the only few sensors that located inside the SRFDs can easily detect the blockage abnormal condition in the parallelized microreactors system.

Keywords:

Optimal design; *Split-and-recombine-type flow distributors*; *Microreactors*; *Microchannels*; *Blockage*;

1. Introduction

Chemical reactions happen faster at microscale as a result of faster mass transfer and efficient heat transfer. The low hold-up in microreactors can offer excellent controllability, reduce safety risks and result in cheaper and more environmentally friendly operation [1]. Commercially available microreactor products for the industry are however limited. In order to realize microreactors with high throughput, the parallelization of microreactors, i.e., numbering-up technology is an effective approach. In these scale-out structures the challenge is to keep satisfactory uniformity in the fluid distribution among microreactors [2]. With the size limitation of microreactors, it is not practical to install sensors in each microreactor when parallelization structures are adopted. Therefore, another critical problem is how to detect the blockage abnormal condition which is the most recognized trouble in microreactors [3].

It is not a trivial thing to keep the desired transport and reaction characteristics previously achieved in one single microchannel during the numbering-up process. Therefore, the design of proper fluid distributors to guarantee uniformity flow distribution among parallelized microchannels is very important. Saber *et al.* proposed multi-scale microreactors networks for numbering-up process and analyzed the impact of flow uniformity on the microreactors performances [4]. For one-scale microreactors, different distributors have been developed toward solving this problem. Most of these distributors fall into one of two categories: manifold-type (see Fig. 1) and bifurcation-type (Fig. 2) [5]. In the manifold-type distributor research, Griffini and Gavriilidis built a two-dimensional and a three-dimensional computational fluid dynamics (CFD) models [2], and found that the flow distribution chambers length and shape, and plate width and inlet/outlet location are the most important parameters that influence the uniformity of microchannels. Commenge *et al.* built an approximate pressure drop model to realize the optimal design for flow uniformity in microreactors [6]. In the bifurcation-type research, Yue *et al.* investigated the flow distribution and mass transfer characteristics of gas-liquid flow in a parallelized microchannel contactor integrated with two designed distributors numerically and experimentally. A nearly uniform gas–liquid distribution at high gas flow rates can be ensured [7]. Tonomura *et al*. proposed a new type of distributor named as ‘‘split-and-recombine-type flow distributors (SRFDs) ’’ which was composed three or more bifurcation points and one or more junction points [8]. Tanaka *et al.* examined

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