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Clogging mechanism of poly(styrene) particles in the flow through a single micro-pore

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Abstract

In this study, the clogging mechanism of poly(styrene) particles in the flow through a single micro-pore was investigated. Together with the microscopic observation, the pressure drop was also measured. The pressure drop fluctuated according to the amount of particles deposited inside the channel. When the particles deposited and blocked the channel, the channel was clogged and the pressure drop increased sharply. During the clogging process, the particles were often detached by the flow, and interesting behaviors, such as "rolling" and "stick and detach", were found to be the key factors that determine whether the clogging completely occurs or not. Above a certain flow rate, the channel was not clogged and the pressure drop did not increase further. The particles deposited in the upstream had an influence on the flow path. When the particles were deposited in the upstream, the flow detoured and the vortex was formed. The effect of viscosity was examined by controlling the concentration of glycerol solution. As the viscosity and the flow rate increased, the shear stress applied to the particles became larger and it was more difficult for the particles to get accumulated. The normalized clogging pressure drop decreased exponentially with shear stress. It was unity above a certain shear stress, in which the particles did not clog the channel completely.

Keywords: clogging mechanism, single micro-pore, vortex, shear stress

1. Introduction

Contraction flow has been studied for a long time. A membrane carries numerous pores and the flow through this pore can be represented by a flow through a single contraction channel [1, 2]. When a fluid flows inside a contraction channel, various flow behaviors, such as vortex generation and extra pressure drop, can be observed depending on the properties of the fluid, flow rate, and the shape of the channel [3]. To examine these behaviors, not only a macro-scale channel larger than millimeter but also micro-fabricated devices have been employed [4, 5]. In a micro channel, a behavior of a polymer solution, which is viscoelastic, rather than a Newtonian fluid has been studied intensively and they showed notable features, such as divergent flow and elastic lip vortex, none of which appear in Newtonian fluids [5, 6]. The previous studies have focused on the behaviors of a Newtonian fluid or a simple polymeric solution. Although the materials used in practice are usually a suspension consisting of particles, there are few studies on the flow of suspensions inside complex geometry. Han et al. studied the flow of alumina suspension in the contraction channel [7]. The effect of polymer-particle interaction on the fluid dynamics in micro contraction geometry was also studied [8]. The common feature in these studies is that the particles did not adsorb onto the wall.

However, it is typical that the particles deposit on the wall of a channel, and the retention of particles cause several problems, such as pressure drop, clogging or fouling. To prevent a fouling problem, patterned membranes [9-11] or self-cleaning membranes [12] have been applied. It is important to understand how a membrane is fouled or clogged and how they block the channel, which is very complicated. There have been many studies on clogging. Ramachandran and Fogler [13] studied that the clogging formation of particles smaller than the pore size originates from the hydrodynamic bridging in dead end filtration. Although the particle size is smaller than the pore size, the clogging was built up by the hydrodynamic bridging and the pressure drop increased when the hydrodynamic force was strong enough to overcome the interparticle and particle-pore surface colloidal repulsion. In clogging or fouling, colloidal interactions play an important role. When the particle mass flux cannot overcome the particle-pore surface force, the particles cannot deposit on the wall. This concept is referred to as the critical flux density [14]. Agbangla et al. [15] studied the effect of the volume fraction of the particles, flow rate, and the properties of the particle on the clogging process both in the dead-end mode and in the cross flow mode. When the flow was slow or the volume fraction of the particle was