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Deterministic and Stochastic Modeling of Clogging Effects on Flow in Lattice-shaped Microchannel

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Abstract

Flow systems consisted of multiple channels, bifurcations, and joints (junctions), which are observed in nature and applications as vascular networks and bundles, heat exchangers, and microfluidic devices, compose complicated structures. Failure of the channels and elements affects the local flow and can develop to a system failure. Clogging is one of the important factors that can induce channel failure. Clogging is a random event, however, the effect of the clogging on the channel flow and vice versa can be represented as a deterministic event.

In this study, two-dimensional numerical computation was conducted for particle flows in lattice-shaped microchannel applying conjugate analysis of flow computation based on finite volume method and stochastic model of the clogging with the aim to evaluate and model the clogging, flow, and pressure loss characteristics of the channel. Clogging probability of the model was defined as Eq. (1). C_0 is constant and $\dot{\phi}(t)$ is a function of the number of particles flowing through the considering point.

$$p(t) = C_0 \dot{\phi}(t) \Delta t \tag{1}$$

Two stochastic models were applied: one with the clogging event occurring randomly ($\dot{\phi}(t) = 0$), and the other with $\dot{\phi}(t)$ depending on the flow rate at the considering point. Measurement of particle flows and clogging in lattice-shaped microchannel was also conducted under the same condition of the computation for validation.

The results showed that the pressure loss characteristics changes in three steps over time following the power law with different exponents (Fig. 1(a)). The first region was presented by dispersed clogging appearing in the channel. The second region was due to the clustering of the clogged areas. In the third stage, clusters combined and developed to large clusters, and finally blocking the channel. The theoretical model for porous media applying the tortuosity and percolation theory[1] gave a good agreement with the random model case. In the case of flow-dependent model, pressure loss distribution also varied by time and showed three different regions. However, the value increased significantly compared to the random model case. The clogging increased the local pressure loss which changed the flow and distributed the fluid spatially and temporally over the channel (Fig. 1 (b)). This produced a uniform clogging distribution and increased the overall pressure loss. We showed that this clogging pattern formed in the first region increased the clustering rate at the second and third stages of smaller porosity. From the present results, we confirmed that deterministic phenomenon should be considered with stochastic events to correctly evaluate the clogging effect on the channel flow and pressure loss.

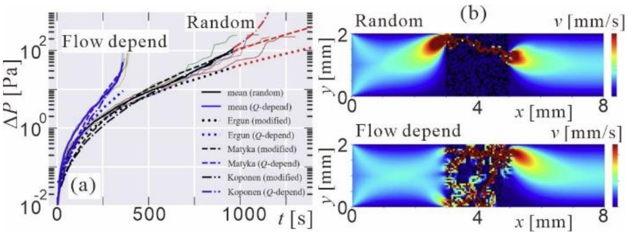

Fig. 1: (a) Time distribution of pressure loss and (b) instantaneous flow velocity distributions of the two models.

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References

1) Matyka, M., et al. *Physical Review E*, **78** (2008) 026306.