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Stokes Flow through a Microchannel with Periodical Protuberances on the Wall

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Abstract

In this study, we analyze the Stokes flow through a microchannel with semicircular periodic protuberances on the walls. The radius and period of semicircular protuberances and the stagger ratio of the staggered protuberance arrangement on both walls are arbitrary. Considering the periodicity and symmetry of the flow, the Fourier series expansion and least squared error method are applied. The stream function, pressure distribution in the flow region, and shear stress distribution on the semicircular protuberances are determined, and the results for some cases of arrangement of protuberances are presented in this paper. In particular, the average pressure gradient along the microchannel is calculated as a function of the size, period, and the stagger ratio of the protuberances on the walls. The results are compared with those obtained by lubrication analysis when the protuberances are close to the opposite protuberances or the opposite wall. As the limiting case of large periodicity, the induced pressure drops attributed to a single pair of semicircular protuberances on both walls and attributed to a single semicircular protuberance on a wall are also considered.

Keywords: eigenfunction; lubrication analysis; microchannel; periodic flow; protuberance, pressure drop; stagger ratio; Stokes flow

1. Introduction

Microchannel flows have been studied for various applications, such as the micro heat exchanger for increasing the efficiency of heat transfer, micro nozzle for controlling the route of small satellites, and medical fields investigating synovial flow, capsular locomotive micro robots, and so on[1-3].

Wang analyzed the Stokes flow through a channel with longitudinal ribs[4], transverse fins[5], and transverse cylinders[6] of constant spacing and determined the flow resistance by using the method of eigenfunction expansion. Yang et al.[7] investigated the hydrodynamic forces and torques on a rotating cylinder in a narrow channel by lubrication analysis and scaling analysis and compared the results with numerical solutions for the case in which the gap between cylinder and wall is small. Pozrikidis[8] presented the change in shear stress on the surface of a circular tube with a permeable wall; viscous fluid flowed through to model the blood flow through a capillary vessel. Davis[9] studied two-dimensional creeping flow due to a periodic array of wall-attached barriers by the boundary singularity method. Kirsh[10] presented the flow along parallel cylinders with porous permeable shells by using Stokes and Brinkman equations. Jeong[11] theoretically analyzed the Stokes flow through a slit in a microchannel by using the slip boundary condition. Jeong and Yoon[12] and Jeong and Jang[13] analyzed the two-dimensional Stokes flow around a free-drifting circular cylinder inside a microchannel.

As described above, many studies have been conducted on microchannel flow past a single obstacle or a series of obstacles.

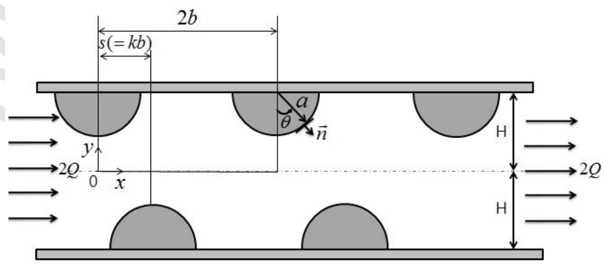

Fig. 1. Geometry of a microchannel.

In this work, we considered the two-dimensional Stokes flow through a microchannel in which a series of semicircular protuberances is attached to each wall with constant spacing, as shown in Fig. 1. The presence of protuberances is considered to model the flow in the geometric complexity of microchannel. Previously, Son and Jeong[14] analyzed a specific microchannel flow where the protuberances attached to both walls of a microchannel were aligned with each other ($s = 0$ in Fig. 1).

2. Problem description and analysis

2.1 Periodicity and symmetry of the flow

Fig. 1 shows the two-dimensional viscous flow with a flow rate $2Q$ through a microchannel where semicircular protuberances are attached to each wall of the microchannel. The height of the channel is $2H$; the radius of the semicircular protuberances is a; the constant spac-

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