Foreword by Chih-Ming Ho

Fluid flow through small channels has become a popular research topic due to the emergence of biochemical lab-on-the-chip systems and micro electromechanical system fabrication technologies, which began in the late 1980s. This book provides a comprehensive summary of using computational tools (Chapters 14–18) to describe fluid flow in micro and nano configurations. Although many fundamental issues that are not observed in macro flows are prominent in microscale fluid dynamics, the flow length scale is still much larger than the molecular length scale, allowing for the continuum hypothesis to still hold in most cases (Chapter 1). However, the typical Reynolds number is much less than unity, due to the small transverse length scale, which results in a high-velocity gradient. For example, a $10^5\,\mathrm{sec}^{-1}$ shear rate is not an uncommon operating condition, and thus high viscous forces are prevalent, resulting in hundreds or thousands of ψ hydrodynamic pressure drops across a single fluidic network. Consequently, it is not a trivial task to design micropumps that are able to deliver the required pressure head without suffering debilitating leakage. Electrokinetic and surface tension forces (Chapters 7 and 8) are used as alternatives to move the embedded particles and/or bulk fluid. The high viscous damping also removes any chance for hydrodynamic instabilities, which are essential for effective mixing. Mixing in micro devices is often critical to the overall system's viability (Chapter 9). Using electrokinetic force to reach chaotic mixing is an interesting research topic. In these cases, the electrical properties, e.g., dielectric constants, rather than the viscosity determine the efficiency of transport.

The National Nano Initiative, established first in the USA (www.nano.gov) and subsequently in many other countries, has pushed the length scale range of interest from microns down to nanometers. Flows in these regimes start to challenge the fundamental assumptions of continuum mechanics (Chapter 1). The effects of the molecules in the bulk of the fluid versus those molecules in proximity to a solid boundary become differentiated (Chapter 10). These are extremely intriguing aspects to be investigated for flows in small configurations. The demarcation between the continuum and the noncontinuum boundary has yet to be determined and inevitably will have a tremendous influence on the understanding of small-scale fluid behavior as well as system design.

The ratio between the size of the channel and that of the molecule is not the only parameter that validates the continuum assumption. In biological applications, for example, molecules with large conformation changes, electrical charges, and polar structures are frequently encountered. These variables make it impossible to determine whether a flow can be considered a continuum based only on a ratio of sizes (Chapter 11). When a continuum flow of a Newtonian fluid is assumed, molecular effects are defined by the governing equations of traditional fluid mechanics. Interactions among fluid molecules are expressed by a physical constant, which is viscosity. The no-slip condition represents the interactions between the fluid and the solid surface molecules. Both viscosity and the no-slip condition are concepts developed under the framework of continuum. Deviations from the bulk viscosity and the no-slip condition can lead to other results due to the breakdown of the continuum assumption (Chapters 2 and 10).

In the nanoflow regime, not many molecules are situated far away from the channel wall. Therefore, the motion of the bulk fluid is significantly affected by the potential fields generated by the molecules near the solid wall. Near the surface, the fluid molecules do not flow freely. At a distance of a few fluid molecule layers above the surface, the flow has very different physical constants from the bulk flow. The surface effects are strong not only in nano configurations (Chapter 10); even in microfluidic devices, the performance, e.g., surface fouling, is dependent on the surface property. We frequently spend more time on modifying the surface properties than on designing and fabricating devices. As a result of our limited understanding of fluidic behavior within nanoscale channels (Chapters 10 through 13), many vital systematic processes of today's technology are arduously, yet imperfectly, designed. Delivering and stopping a picoliter volume of fluid to a precise location with high accuracy as well as the separation and mixing of nano/micro particles in a fluid medium of high ionic concentration remains a challenging task. By furthering the understanding of fluid interactions in the nano world, many of the interesting mysteries and challenges that have puzzled scientists will be revealed.

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