Micro Flows Fundamentals and Simulation

by G.E. Karniadakis and A. Beskok (Springer-Verlag, Berlin, 2002) ISBN 0 387 95324 8

The microfluids sessions of last fall's APS Division of Fluid mechanics meeting in San Diego, had the electrifying energy of an emerging new field. This new monograph is a timely effort to provide an inroad into it. As chips are evolving into devices for DNA sequencing and biological and chemical agent testing, it is necessary to understand the hydrodynamics of the tiny pumps, valves and mixing devices that make them work.

At small scales, the effect of the graininess of matter is felt and remarkable phenomena in gases such as slip and thermal creep become important. Also the microscopic structure of the boundaries and electrical double layers in fluids are instrumental in the conception of microfluid devices. This monograph mentions a few examples of these devices, but concentrates on the tools needed to simulate fluid dynamics in this tiny world.

One could wonder what new fluid dynamics there is; after all, fluid dynamicists know their dimensionless numbers. The surprise is that these numbers emerge in unfamiliar combinations at the microscale. Although rarefied gas dynamics is an old and venerable subject, it comes in surprising guises at the microscale where Mach numbers can be small and fluctuations may become important at Knudsen numbers which are not very large.

The monograph is a must for someone interested in methods for computing rarefied gas flow, methods that are not restricted to flows at the microscale. Given the wide scope of the book, the derivation of the equations that govern gas flow at scales comparable to the mean free path between collisions, could not be exhaustive. For a complete understanding additional texts on kinetic theory are necessary. I am fond of simple kinetic models to explain phenomena, such as slip and thermal creep, as they can get most things right, except of course for the prefactor. I found a few, but it is never enough.

Two chapters describe the results of computations of a few characteristic flows using both the continuum and a single-molecule Monte Carlo approach. Thermal creep is an effect that does not fail to surprise the student who is exposed to kinetic theory. It can make micro-scale pumps without moving parts. To me, the mysterious thermal ghost effect remained elusive after reading the book. All of these phenomena were well understood before the dawn of the nano era, therefore I appreciated the application to real microfluid devices. It is a pity that there were not more of these examples.

Apart from the computation of rarefied gas flows, the authors have contributed to computational methods of flows driven by electric double layer effects. Microdevices can use these to make pumps and valves without moving parts. A description of numerical methods, both for a continuum description and for atomistic simulations, together with a discussion of the Boltzmann equation complete the monograph.

For those who want to compute flows at the micro scale, this monograph is a must. It describes the state of the art and helps by providing the coefficients, such as needed in situations of slip. Those who wonder what new fluid dynamics there is in the microworld are served by the overview of theory and treasures of numerical methods. Those planning a course on microfluids may want to supplement this book with a more specialized text on kinetic theory.

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