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Fluid Transport

Theory, Dynamics and Applications

Emma T. Berg
Editor

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PREFACE

Applications of microscale and nanoscale thermal and fluid transport phenomena involved in traditional industries and highly specialized fields such as bioengineering, micro-fabricated fluidic systems, microelectronics, aerospace technology, micro heat pipes, and chips cooling, have become especially important since the late 20th century. This book presents topical research data in the study of fluid transport, including vertical two-phase gas-solid and liquid-solid flow in chemical, biochemical and mechanical processes; computational fluid dynamics; measuring diffusion of water protons and specific chemicals encountered in MRI methods; and microscale and nanoscale thermal and fluid transport phenomena.

Chapter 1 - The research of vertical two-phase gas-solid and liquid-solid flow is generally important in chemical, biochemical and mechanical processes. The modeling of a vertical gas-solid and liquid-solid flow, where the solid is coarse spherical particles, is very important for practical applications such as spouted beds and modified spout-fluidized beds with draft tube. For modeling of these systems two-phase flow equations must be used.

For vertical non-accelerating fluid-solids flow of coarse spherical particles the one-dimensional steady-state model has been presented.

The theoretical bases of the model are the continuity and momentum equations for the fluid and particle of Nakamura and Capes, and the variational model for calculating the fluid-particle interphase drag coefficient. The main model objective is establishing relations for: the fluid-particle interphase drag coefficient, the fluid-wall friction coefficient and the particle-wall friction coefficient.

A new method for the indirect determination of the particle-wall friction coefficient in the vertical pneumatic and hydraulic transport of coarse particles is presented. The proposed procedure simplifies experimental work since it does not require experimental determination of the voidage in the transport system.

In vertical gas-solid flow two major flow regimes are exist. There is dilute flow with an apparently uniform distribution of solid in the flowing mixture and the dense phase flow. In vertical liquid-solid flow two different flow regimes are identified: "turbulent" and "parallel".

The method for predicting the regime transition for the gas-solid flow is the choking criterion proposed by Day et al. Besides that, choking criterion for vertical gas-solid flow could be used for predict of the regime transition in liquid-solid flow.

Chapter 2 - Flow past bluff porous bodies has attracted relatively less attention so far although such flow occurs widely in industries and everyday life. In the present study, computational fluid dynamics is applied to investigate this type of problems. The coupling flow in both porous medium and homogenous fluid regions is solved by a finite volume method based on the body-fitted and multi-block grids. At the porous-fluid interface, a shear stress jump condition that includes both the viscous and inertial effects is imposed, together with a continuity of normal stress. The steady flows are simulated in a wide range of the Reynolds and Darcy numbers. Three most commonly used shapes of the bluff body in the literature, that is, circular cylinder, square cylinder and sphere, are examined. Several interesting flow phenomena, which are different from those of flow past a solid bluff body, are revealed by the present simulations. It is found that the recirculating wake existing downstream of a porous bluff body may be completely detached from the body in a certain range of parameters. In a certain range of Darcy number, the wake may initially increase in size with an increase in Reynolds number but then decrease in size and eventually disappear when the Reynolds number is sufficiently large. There is only one "separation" point along the horizontal axis of the porous bluff body, but not a pair of separation points on the surface of the solid one. The present findings may provide a starting point for re-evaluating the flow around and through a porous bluff body and stimulate new studies to understand the underlying mechanics of the new flow phenomena which have not been answered here.

Chapter 3 - Subsurface fluid flow and heat transport play an important role in many geological processes, such as hydrocarbon migration, structural geology, plate tectonics, diagenesis, and metamorphism, and in particular they have major implications for both the formation and preservation of almost every class of economic ore deposit, especially those in sedimentary basins. This chapter is dedicated to addressing fundamental theory and numerical modeling technique of fluid flow and heat transport in subsurface porous media as well as presenting two application examples associated with ore genesis under different geological conditions. The chapter is organized into four sections. The first section is aimed at theoretical aspect of fluid flow and heat transport. It first introduces major physical processes involved in a hydrothermal flow system and outlines a variety of driving mechanisms deemed responsible for large-scale groundwater flow (i.e., topography, buoyancy, tectonic deformation, and sediment compaction), and then describes the mathematical equations that govern and control the behavior of subsurface fluid migration and thermal regime. It ends up with deriving an analytical solution using the Laplace transformation to address the heat transport process subject to a constant fluid flow in a single fracture embedded in an impermeable host porous medium. The second section concentrates on the numerical modeling aspect of fluid flow and heat transport by detailing the Galerkin finite element technique that is capable of numerically simulating complex hydrothermal flow systems. Noticing that topography and buoyancy are the two top driving forces commonly encountered in reality and that the interactions between them are still poorly understood, the third section is therefore attempts to quantify the relative importance of these two mechanisms in driving fluid transport via a series of numerical experiments, and also to determine under what conditions both topography- and buoyancy-driven flows coexist and under what conditions one flow system dominates the other. The fourth section of this chapter focuses on the application aspect of fluid flow and heat transport associated with the formation of mineral deposits, including the Sedex-type lead-zinc deposits in northern Australia (with buoyancy as the primary driving force), and the Dachang polymetallic deposits in southern China (with tectonic deformation as the primary driving force).

Chapter 4 - Parallel plate reactors are prevalent both at laboratory and industrial scales. They are easy to construct and are versatile when choosing separators and electrodes as well as in the mode of electrical operation and flow manifolds. A successful scale-up procedure includes several steps: the analysis of a variety of dimensionless groups which describe the geometric, kinematic, thermal, chemical and electrical characteristics. Accordingly, mass transport and fluid dynamics are among the main parameters in a reliable scale-up procedure. The hydrodynamic behaviour of a parallel plate reactor can be described the flow through a rectangular channel where the flow pattern is strongly linked to the rate of mass transport (k_m), according to the following equation.

Chapter 5 - Most mass and energy transport systems through fluid flow in porous media can be mathematically treated as coupled nonlinear multiple-process problems, for which instabilities are common emerging phenomena that control the fundamental behaviours of such coupled nonlinear systems. This chapter deals with the computational simulation aspects of two common instability phenomena, namely thermodynamic instability and chemical-dissolution front instability, which are closely associated with energy (through heat transfer) and reactive mass (through chemical reaction) transport in fluid-saturated porous media. The physical appearance of thermodynamic instability displays actually a kind of convective pore-fluid flow in a fluid-saturated porous medium so that thermodynamic instability is also called the convective instability of pore-fluid flow. This kind of convective pore-fluid flow can play an important role in transporting heat energy and aqueous minerals in the Earth's crust that is often comprised of porous rocks. However, the physical appearance of chemical-dissolution front instability shows a fundamental change in the morphology of an initial chemical-dissolution front. This kind of instability is the direct consequence of an interaction between nonlinear pore-fluid flow and reactive mass transport through nonlinear porosity-permeability feedback effects in the fluid-saturated porous medium. After the mathematical formulations for simulating both thermodynamic instability and chemical-dissolution front instability are described, computational simulation methods, such as the finite element method and the finite difference method, are used to solve the coupled nonlinear problems associated with energy and mass transport processes in fluid-saturated porous media.

Chapter 6 - During the past decade, major breakthroughs in magnetic resonance imaging (MRI) quality were made by means of great improvement in scanner hardware and pulse sequences. Some advanced MRI techniques have truly revolutionized the detection of disease states and MRI can now-within a few minutes-acquire important quantitative information non-invasively from an individual in any plane or volume at comparatively high resolution. However, the very basic physics of this promising technological breakthrough is not well understood. Parameters that are measured from time to time in advanced MRI seem to be logically and functionally related but the theoretical facility to optimally explore them is still missing. In a single experimental investigation, for example, few of huge amount of information available are effectively used. This study intends to provide a very straightforward theoretical background for measuring diffusion of water protons and specific chemicals encountered in most common advanced MRI methods including diffusion MRI, perfusion MRI, functional MRI.

Chapter 7 – It is accepted now that majority of the biological and industrial fluids are non-Newtonian. Unlike the Newtonian fluids, the non-Newtonian fluids cannot be described by a single constitutive relationship between stress and strain rate. Such constitutive equations give rise to complicated mathematical problems and thus, the mathematicians, modelers, physicists and computer scientists encounter wide variaty of challenges in constructing analytical and numerical solutions. Generally, the classification of non-Newtonian fluids is based into three categories, namely, the differential type, the rate type and an integral type.

Maxwell model is the simplest subclass of rate type fluids. The objective of the present work is to analyze the effect of viscoelasticity on the dynamics of a non-Newtonian fluid by studying the peristaltic flow of a compressible Maxwell fluid through the gab between two coaxial tubes (annulus). This peristaltic flow is actually a result of the influence of ultrasonic radiation on the flow of a liquid through an annulus which deforms the walls of the outer tube in the shape of traveling transversal waves exactly like peristaltic pumping. Those traveling transversal waves induce a net flow of the liquid inside the annulus. This problem has numerous applications in various branches of science, including stimulation of fluid flow in annulus under the effect of elastic waves , the production process of oil, and studies of blood flow dynamics in living creatures(catheter in an artery). Navier-Stokes equations for an annulus are solved by means of a perturbation analysis, in which the ratio of the wave amplitude to the outer tube radius is a small parameter. In the second order approximation, a net flow induced by the travelling wave is calculated for various values of the Reynolds number, Maxwell relaxation time, the compressibility parameter and the annulus radius ratio. The calculation disclose that the compressibility of the liquid and the non-Newtonian effects in presence of peristaltic transport have a strong influence on the net flow induced. Variation of emerging parameters embedded in the flow system are discussed numerically and graphicly.

Chapter 8 - With the emergence of microscale and nanoscale thermal, fluidic and chemical systems, MEMS (Micro-Electro-Mechanical-Systems), NEMS (Nano-Electro-Mechanical-Systems), thermal management technologies for microelectronics, power electronics, aerospace and defence technologies etc., the development of ultra-compact heat exchangers, miniature and micro pumps, miniature compressors, micro-turbines, micro thermal systems for distributed power production, microfluidic and nanofludic device, lab-on-a-chip, microscale and nanoscale energy systems, nanofluid heat transfer technologies and others has become an important agenda of many researchers, research institutions and funding agencies. Applications of microscale and nanoscale thermal and fluid transport phenomena involved in traditional industries and highly specialized fields such as bioengineering, micro-fabricated fluidic systems, microelectronics, aerospace technology, micro heat pipes, chips cooling etc. have been becoming especially important since the late 20th century. However, microscale and nanoscale thermal and fluid transport phenomena are quite different from those at conventional scale or macroscale. For example, gas liquid two-phase flow and flow boiling heat transfer characteristics in microcale channels are quite different from those in macroscale channels. Channel confinement also has a great effect on two-phase flow and flow boiling heat transfer characteristics. Furthermore, the available experimental results of single phase heat transfer and fluid flow in microscale channels are quite contradictory from one study to another. Studies of supercritical fluid flow and heat transfer in microscale channels have also exhibited contradictory results by various researchers. Just to show several examples here. Therefore, there are many aspects to be clarified from both theoretical and applied aspects in microscale and nanoscale thermal and fluid transport phenomena. Furthermore, new research areas and technologies in the relevant fields have been emerging from time to time. For example, as a new research frontier of nanotechnology, the research of nanofluid two-phase flow and thermal physics is growing rapidly, however it has also posed new challenges as there are quite contradictory results in the available research. For another example, advances in micro-electronics technology continue to develop with surprisingly rapidity and the thermal energy density of electronic devices to be dissipated is becoming much higher and higher. Therefore, it is essential to develop new high heat flux cooling technology to meet the challenging heat dissipation requirements. All the newly emerging research areas require the understanding of fundamentals and applications of the microscale and nanoscale fluid and thermal transport phenomena.

Chapter 9 - This chapter presents an overview of recent results on the electric field control and manipulation of fluids in microfluidic devices. The newer approaches are based on using alternating or a combination of alternating and direct current fields. The alternating field can be locally converted to direct by semiconductor diodes that may be placed at key locations where an electroosmotic force has to be applied to the fluid. Such techniques allow to design and fabricate small micrometer sized pumps and mixers. The latter are important because of the inherent low Reynolds characteristics of the flow in microchannels. The diode mixers are simple to fabricate and can be turned on and off depending on the operational requirements. Combining alternate and direct current fields and diode pumps makes possible the decoupling of the electroosmotic fluid flow from the electrophoretic particle or macromolecular mass flux. This can be exploited for precise analyte focusing, preconcentration and separation.

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Chapter 6

THE DYNAMICS OF NMR – DIFFUSION DIFFERENTIAL EQUATION FOR QUALITATIVE ANALYSIS OF HEMODYNAMIC AND METABOLIC CHANGES IN BIOLOGICAL TISSUE

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ABSTRACT

During the past decade, major breakthroughs in magnetic resonance imaging (MRI) quality were made by means of great improvement in scanner hardware and pulse sequences. Some advanced MRI techniques have truly revolutionized the detection of disease states and MRI can now-within a few minutes-acquire important quantitative information non-invasively from an individual in any plane or volume at comparatively high resolution. However, the very basic physics of this promising technological breakthrough is not well understood. Parameters that are measured from time to time in advanced MRI seem to be logically and functionally related but the theoretical facility to optimally explore them is still missing. In a single experimental investigation, for example, few of huge amount of information available are effectively used. This study intends to provide a very straightforward theoretical background for measuring diffusion of water protons and specific chemicals encountered in most common advanced MRI methods including diffusion MRI, perfusion MRI, functional MRI.

Keywords: Bloch NMR flow equations, Diffusion, Brownian motion, Perfusion, fMRI, Biological flow.

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