



Generalized Reynolds equation for microscale lubrication between eccentric circular cylinders based on kinetic theory

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A microscale lubrication flow of a gas between eccentric circular cylinders is studied on the basis of kinetic theory. The dimensionless curvature, defined by the mean clearance divided by the radius of the inner cylinder, is small, and the rotation speed of the inner cylinder is also small. The Knudsen number, defined by the mean free path divided by the mean clearance, is arbitrary. The Boltzmann equation is studied analytically using the slowly varying approximation following the method proposed in the author's previous study (Doi, *Phys. Rev. Fluids*, vol. 7, 2022, 034201). A macroscopic lubrication equation, which is a microscale generalization of the Reynolds lubrication equation, is derived. To assess this, a direct numerical analysis of the Boltzmann equation in a bipolar coordinate system is conducted using the Bhatnagar–Gross–Krook–Wendler kinetic equation. It is demonstrated that the solution of the derived lubrication equation approximates that of the Boltzmann equation over a wide range of the eccentricity and the whole range of the Knudsen number. It is also demonstrated that another lubrication equation derived by a formal application of the slowly varying approximation produces a non-negligible error of the order of the square root of the dimensionless curvature for large Knudsen numbers.

Key words: non-continuum effects, microfluidics, kinetic theory

1. Introduction

Lubrication is indispensable in all technologies involving bodies in a relative motion. The basic equation of fluid film lubrication was derived by Reynolds (1886) from the Navier–Stokes equations. When the size of the gap between two surfaces is so small

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Approximative Methods In Kinetic Theory Models For Microscale Phenomena

Yury Gogotsi, V. Domnich



Approximative Methods In Kinetic Theory Models For Microscale Phenomena:

Transport Phenomena in Multiphase Systems Hamid Arastoopour, Dimitri Gidaspow, Robert W. Lyczkowski, 2021-08-21
This volume fills the need for a textbook presenting basic governing and constitutive equations followed by several engineering problems on multiphase flow and transport that are not provided in current advanced texts monographs or handbooks The unique emphasis of this book is on the sound formulation of the basic equations describing multiphase transport and how they can be used to design processes in selected industrially important fields The clear underlying mathematical and physical bases of the interdisciplinary description of multiphase flow and transport are the main themes along with advances in the kinetic theory for particle flow systems The book may be used as an upper level undergraduate or graduate textbook as a reference by professionals in the design of processes that deal with a variety of multiphase systems and by practitioners and experts in multiphase science in the area of computational fluid dynamics CFD at U S national laboratories international universities research laboratories and institutions and in the chemical pharmaceutical and petroleum industries Distinct from other books on multiphase flow this volume shows clearly how the basic multiphase equations can be used in the design and scale up of multiphase processes The authors represent a combination of nearly two centuries of experience and innovative application of multiphase transport representing hundreds of publications and several books This book serves to encapsulate the essence of their wisdom and insight and **Rarefied Gas Dynamics** Lei Wu, 2022-09-09 This book highlights a comprehensive description of the numerical methods in rarefied gas dynamics which has strong applications ranging from space vehicle re entry micro electromechanical systems to shale gas extraction The book consists of five major parts The fast spectral method to solve the Boltzmann collision operator for dilute monatomic gas and the Enskog collision operator for dense granular gas The general synthetic iterative scheme to solve the kinetic equations with the properties of fast convergence and asymptotic preserving The kinetic modeling of monatomic and molecular gases and the extraction of critical gas parameters from the experiment of Rayleigh Brillouin scattering The assessment of the fluid dynamics equations derived from the Boltzmann equation and typical kinetic gas surface boundary conditions The applications of the fast spectral method and general synthetic iterative scheme to reveal the dynamics in some canonical rarefied gas flows The book is suitable for postgraduates and researchers interested in rarefied gas dynamics and provides many numerical codes for them to begin with Microscale and Nanoscale Heat Transfer C.B. Sobhan, G.P. Peterson, 2008-06-12 Through analyses experimental results and worked out numerical examples Microscale and Nanoscale Heat Transfer Fundamentals and Engineering Applications explores the methods and observations of thermophysical phenomena in size affected domains Compiling the most relevant findings from the literature along with results from their own re Macroscopic Transport Equations for Rarefied Gas Flows Henning Struchtrup, 2006-06-15 The well known transport laws of Navier Stokes and Fourier fail for the simulation of processes on lengthscales in the order of the mean free

path of a particle that is when the Knudsen number is not small enough Thus the proper simulation of flows in rarefied gases requires a more detailed description This book discusses classical and modern methods to derive macroscopic transport equations for rarefied gases from the Boltzmann equation for small and moderate Knudsen numbers i e at and above the Navier Stokes Fourier level The main methods discussed are the classical Chapman Enskog and Grad approaches as well as the new order of magnitude method which avoids the short comings of the classical methods but retains their benefits The relations between the various methods are carefully examined and the resulting equations are compared and tested for a variety of standard problems The book develops the topic starting from the basic description of an ideal gas over the derivation of the Boltzmann equation towards the various methods for deriving macroscopic transport equations and the test problems which include stability of the equations shock waves and Couette flow

Mesoscopic Theories of Heat Transport in Nanosystems Antonio Sellitto,Vito Antonio Cimmelli,David Jou,2016-02-03 This book presents generalized heat conduction laws which from a mesoscopic perspective are relevant to new applications especially in nanoscale heat transfer nanoscale thermoelectric phenomena and in diffusive to ballistic regime and at the same time keep up with the pace of current microscopic research The equations presented in the book are compatible with generalized formulations of nonequilibrium thermodynamics going beyond the local equilibrium The book includes six main chapters together with a preface and a final section devoted to the future perspectives as well as an extensive bibliography

Scientific and Technical Aerospace Reports ,1995

High Pressure Surface Science and Engineering Yury Gogotsi,V. Domnich,2019-09-19 In many instances of mechanical interaction between two materials the physical contact affects only the outermost surface layer with little discernible influence on the bulk of the material The resultant high pressures in these localised regimes can induce surface structural changes such as deformation phase transformation and amorphization

MEMS Mohamed Gad-el-Hak,2005-11-29 Thoroughly revised and updated the new edition of the best selling MEMS Handbook is now presented as a three volume set that offers state of the art coverage of microelectromechanical systems The first volume MEMS Introduction and Fundamentals builds the required background and explores various physical considerations of MEMS Topics include scaling simulation models the basics of control theory and the physics of materials flow thin liquid films and bubble drop transport New chapters in this edition address lattice Boltzmann simulations and microscale hydrodynamics Standing well on its own this books builds an outstanding foundation for further exploration of MEMS and their applications

Food Freezing and Thawing Calculations Q. Tuan Pham,2014-04-16 Freezing time and freezing heat load are the two most important factors determining the economics of food freezers This Brief will review and describe the principal methods available for their calculation The methods can be classified into analytical methods which rely on making physical simplifications to be able to derive exact solutions empirical methods which use regression techniques to derive simplified equations from experimental data or numerical calculations and numerical methods which use

computational techniques such as finite elements analysis to solve the complete set of equations describing the physical process The Brief will evaluate the methods against experimental data and develop guidelines on the choice of method Whatever technique is used the accuracy of the results depends crucially on the input parameters such as the heat transfer coefficient and the product's thermal properties In addition the estimation methods and data for these parameters will be reviewed and their impacts on the calculations will be evaluated Freezing is often accompanied by mass transfer moisture loss solute absorption super cooling and nucleation and may take place under high pressure conditions therefore methods to take these phenomena into account will also be reviewed Macro- to Microscale Heat Transfer D. Y. Tzou, 2014-11-17

Physical processes taking place in micro nanoscale strongly depend on the material types and can be very complicated Known approaches include kinetic theory and quantum mechanics non equilibrium and irreversible thermodynamics molecular dynamics and or fractal theory and fraction model Due to innately different physical bases employed different approaches may involve different physical properties in describing micro nanoscale heat transport In addition the parameters involved in different approaches may not be mutually inclusive Macro to Microscale Heat Transfer The Lagging Behavior Second Edition continues the well received concept of thermal lagging through the revolutionary approach that focuses on the finite times required to complete the various physical processes in micro nanoscale Different physical processes in heat mass transport imply different delay times which are common regardless of the material type The delay times termed phase lags are characteristics of materials Therefore the dual phase lag model developed is able to describe eleven heat transfer models from macro to nanoscale in the same framework of thermal lagging Recent extensions included are the lagging behavior in mass transport as well as the nonlocal behavior in space bearing the same merit of thermal lagging in time in shrinking the ultrafast response down to the nanoscale Key features Takes a unified approach describing heat and mass transport from macro micro to nanoscale Compares experimental results for model validation Includes easy to follow mathematical formulation Accompanied by a website hosting supporting material Macro to Microscale Heat Transfer The Lagging Behavior Second Edition is a comprehensive reference for researchers and practitioners and graduate students in mechanical aerospace biological and chemical engineering Theoretical and Computational Chemistry Iwona Gulaczyk, Bartosz Tylkowski, 2021-06-08 This book explores the applications of computational chemistry ranging from the pharmaceutical industry and molecular structure determination to spectroscopy and astrophysics The authors detail how calculations can be used to solve a wide range of practical challenges encountered in research and industry *Lattice Boltzmann Modeling of Complex Flows for Engineering Applications* Andrea Montessori, Giacomo Falcucci, 2018-02-20 Nature continuously presents a huge number of complex and multi scale phenomena which in many cases involve the presence of one or more fluids flowing merging and evolving around us Since its appearance on the surface of Earth Mankind has tried to exploit and tame fluids for their purposes probably starting with Hero's machinery to open the doors of the Temple of Serapis

in Alexandria to arrive to modern propulsion systems and actuators Today we know that fluid mechanics lies at the basis of countless scientific and technical applications from the smallest physical scales nanofluidics bacterial motility and diffusive flows in porous media to the largest from energy production in power plants to oceanography and meteorology It is essential to deepen the understanding of fluid behaviour across scales for the progress of Mankind and for a more sustainable and efficient future Since the very first years of the Third Millennium the Lattice Boltzmann Method LBM has seen an exponential growth of applications especially in the fields connected with the simulation of complex and soft matter flows LBM in fact has shown a remarkable versatility in different fields of applications from nanoactive materials free surface flows and multiphase and reactive flows to the simulation of the processes inside engines and fluid machinery LBM is based on an optimized formulation of Boltzmann's Kinetic Equation which allows for the simulation of fluid particles or rather quasi particles from a mesoscopic point of view thus allowing the inclusion of more fundamental physical interactions in respect to the standard schemes adopted with Navier Stokes solvers based on the continuum assumption In this book the authors present the most recent advances of the application of the LBM to complex flow phenomena of scientific and technical interest with particular focus on the multi scale modeling of heterogeneous catalysis within nano porous media and multiphase multicomponent flows

Seismoelectric Exploration Niels Grobbe, André Revil, Zhenya Zhu, Evert Slob, 2020-10-13 Seismoelectric coupling and its current and potential future applications The seismoelectric method the naturally occurring coupling of seismic waves to electromagnetic fields can provide insight into important properties of porous media With a variety of potential environmental and engineering uses as well as larger scale applications such as earthquake detection and oil and gas exploration it offers a number of advantages over conventional geophysical methods Seismoelectric Exploration Theory Experiments and Applications explores the coupling between poroelastic and electromagnetic disturbances discussing laboratory experiments numerical modeling techniques recent theoretical developments and field studies Volume highlights include Physics of the seismoelectric effect at the microscale Governing equations describing coupled seismo electromagnetic fields Examples of successful seismoelectric field experiments in different geological settings Current and potential applications of seismoelectric coupling Noise removal techniques for seismoelectric field measurements The American Geophysical Union promotes discovery in Earth and space science for the benefit of humanity Its publications disseminate scientific knowledge and provide resources for researchers students and professionals

Operando Research in Heterogeneous Catalysis Joost Frenken, Irene Groot, 2016-12-26 This book is devoted to the emerging field of techniques for visualizing atomic scale properties of active catalysts under actual working conditions i.e. high gas pressures and high temperatures It explains how to understand these observations in terms of the surface structures and dynamics and their detailed interplay with the gas phase This provides an important new link between fundamental surface physics and chemistry and applied catalysis The book explains the motivation and the necessity of

operando studies and positions these with respect to the more traditional low pressure investigations on the one hand and the reality of industrial catalysis on the other The last decade has witnessed a rapid development of new experimental and theoretical tools for operando studies of heterogeneous catalysis The book has a strong emphasis on the new techniques and illustrates how the challenges introduced by the harsh operando conditions are faced for each of these new tools Therefore one can also read this book as a collection of recipes for the development of operando instruments At present the number of scientific results obtained under operando conditions is still limited and mostly focused on a simple test reaction the catalytic oxidation of CO This reaction thus forms a natural binding element between the chapters linking the demonstrations of new techniques and also connecting the theoretical and experimental studies Some first results on other reactions are also presented If there is one thing that can be concluded already in this early stage it is that the catalytic conditions themselves can have dramatic effects on the structure and composition of the surfaces of catalysts which in turn can greatly affect the mechanisms the activity and the selectivity of the chemical reactions that they catalyze

Dynamic Process Modeling

,2013-10-02 Inspired by the leading authority in the field the Centre for Process Systems Engineering at Imperial College London this book includes theoretical developments algorithms methodologies and tools in process systems engineering and applications from the chemical energy molecular biomedical and other areas It spans a whole range of length scales seen in manufacturing industries from molecular and nanoscale phenomena to enterprise wide optimization and control As such this will appeal to a broad readership since the topic applies not only to all technical processes but also due to the interdisciplinary expertise required to solve the challenge The ultimate reference work for years to come

Space and Astrophysical Plasma Simulation Jörg Büchner,2023-03-01 This book is a collection of contributions covering the major subjects in numerical simulation of space and astrophysical plasma It introduces the different approaches and methods to model plasma the necessary computational codes and applications in the field The book is rooted in the previous work Space Plasma Simulation Springer 2003 and includes the latest developments It is divided into three parts and all chapters start with an introduction motivating the topic and its use in research and ends with a discussion of its applications The chapters of the first part contain tutorials of the different basic approaches needed to perform space plasma simulations This part is particularly useful for graduate students to master the subject The second part presents more advanced materials for students and researchers who already work with pre existing codes but want to implement the recent progresses made in the field The last part of the book discusses developments in the area for researchers who are actively working on advanced simulation approaches like higher order schemes and artificial intelligence agent based technologies for multiscale and multi dimensional systems which represent the recent innovative contributions made in space plasma research

Use of Optical Correlation Techniques for Characterizing Scattering Objects and Media Oleg V. Angelsky,Steen G. Hanson,Peter P.

Maksimyak,1999 Optical fields carry vital diagnostic information such as amplitude phase polarization spectral angular and

correlation characteristics The metrology of random optical fields plays an important role in optical diagnostics and optical recognition studies with applications ranging from astronomy to industrial quality control This monograph examines the possibilities for diagnostics of light scattering objects and media by utilizing the properties of coherent optical radiation Special emphasis is placed on diagnostics of rough surfaces Ideas formulated in classical work on statistical radiophysics and optics have been adapted to diagnostic application The text includes techniques and unconventional methods aimed at obtaining the maximum information available

Nano/Microscale Heat Transfer Zhuomin Zhang, 2007-04-20 A THOROUGH EXPLANATION OF THE METHODOLOGIES USED FOR SOLVING HEAT TRANSFER PROBLEMS IN MICRO AND NANOSYSTEMS Written by one of the field's pioneers this highly practical focused resource integrates the existing body of traditional knowledge with the most recent breakthroughs to offer the reader a solid foundation as well as working technical skills THE INFORMATION NEEDED TO ACCOUNT FOR THE SIZE EFFECT WHEN DESIGNING AND ANALYZING SYSTEMS AT THE NANOMETER SCALE WITH COVERAGE OF Statistical Thermodynamics Quantum Mechanics Thermal Properties of Molecules Kinetic Theory and Micro Nanofluidics Thermal Transport in Solid Micro Nanostructures Electron and Phonon Scattering Size Effects Quantum Conductance Electronic Band Theory Tunneling Nonequilibrium Heat Conduction and Analysis of Solid State Devices Such As Thermoelectric Refrigeration and Optoelectronics Nanoscale Thermal Radiation and Radiative Properties of Nanomaterials Radiation Temperature and Entropy Surface Electromagnetic Waves and Near Field Radiation for Energy Conversion Devices IN THE NANOWORLD WHERE THE OLD AXIOMS OF THERMAL ANALYSIS MAY NOT APPLY NANO MICROSCALE HEAT TRANSFER IS AN ESSENTIAL RESEARCH AND LEARNING SOURCE Inside Statistical Thermodynamics and Kinetic Theory Thermal Properties of Solids Thermal Transport in Solids Micro Nanostructures Micro Nanoscale Thermal Radiation Radiative Properties of Nanomaterials

Selected Papers from the ISTE GIM'19 Lucien Baldas, Jürgen J. Brandner, Gian Luca Morini, 2021-03-01 This Special Issue compiles 11 scientific works that were presented during the International Symposium on Thermal Effects in Gas Flow in Microscale ISTE GIM 2019 held in Ettlingen Germany in October 2019 This symposium was organized in the framework of the MIGRATE Network an H2020 Marie Skłodowska Curie European Training Network that ran from November 2015 to October 2019 www.migrate2015.eu MIGRATE intends to address some of the current challenges in innovation that face the European industry with regard to heat and mass transfer in gas based microscale processes The papers collected in this book focus on fundamental issues that are encountered in microfluidic systems involving gases such as the analysis of gas surface interactions under rarefied conditions the development of innovative integrated microsensors for airborne pollutants new experimental techniques for the measurement of local quantities in miniaturized devices and heat transfer issues inside microchannels The variety of topics addressed in this book emphasizes that multi disciplinarity is the real common thread of the current applied research in microfluidics We hope that this book will help to stimulate early stage researchers who are

working in microfluidics all around the world This book is dedicated to them *International Aerospace Abstracts* ,1999

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