

Preface

This book is the outgrowth of work done over 30 years by the first author's group in the departments of Mechanical Engineering at Kyoto University, Mechanical Systems Engineering at Toyama Prefectural University, and Mechanical and Space Engineering at Hokkaido University. The work is concerned with basics of evaporation and condensation at the vapor–liquid interface where the bulk vapor phase and the bulk liquid phase of the same molecules coexist side by side. It focuses on physical understanding and mathematical description of interfacial phenomena in length scales ranging from a molecular size to a usual fluid-dynamic one, such as kinetic and fluid-dynamic boundary conditions including the evaporation and condensation coefficients, vapor pressure and surface tension for nanodroplets, and applications of fluid-dynamic boundary conditions to vapor bubble dynamics.

The meaning and significance of subjects to be discussed in the book are described in some detail in Chap. 1. It is needless to say that the evaporation and condensation are of paramount importance in various fields of engineering, physics, chemistry, meteorology, and oceanography. As examples of current topics related to the evaporation and condensation, we can refer to flows around aircraft in clouds, bubble formation in liquid fuels of rockets, vapor explosion in nuclear reactors and volcanoes, vapor bubble formation in LNG transport process, heterogeneous reaction on droplet and aerosol surfaces in the atmosphere, and so on. The crucial point in these problems can be attributed to boundary conditions at the interface for both the Boltzmann equation and the set of Navier–Stokes equations.

It was 2005 when a kinetic boundary condition (KBC) for the Boltzmann equation was formulated in a physically correct form. However, accurate values of the evaporation and condensation coefficients for any vapors have not been determined up to now, and therefore, we can not obtain still now physically correct solutions to these problems in theoretical and numerical ways. Historically, since the end of nineteenth century, it has been known that the evaporation or condensation process requires the kinetic theory of gases for its analysis, and numerous investigations have been made by the kinetic approach, resulting in various fruits. However, in 1990s, it has been recognized that the kinetic theory of gases on the evaporation or condensation further needs microscopic information of molecules at the interface, e.g., correct KBC, exact values of the evaporation and condensation coefficients included in the KBC. Since then, molecular dynamics (MD) has received much

attention for simulation of the evaporation and condensation, and become a powerful tool to get microscopic information of the interface at atomic and molecular levels.

The authors have engaged in investigation of the evaporation and condensation at the interface by using their unique methodology based on MD, molecular gas dynamics, and shock wave. Using MD, they have made numerical simulations of molecular motions in domains consisting of the bulk vapor of argon, its liquid, and the planar interface between them, and thereby formulated the physically correct KBC. Furthermore, using shock waves, they have made experiments of condensation for methanol and water vapors in nanometer and microsecond scales and deduced values of the evaporation and condensation coefficients of these materials by the aid of the polyatomic version of the Gaussian–BGK Boltzmann equation, a governing equation in molecular gas dynamics.

The authors try to describe contents dealt with in this book as precisely as possible by restricting them to only their own work and to connect tightly them ranging from the microscopic to macroscopic scales. The evaporation or condensation phenomenon in the three space domains with utterly different length scales is analyzed by means of MD, the Gaussian–BGK Boltzmann equation, and the set of Navier–Stokes equations. Matching methods among the domains or the different governing equations are presented, and the reasonable matching between the microscopic and macroscopic scales is carried out to give the closed forms of the boundary conditions for both the Gaussian–BGK Boltzmann equation and the set of Navier–Stokes equations. A set of boundary conditions for the latter is applied to dynamics of a single vapor bubble in liquids as an application.

However, the authors must say that they had to restrict the problems on the boundary conditions and the evaporation and condensation coefficients to only a single-component vapor–liquid two-phase system and to weak evaporation or condensation because of overwhelming difficulties of the problems. A two-phase system consisting of a liquid and its vapor-noncondensable gas mixture is of importance in engineering applications. However, the derivation of physically correct kinetic and fluid-dynamic boundary conditions have not been accomplished and these are under development. Problems of such a system as well as strong evaporation or condensation are left as challenging subjects in the future.

The contributions to the chapters of this book are as follows: S. Fujikawa to Chaps. 1, 3, and 4; T. Yano to Chap. 2, and Appendices A and B; M. Watanabe to Chap. 5 and Appendix C. In writing this book, the authors are indebted to the following colleagues, their former Ph. D students; Prof. T. Ishiyama has contributed to Chap. 2 as his Ph. D work, Prof. K. Kobayashi to Chap. 3 as his Ph. D work, Dr. H. Yaguchi to Chap. 4 as his Ph. D work, and Drs S. Nakamura and M. Inaba partly to Chap. 3 as their Ph. D works. Without their contributions, this book might not have been born. The authors would also like to appreciate helps of Mr. Y. Nozaki, the technician in the first author’s laboratory, for his fine technique in making the experimental apparatuses, Miss K. Itagaki for typing the manuscripts, and Mrs. Y. Fujikawa for making fine figures. Finally, the first author would like to express his deepest gratitude to Ministry of Education, Culture, Sports, Science

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