Preface

In everyday experience we encounter a variety of multi-bubble systems in liquids. The formation of these two-phase systems can be achieved in many different ways such as by mechanical, chemical, thermal, acoustic and optical excitations. The dynamics and cooperative motion of many of these complex systems are, however, poorly understood because of their multiple time scales and polydispersed nature, making their modelling and analysis quite difficult. Nevertheless, in recent years, much effort has been spent in modelling bubble cloud dynamics by taking ensemble averages to account for various interactions within the cloud. Utilizing these models, many advanced numerical methods have been developed and applied to investigate the propagation of nonlinear acoustic and shock waves in bubble clouds. In addition, direct numerical simulations of nonlinear pressure waves in bubble clouds containing a moderate number of bubbles are also achieved, and the results are compared with those of the model equations to improve on the assumptions made.

The investigation of bubble cloud dynamics is particularly important in cavitating flows observed in naval structures and hydraulic machinery. In this case the destructive action of cavitation can arise from the strong shock waves emitted during the collapse of the bubble clouds leading to erosion. Cavitation damage can also arise on a smaller scale in biomedical applications, e.g. the damage to red blood cells in artificial heart valves or the damage due to impact head injuries. On the other hand, cavitation bubble collapse in a deliberate and controlled fashion has found useful applications in surface cleaning and biomedical applications such as shock wave lithotripsy and drug delivery systems. Bubble cloud dynamics can also serve for modelling volcano eruption as well. The present book is devoted to these investigations by well-known researchers.

The book is divided into four parts, labelled as A, B, C and D. Part A discusses the fundamental issues of shock wave formation during single bubble or bubble cloud collapse together with emission of shock waves by laser-generated bubbles, and their interaction with single or multiple bubbles. In Part A, Chapter 1, written by C.D. Ohl and S.W. Ohl, the recent work on the interaction of shock waves with stable bubbles or cavitation bubbles in clouds is summarized. In Chapter 2, by D.M. Leppinen, Q.X. Wang and J.R. Blake, the highly nonlinear behavior of vigorously pulsating non-spherical bubbles near rigid and compliant boundaries, free surfaces and fluid-fluid interfaces is presented, through an appreciation of the underlying fundamental physics, together with the latest analytical and computational developments and the available knowledge provided by experimentation. Chapter 3, by W. Lauterborn and A. Vogel, reviews the phenomena occurring when short pulses of laser light are focused into a liquid. Consequently, the dielectric breakdown with plasma and bubble formation, the breakdown shock wave, bubble dynamics with expansion and collapse, and the bubble collapse shock wave(s) are addressed.

Part B discusses nonlinear pressure wave propagation, particularly the propagation of shock waves, in bubbly liquids using model equations and direct numerical simulations. In Chapter 4 of this part, written by T. Yano, T. Kanagawa, M. Watanabe and S. Fujikawa, weakly nonlinear wave equations for pressure waves in bubbly liquids are derived in a general and systematic way based on the asymptotic expansion method of multiple scales. Various governing equations describing weakly nonlinear wave propagation in bubbly liquids, such as the Korteweg-de Vries-Burgers equation, the nonlinear Schrdinger equation and the Khokhlov-Zabolotskaya-Kuznetsov equation are derived in a unified fashion. In Chapter 5, written by K. Ando, T. Colonius and C.E. Brennen, the shock dynamics of liquid flows containing small gas bubbles is investigated by numerical simulations based on a continuum bubbly flow model. Particular attention is devoted to the effects of distributed bubble sizes and gas-phase nonlinearity on shock dynamics. Finally in Chapter 6 of this part, written by G. Tryggvason and S. Dabiri, Direct Numerical Simulations (DNS) for the propagation of nonlinear pressure waves, where every continuum length and time scale are fully resolved, is carried out to understand the effect of bubble-flow and bubble-bubble interactions.

Part C is devoted to the investigation of the formation of shock waves, their propagation properties and their interaction with boundaries in cavitating flows using different cavitation models. Chapter 7, by C.F. Delale, G.H. Schnerr and Ş. Pasinlioğlu, considers stationary and propagating shock waves in bubbly cavitating flows through quasi-one-dimensional converging-diverging nozzles using a homogeneous bubbly liquid flow model. In particuler, the temporal stability of stationary shock waves shows that they are unstable with respect to small perturbations. In Chapter 8, by N.A. Adams and S.J. Schmidt, numerical methods based on a two-fluid method using sharp interface treatment and non-equilibrium mass transfer and on a single-fluid method using local thermodynamic equilibrium, are presented for the simulation of compressible multiphase flows with phase transition. Results provide insight into the bubble collapse phenomena and the resulting peak loads observed in cavitating flows.

The concluding part, Part D, is devoted to applications in medical and earth sciences utilizing the interplay between bubble dynamics and shock waves. Chapter 9, by A.A. Doinikov, A. Novell, J.M. Escoffre and A. Bouakaz, considers the dynamics of encapsulated gas microbubbles which are used in medical ultrasound as contrast agents for imaging and as a therapeutic tool for drug delivery. Chapter 10, by P. Zhong, provides a comprehensive review of the primary technologies used for shock wave generation and focusing, followed by an in depth discussion of the acoustics of shock wave-stone interaction, mechanisms of stone fragmentation and tissue injury during shock wave lithotripsy (SWL). In Chapter 11, by A. Abe and H Mimura, a new sterilization technique is presented using shock pressure and microbubbles to develop more secure and environmentally friendly treatment methods for ships' ballast water. Finally, in Chapter 12, written by V. Kedrinskii and K. Takayama, the dynamics and structure of eruptions of explosive volcanic systems are investigated using a multi-phase mathematical model whose numerical solution shows that bubble dynamics in the cavitating melt takes a collective character and that the diffusion of the dissolved gas from the melt plays the key role in the formation of two types of decompression waves.

This book is organized in such a manner to stimulate the interplay between bubble dynamics and shock waves for novel applications. The book, by no means, is intended to cover a complete description of the subject and, unfortunately, many interesting topics are left out. The topics covered are chosen to give an up-to-date description of each fundamental or applied field of current interest. The authors of the chapters are not only well-known experts in their field, but have also devoted many years of their profession to the topics covered. I am indebted to each one of them for their contribution. I hope that the book would serve as a comprehensive reference book for the interested reader on the topics covered.

Işık University, Istanbul, August 2012 Can F. Delale