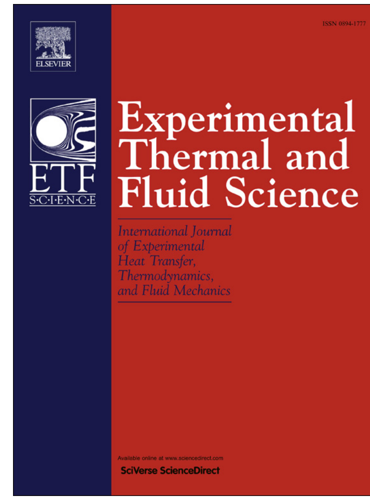
Accepted Manuscript



Multiphase Phenomena in Underwater Explosion

Nikita V. Petrov, Alexander A. Schmidt

PII: S0894-1777(14)00129-0
DOI: http://dx.doi.org/10.1016/j.expthermflusci.2014.05.008
Reference: ETF 8224

To appear in: *Experimental Thermal and Fluid Science*

Received Date: 26 March 2014
Revised Date: 5 May 2014
Accepted Date: 6 May 2014

Multiphase Phenomena in Underwater Explosion

Nikita V. Petrov, Alexander A. Schmidt,

Computational Physics Laboratory, Ioffe Physical Technical Institute, Saint Petersburg, 194021, *Russia*

Keywords: numerical simulation, underwater explosion, blast wave, rarefaction wave, free surface, cavitation

Abstract

The paper is devoted to numerical investigations of processes accompanying an underwater explosion near the free surface. A model of evolution of liquid and gas separated by free surface is implemented. The model enables one to take into account cavitation in rarefaction waves propagating through the liquid. Thus, the study is directed at phenomena of propagation of compression and rarefaction waves in the liquid and in the gas, of interaction of the waves with each other and with moving free surface, and of cavitation due to pressure drop in the liquid. Governing equations are solved by a numerical method based on Godunov-type high resolution scheme. Location of the free surface is determined utilizing information on distribution of the liquid volume fraction taking into account compressibility of both media. Computations of underwater explosion near the free surface have demonstrated robustness of the proposed algorithm.

1. Introduction

Although the problem of underwater explosion near free surface has been attracting attention of many researchers for a long time (see, in particular, [1]), many challenges still remain.

Typical structure of flow, induced by energy release in water, is presented in Fig. 1, which shows Schlieren visualization of early stage of underwater detonation of 10 mg AgN_3 [2]. Compression and rarefaction waves propagating in liquid, shock wave transmitted in outer gas, and domain of cavitation behind the rarefaction wave are clearly seen in the figure.

It should be noted that evolution of cavitation bubbles in changing liquid pressure is one more important process, accompanying the underwater explosion. Effects of ambient pressure and interphase mass transfer result in complex oscillating behaviour of the bubbles. For example, Fig. 2 demonstrates experimental data on time variation of radius of a bubble induced by laser energy release in glycerin [3].

In this paper the main attention is paid to propagation of blast and rarefaction waves in liquid and gas, to their interaction with each other and with the free surface, and to inception and development of cavitation in domains of pressure drop.

Analysis of these phenomena is important for both development of theory of heterogeneous media and a wide range of applications utilizing specific features of underwater explosions. One of goals of this study is development of an efficient, convenient, and flexible tool for investigation of such phenomena.

Since due to cavitation the liquid becomes a two-phase bubbly medium simulation of the processes initiated by local energy release in such a medium is based on combined Euler-Lagrange approach treating the carrier phase (liquid) as continuum and the dispersed phase (cavitation bubbles) as a set of test particles. A modification of well known liquid volume fraction (VOF) method [4] is used to determine location of the interface between the bubbly liquid and the outer gas.

To close the mathematical model it is important to choose adequate constitutive equations of the involved media.

The liquid (water the case under study) is considered a barotropic medium obeys the Tait constitutive equation, while gas is considered an ideal perfect medium.

Besides, an attempt is made to introduce the stiffened gas model as the constitutive equations for both water and gas.

An algorithm proposed for solution of the governing equations uses a high-resolution Godunov type numerical scheme [5] providing the second order accuracy for both spatial and temporal coordinates in domains of smooth gas dynamic function behaviour. Since there is no analytical solution of the Riemann problem for water, numerical procedure based on Newton iterations is implemented.

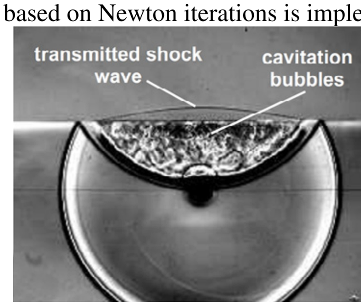


Fig. 1 Schlieren visualization of underwater explosion [2].

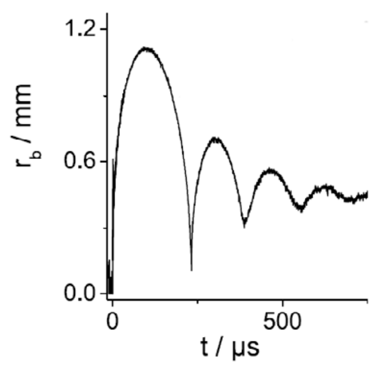


Fig. 2. Time variation of radius of bubble induced by laser energy release in glycerin [3].