Compressible hydrodynamic consideration of cavitating jets on the scraping action of organisms attached on marine structures

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ABSTRACT

Marine organisms adhering to hulls make fluid resistance increase and fuel consumption worse. In the collapse process of microbubbles contained in cavitating jets, the temperature and the pressure inside bubbles are increased extremely high and shock waves and micro-water jets are generated. However, many aspects of various fluid flow phenomena with cavitating jets have not been clarified, and there are issues in improving the efficiency of removing attached organisms. In this study, visualization experiments were conducted to elucidate the phenomena of cavitating jets and to obtain knowledge for their application to removal work.

KEY WORDS: cavitating jets; microbubbles; shock wave generation area; visualization experiments

INTRODUCTION

As a maritime nation, Japan’s international logistics by ship plays an important role, accounting for 99.6% of its trade volume (Japan Maritime Center ed., 2021). In the current global trend toward the SDGs, the field of marine transport is also required to actively address global environmental conservation, including both atmospheric and oceanic issues. The challenges in marine transportation are the prevention of transboundary marine organisms from ballast water and ship bottom biofouling and the achievement of zero emissions of greenhouse gases (GHG) from large vessels (Gerhard et al., 2019; IMO Arctic Summit, 2020; Valković and Obhođaš, 2020). In particular, organisms adhering to the bottom of ships are a cause of adverse effects on both the marine and atmospheric environment because, in addition to the transgression of marine organisms, they reduce the propulsion efficiency of ships and worsen their fuel consumption. However, there is concern about the long-term accumulation of dissolved substances in the paint in the sea, which could affect the marine environment (Yuan, Nag and Cummins, 2022; Abiaye, Loto and Fayomi, 2019).

Similarly, the mechanical removal of ship bottom deposits is performed during periodic maintenance of ship bottoms in dry docks, but this involves disposal as industrial waste and the health concerns of workers due to dust. If routine cleaning of ships at anchor were inexpensive and easy to perform, it would be possible to remove adherent organisms before they become attached to the ship's bottom and always maintain a smooth ship bottom.

One effective method for removing ship bottom deposits in water is the use of cavitating jets (Tamaki, Shimokawa and Abe, 2019; Wang and Abe, 2016). It has been shown that the contraction and expansion motion of the microbubbles that make up the cavitating jet not only produces shock waves during rebound and water jets during collapse, but also that the high temperature and high-pressure state inside the bubbles achieved during bubble contraction produces OH radicals, which inactivate bacteria subject to ballast water discharge regulations (Wang and Abe, 2016; Wang et al., 2018a; Wang et al., 2018b). The application and development of this technology is expected to become a fundamental technology in the maritime field. Therefore, it is significant to observe the phenomena occurring in the jet field in detail and to understand the morphology and characteristics of the flow field, because more effective and efficient use of cavitating jets can contribute to the further development of ship bottom debris removal technology and ballast water treatment technology.

In this study, we attempted to visualize the multiphase flow field of a cavitating jet containing microbubbles to elucidate the phenomenon from the viewpoint of compressible hydrodynamics, focusing on the generation of shock waves in the jet field, with the aim of creating new basic technologies and improving environmental protection technologies in the field of maritime science as mentioned above.

METHODOLOGY

A schematic of the apparatus used in this experiment is shown in Fig. 1. A triple plunger pump (MF1513P, FLUTECH CO., LTD.) was used to generate the cavitating jet. The jet was injected vertically upward through an orifice (Fig. 2(a)) from a nozzle installed at the center of the bottom of an acrylic tank (width: 400 mm × depth: 400 mm × height: 480 mm). The orifices used in this study are shown in Table 1. The diameters of the orifices are 0.75, 1.00 and 1.25 mm, and thicknesses of orifices (Typ. 1, 2, 3: 2 mm thick, Typ. 4: 4 mm thick, Typ. 5: 6 mm thick) are shown in Fig. 2(a). The orifice (Typ.6) which has a conical constriction channel upstream of the orifice shown in Fig. 2(b) with a length of approximately 24 mm was used. The images were taken by the schlieren method at 100,000 fps with an exposure time of 10 ns.