International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 27, No. 1, March 2017, pp. 1–10; https://doi.org/10.17736/ijope.2017.jc681

http://www.isope.org/publications/publications.htm

Experimental Observation of the Effects of Liquid Temperature and Bubbles on Impact Pressure Inside Gas Pocket

Yonghwan Kim*, Jeoungkyu Lee and Jieung Kim
Department of Naval Architecture and Ocean Engineering, Seoul National University
Seoul, Korea

In this study, a series of drop tests were carried out to observe the effects of the impact pressure inside a gas pocket of water with different temperatures and/or a lot of bubbles. Cylindrical gas pockets were generated by dropping the body into the water with different temperatures and/or different bubble sizes. Dynamic pressures in gas pockets were measured by various types of pressure sensors installed on the disc that was part of the body. The results of this study are expected to be very useful in understanding the physical phenomena of sloshing inside real liquefied natural gas (LNG) cargo.

INTRODUCTION

A liquefied natural gas (LNG) carrier involves sloshing issues due to partially filled LNG inside a cargo containment system (CCS). As the size of ships becomes larger with the LNG tank, the importance of a sloshing analysis inside the tank is increased. In order to investigate the sloshing phenomenon, plenty of studies have performed model tests rather than numerical analyses. In the traditional model test, Froude and geometric scaling have been generally applied, so the impact pressure measured in the model test used to be scaled up to full scale with those scaling laws. However, Froude scaling does not consider some physical phenomena, such as the phase transition and fluid-structure interaction, which occur during the impact. Although Froude scaling shows good agreement in global flow, there is limited accuracy in local impact. As the sloshing impact occurs due to local flow, it is necessary to find the appropriate scale parameter considering the fluid properties.

The local sloshing impact can be categorized into three modes: impact without a gas pocket, impact with a gas pocket between the liquid and the wall, and impact by a broken wave with mixed gas bubbles (Lugni et al., 2010). In the first mode, the incipient breaking wave leads to the formation of jet flow such as a flip-through event on a tank wall, and the impact pressure shows nonoscillating behavior due to the absence of a gas pocket. In other modes, the air-liquid interaction is considered during the impact. Especially in the second mode, entrapped pure gas generates the oscillation of the impact pressure. In the real sloshing problem, a phase transition occurs between the entrapped gas and surging liquid. In addition, a lot of bubbles are generated inside liquid during the violent sloshing flows, so a study of the gas pocket and bubbles should be conducted, which considers the characteristics of gas such as the density ratio between liquid and gas, ullage pressure, compressibility of gas, and phase transition.

There have been several studies of the sloshing impact focusing on the characteristics of the gas. Maillard and Brosset (2009) investigated the relation between the density ratio and sloshing impact pressure in the 2D rectangular tank with the regulating temperature, the ullage pressure, and a component of gas. In the study, an increase of the gas to liquid density ratio led to a reduction of the peak pressure and an increase of the rising time. Moreover, with the condensation of the gas fraction due to the overpressure, the oscillations were damped, and the statistical pressures were reduced. Ahn et al. (2013) also investigated the influence of the density ratio on the sloshing impact pressure in the 3D prismatic tank. While those studies dealt with the statistical pressure, some studies focused on a single impact involving a gas pocket. Lugni et al. (2010) measured the pressure and velocity of the flip-through event using Particle Image Velocimetry (PIV). Abrahamsen and Faltinsen (2011) studied the effect of air leakage and heat exchange on the pressure decay during the oscillation when the wave touches the roof. Braeunig et al. (2010) and Ancellin et al. (2012) investigated the effect of phase transition on sloshing impact. Loysel et al. (2013) performed a comparative study of three types of sloshing impacts acting on the tank roof with a gas pocket.

However, there are few studies that treated the phase transition and bubble effect on the sloshing impact. The phase transition between liquid and gas might be one of the main factors that discriminate the sloshing flow of natural gas (NG)/LNG and air/water. Therefore, by means of boiling the water, the cavitation number can be zero, and when the vapor pressure exceeds the atmospheric pressure, a phase transition occurs. In the case of the bubble effect, bubbles inside the liquid generated from violent sloshing flows may influence the shape of the free surface and density ratio.

The main interest of this study was the effect of the phase transition and bubbles inside the liquid on the impact pressure. A series of drop tests were carried out to investigate the impact pressure when the gas pocket was entrapped by liquid. Therefore, the temperature and intensity of the bubble generator were considered as the main experimental variables. Additionally, other variables were also considered for parametric study to investigate the characteristics of the gas pocket: the impact velocity and depth of the gas pocket inside the cylindrical ring. Those variables were systematically analyzed from the measured pressure data through the investigation of the peak pressure and impact duration.

*ISOPE Member.

Received August 10, 2016; updated and further revised manuscript received by the editors November 12, 2016. The original version (prior to the final updated and revised manuscript) was presented at the Twenty-sixth International Ocean and Polar Engineering Conference (ISOPE-2016), Rhodes, Greece, June 26–July 1, 2016.

KEY WORDS: Sloshing, sloshing impact, phase transition, bubble effects, LNG CCS design.