ABSTRACT

This paper is Volume 2 of the ISOPE-2009 paper "Optimization of LNG tank shape in terms of sloshing impact pressure" and focuses on the sloshing parameter analysis. For this study a computationally efficient approach has been used, which is flexible in geometry and load spectrum. It provides time accurate wall pressure results in three dimensions and 6 Degrees-of-Freedom. Based on the results of specific test cases in volume 1 of this study, rectangular, cylindrical and spherical test tanks are discussed to optimize the tank shape in terms of impact pressure loading. Thereby, the LNG tank geometry has been varied in terms of curvature, steepness of the walls, and length-to-height ratio in order to minimize the LNG impact pressure on the tank. Cylindrical and spherical tank shapes have been analyzed in a multi-tank configuration undergoing forced oscillations in 6 Degrees-of-Freedom representing ocean waves. It has been found that in a multi-tank configuration, the spherical tanks help reducing the overall loads in a specific natural frequency domain when combined with corner-shaped tanks.

KEY WORDS: LNG tank; sloshing; wall pressure; particle-cluster approach; natural frequencies; rectangular and cylindrical tanks; multi-tank configuration.

INTRODUCTION

The Liquefied Natural Gas (LNG) provides an efficient way for long distance transport in large vessels. The gas is cooled down to extremely low temperatures such that it can be transported in the liquid state. Hence, the liquefied gas obeys the laws of liquid dynamics. During the filling process, the LNG exercises unsteady forces on the tank walls and makes the vessel react to these forces by ship motion. The ship motion, however, is the driver for LNG sloshing in the tank. Special focus is given to the tank shape to minimize the impact pressure from sloshing LNG, see Fig. 1. Sloshing in partially filled tanks is a complex physical process. It covers phenomena like wave propagation and liquid-structure interaction; see (Yamamoto and Kataoka and Shioda and Ashitani, 1995). Applying continuum fluid mechanics for a simulation approach, Euler and Navier-Stokes solvers provide a time accurate simulation only if an appropriate free surface determination and propagation is implemented. In consequence, computation time and required memory resources increase with increasing code complexity and accuracy requirements. Recent approaches consider statistical methods for the wall pressure determination see (Gervaise and de Sèze and Maillard, 2009). Briefly, there is still a big amount of uncertainty concerning the physical background of LNG sloshing effects.

In this paper, an innovative approach is highlighted that is able to predict the hydrodynamic wall pressure resulting from LNG sloshing on different tank shapes. This approach does not follow the classical continuum mechanics methods, but is Lagrangian in nature. A large number of microscopic liquid particles (molecules, ions) are supposed to be concentrated in particle-clusters of macroscopic dimensions. These clusters are connected to each other by a Lennard-Jones potential originally in use in molecular dynamics. The potential parameters have been transformed into macroscopic domain using fundamental mechanical and chemical relations. Thermodynamic laws are fulfilled by introducing Fourier’s law of heat transfer and an energy dissipation scheme that obeys the conservation of momentum. Numerically, the cluster trajectories are computed using a Velocity-Verlet integration scheme. An innovative neighborhood list has been designed that permits a linear dependence of the computation time from the number of particle-clusters. A variable time-step scheme allows a drastic