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Influence of DR Between Liquid and Gas on Sloshing Model Test Results

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Pressures induced by the sloshing phenomenon are widely studied through small-scale model tests. This implies the need to satisfy scaling laws governed by dimensionless numbers. While the Froude number is the one governing the overall liquid flow within the tank, other dimensionless numbers, such as the DR between liquid and gas, are likely to govern the local behaviour of the fluids. Consequently, GTT decided to dedicate a specific R&D program on the DR influence, including theoretical (Brauenig et al., 2009; Dias et al., 2007), numerical (Brauenig et al., 2009) and experimental studies. This paper summarizes the experimental work that has been accomplished, including sloshing tests with water and its vapour at different pressures; these tests confirm the major influence of the DR on the statistical results. This paper explains why GTT considers that having fluids in the model tank satisfying the same DR as that of LNG and its vapour within tanks of LNG carriers makes for better experimental modelling, and why it is conservative from a design point of view.

NOMENCLATURE

ρ_L : density of liquid phase
ρ_G : density of gaseous phase
DR : DR between gas and liquid (ρ_G/ρ_L)
DAF : Dynamic Amplification Factor
PDF : Probability Density Function

INTRODUCTION

During a sloshing impact in a tank of an LNG carrier, several local phenomena occur at the same time or sequentially. These include gas escape, compression of the gas fraction while escaping or while entrapped, and beginning of gas condensation together with the rapid change of momentum of the liquid phase forced to avoid the obstacle.

When performing small-scale sloshing model tests with Froude-scaled motion excitations, the overall flow of the liquid is well reproduced regardless of the liquid and the gas in the model tank. But during the impacts the local phenomena described above may radically change, depending on the choice of liquid and gas. Assuming the liquid in the model tank is water and the condensation phenomenon will not be captured at model scale, which could be considered conservative, the choice of the gas turns out to be crucial as it is involved in the escaping phase and the compression phase.

Let us imagine that the compressibility effects could be removed at both scales and for both phases. In that case, provided the Froude number and the ratio of density between the gas and the liquid are equal at both scales, the flows would be completely scalable even during the impacts; this means that the impact pressures would be the same after Froude scaling. This can be observed very simply by use of numerical simulations with a noncompressible 2-fluid CFD Software.

During the impact the gas is pushed away by the liquid. There is a transfer of momentum from the liquid to the gas which is governed by the density ratio (DR). The higher the DR, the more the liquid impact speed is reduced. At the same time, because a heavier gas escapes with more difficulties and so is entrapped more easily, more gas pocket events are expected with heavier gas. These phenomena would remain regardless of the compressibility of the ullage gas. So it means that, regardless of the case, the DR matters during sloshing impacts.

Now the DR between the Natural Gas (NG) and LNG within an LNG tank is around 0.004 (depending on the LNG quality and the gas temperature), while it is around 0.0012 during model tests with water and air at ambient. So a large difference exists that may make the analogy between model scale and full scale irrelevant.

As a mixture of SF_6 and N_2 allows to satisfy the right DR, sloshing model tests have been performed in GTT with water and such an ullage gas mixture. The comparison of the results with those obtained with water and air under the same conditions confirm the important reduction of the statistical pressures (between 20% and 50% depending on the conditions) and the increase in gas pocket events. But this mixture has not the same compressibility factor as the natural gas. Other secondary effects could bias the results. The question now is: Are small-scale tests with fluids satisfying the real DR relevant?

The tests presented below have been designed especially to answer this question.

PRESENTATION OF TESTS

Tests Set-up and Instrumentation

Tests were carried out in the Marintek facilities (Trondheim) with a pressure vessel mounted on a 6-DOF (degree of freedom) test rig, as shown in Fig. 1. This pressure vessel is a steel tank

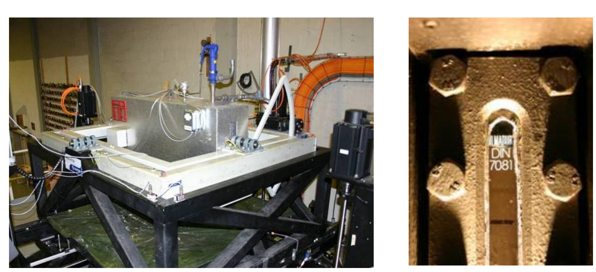

Fig. 1 Left: General view of experimental set-up; right, small window to check boiling level

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KEY WORDS: Sloshing, liquid impact, model tests, scaling laws, dimensionless numbers, DR.