Numerical Investigation of Non-isothermal Axial Sloshing of Liquid Methane

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Introduction

Upper stages of launch vehicles are exposed to a variety of acceleration conditions which induce different sloshing modes inside the propellant tanks. An axial mode of sloshing is invoked when the main engine cuts off and the propellant reorients itself from a gravity dominated equilibrium configuration to its microgravity equilibrium. During this reorientation process the free surface oscillates around it's equilibrium position. The movement of the free surface brings liquid in contact with previously non-wetted and superheated sections of the tank wall. This enhances the phase-change phenomena occurring in the tank, which in turn affects the pressure progression. Understanding these phenomena poses a challenge for propellant management applications. To aid understanding, experiments as well as simulations have been conducted.

Experiments

The experiments using a single species two-phase methane system were carried out by Kulev et al. ([1], [2]). The test cell contains a partially filled glass cylinder, which is placed inside a liquid nitrogen bath cryostat. The glas cylinder is connected to compensating volumes containing gaseous methane at ambient conditions. Along the vessel containing the liquid methane a temperature gradient was imposed along the axial direction. The temperature of the glass container was at or above the saturation temperature for the given vapour pressure.
The test cell was exposed to microgravity in the drop tower of the University of Bremen. The time in microgravity is limited to 4.7 s. This triggers a reorientation process during which the liquid methane reaches superheated parts of the cylinder wall. This initiates a shift in the occurring phase change mass flows.

Evaluation of Experiments

The test cell is equipped with a pressure sensor, and various temperature sensors which measure the wall and vapour temperature. Furthermore, optical measurements were conducted using an endoscope. It was observed, that the position of the liquid on the center axis of the cylinder exhibits a damped oscillation around the new equilibrium position during the microgravity period. The rise of the contact line at the wall was also observed to exhibit oscillatory behaviour. The optical measurements only allow for the evaluation of the oscillation frequency. Positional data could not be accurately acquired due to paralaxic effects.
The vapour pressure also increased which is likely caused by evaporation of the liquid methane.

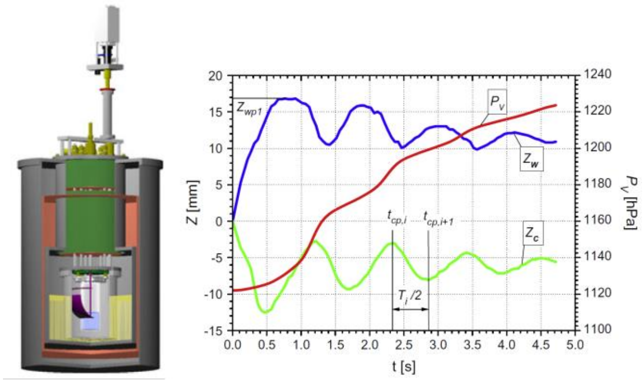

Figure 1: Experimental setup, plots of the vapour pressure, the positions of the center point and the contact line at the wall [1].

Numerical Results

The numerical code used to simulate the experiments is a modified version of the OpenFOAM solver interFoam. The modifications were carried out by the DLR Institute for Space Systems in Bremen as part of the multiphase library.
interFoam was modified to additionally include conjugated heat transfer in a solid region, a phase change model and improved interface reconstruction.
The numerical results are compared to the experimental results in Figure 2. Good agreement can be seen for the surface position. The simulation results were further evaluated with regards to the phase change and the local heat fluxes.

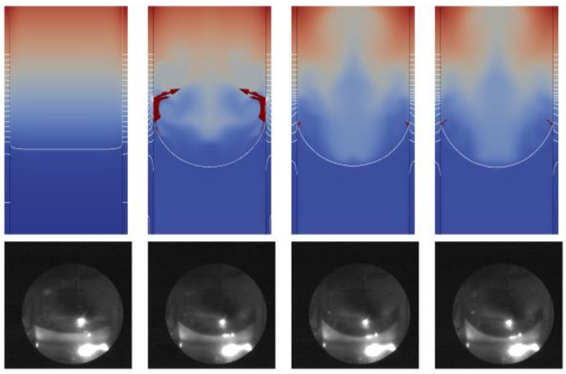

Figure 2: Comparison of numerical results and experimentally generated data. The simulated temperature field is shown.

References

[1] N. Kulev, M. E. Dreyer (2010) Drop tower experiments on non-isothermal reorientation of cryogenic liquids, *Microgravity Sci. Technol.* **22** (4), 463-474

[2] N. Kulev, S. Basting, E. Baensch, M. E. Dreyer (2014) Interface reorientation of cryogenic liquids under non-isothermal boundary conditions, *Cryogenics* **62**, 131-153