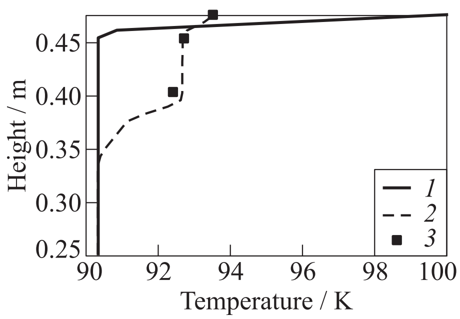

Figure 9 Thermal stratification in the liquid phase (before (*1*) and after 50 s of sloshing LOx/GOx: *2* — numerical and *3* — experimental results)

The temperature near the free surface is no more stratified but homogeneous.

Destratification phenomenon during sloshing is also clearly visible in numerical computations (Fig. 8). Subcooled liquid is going up to the interface and is able to condensate a large quantity of vapor leading to a large pressure decrease in the cryostat.

At the end of the sloshing phase, the temperature distribution in liquid is very different (Fig. 9): At the end of sloshing, temperature near the free surface (liquid phase) is more homogeneous. The free surface temperature has decreased. The experimental and numerical results on thermal destratifications are in good agreement. The vapor phase condensation is thus well computed by the numerical model.

4.2 Pressure Evolution

Figure 10 shows pressure histories obtained in experimental and numerical tests. Two different sloshing experiments are compared for two different fluids (LN_2 pressurized with GN_2 and LOx pressurized with GOx) with the same lateral excitation: frequency 2.1 Hz and amplitude 3 mm.

The pressure histories in the experiments and in the numerical computations are in very good agreement for both liquid nitrogen and liquid oxygen experiments.

It is seen from Fig. 10 that the pressure drop is the fastest during the first 15 s of sloshing (from 2.5 down to 1.7 bar). Pressure stabilizes then at about 1.5 bar.

The pressure decay is more important in the very first seconds of sloshing for the LOx tank initially pressurized with GOx because of the initial stratification in the liquid. This initial stratification in LOx was strong (compared to initial stratification in LN_2) (see Figs. 3 and 5). This stronger initial stratification in LOx has been created due to a faster pressurization phase.

Note that the observed pressure histories have nothing to do with the pressure decay occurring during thrust phases of launcher upper stages (initial stratifications are not so strong and wave amplitude is not so important).

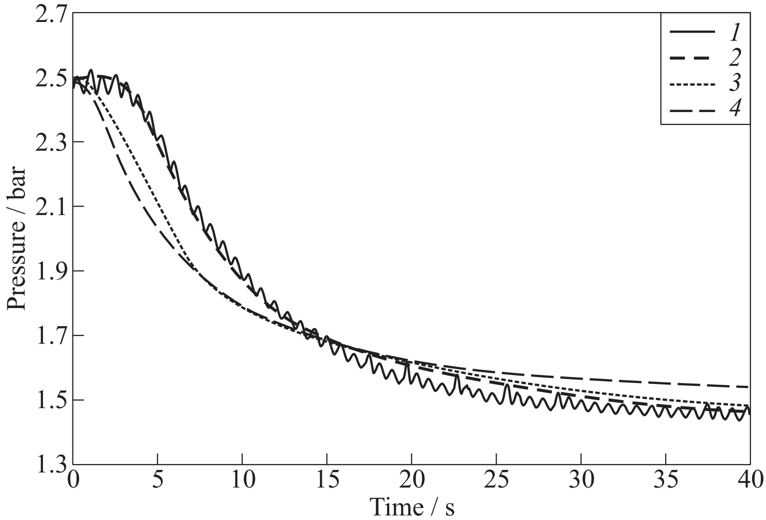

Figure 10 Comparison of measured and calculated pressure histories in the cryostat for LN_2/GN_2 and LOx/GOx sloshing: *1* — LN_2 sloshing after GN_2 pressurization — experimental results; *2* — LN_2 sloshing after GN_2 pressurization — CFD results; *3* — LOx sloshing after GOx pressurization — CFD results; and *4* — LOx sloshing after GOx pressurization — experimental results

5 CONCLUDING REMARKS

The destratification process in the liquid phase is represented in terms of the comparison between experimental sloshing tests with cryogenic fluids and numerical results. The destratification process is shown to be responsible for a large pressure drop in the cryostat.

The pressure and temperature histories in the fluids are well predicted by the numerical model. The numerical model could also be used in the future for computing pressure and temperature evolution in future upper-stage cryogenic tanks submitted to different external perturbations (engine shut-down, separation phase, reoriention before reignition, etc.).

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