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タンク底面から噴射されるミキシングジェットの挙動に対する重力の影響

Gravity Effects for Mixing Jet Behavior Injected from the Bottom of Tank

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1. Introduction

Recently, there is an urgent need to improve the performance of spacecraft propulsion systems to realize a manned Mars. Long-term storage of cryogenic fluids, especially those used for fuels, is an important issue. In the tanks of cryogenic propellants, continuous sunlight and slight heat input from surrounding equipment causes the formation of a thermal stratification near the liquid surface, which leads to significant boil-off from the surface. As a result, the temperature and pressure inside the tank may increase significantly, leading to a tank rupture or other serious accident. Schaffer[1)] reported that the boil-off rate had a significant effect on payload weight in Mars exploration. Therefore, development of Thermodynamic Vent System (TVS)[2-4)], which is reduced Boil-off by breaking down the temperature stratification near the liquid surface with mixing jet, has been conducted to suppress the pressure raise in the tank. Aydelott[4)] performed jet mixing experiments under unheated conditions by using drop tower. He classified four flow patterns according to differences in jet behavior and focused on the height of the jet and the mixing effect. And characteristics of temperature change near the liquid surface caused by the mixing jet should be studied. Up to now, we reported that jet mixing experiment[5)] by using drop tower, and a simple one-dimensional model which was described the jet tip height, proposed in the previous study[6)]. In this study, we repot that the results are conducted jet mixing experiments using aircraft in reduced-, micro-, and normal gravities.

2. Experimental procedure and conditions

Figure 1 shows a schematic of the experimental apparatus. The test tank is made of stainless steel and covered with a glass plate front and back sides for observation of the jet behavior. The volume of the test tank is 150 x 75 x 26 mm^3. To measure the temperatures of the liquid and vapor phases, a bundle of eight thermocouples is installed near the tank wall and 2 bundles of eight thermocouples are set near the center of the tank. Before jet mixing, a temperature stratification is generated by heating from eight ceramic heaters. FC-72 is used as the test fluid. The temperature difference between the jet and the bulk liquid in the tank is kept 20 K. In the aircraft experiment, jet issuing from the tank bottom is injected during reduced gravity condition. Experimental conditions in reduced gravity are as follows; jet flow rate $\dot{m}_j$ = 25 mL/min, 40 mL/min, 60 mL/min, 125 mL/min, gravity conditions 1/2 g, 1/3 g, 1/6 g, 1/20 g, 0 g, (1 g = 9.8 m/s^2), initial liquid height from nozzle outlet h =50 mm, temperature difference between jet and bulk liquid ΔT = 20 K, jet injection time t_j = 20 sec. Ground experimental conditions are as follows; jet flow rate $\dot{m}_j$ = 0-140 mL/min, initial liquid height from nozzle outlet h =30, 50, 75 mm, temperature difference between jet and bulk liquid ΔT = 20 K, jet injection time $t_j = 20$ sec.

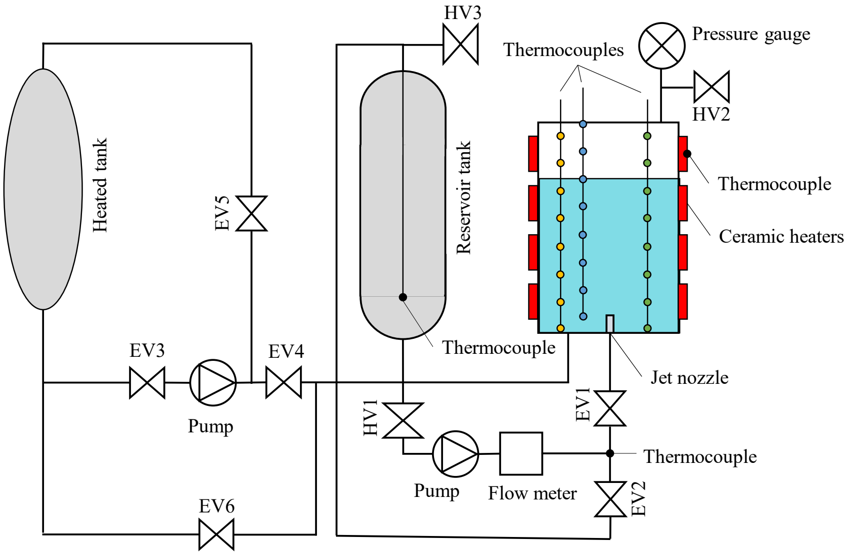

Figure 1. Experimental apparatus. EV and HV are electronic valve and hand valve, respectively.

3. Experimental results

Figure 2 shows the jet behavior observed in reduced and normal gravities. The jet flow pattern classified six flow patterns as follows: Pattern I ; the jet does not reach the liquid surface, Pattern II a; the jet reaches the liquid surface and does not shake the interface, Pattern IIb; the jet reaches the liquid surface and shakes the interface, Pattern III; The jet shows a geyser shape, Pattern IV; The jet collects at the top of the tank, Pattern V; The jet reaches the top of the tank, descends along the tank wall, and returns to the bulk liquid.

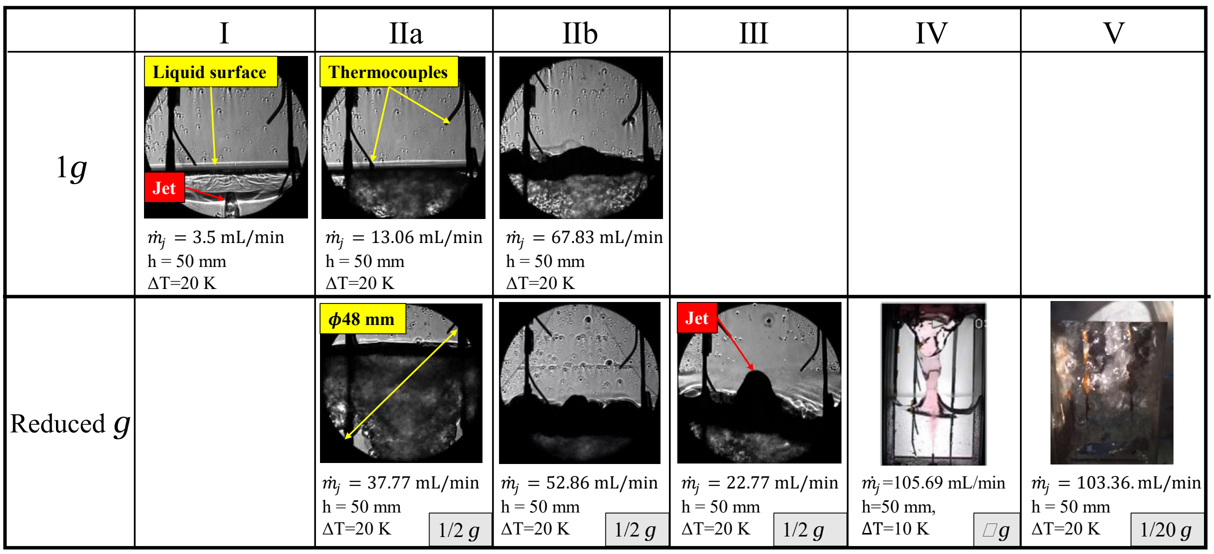

Figure 2. Flow pattern of cooling jet issuing from the nozzle at the tank bottom under reduced gravity and ground gravity.

The jet tip height is measured by Shadowgraph and/or a handy video camera installed in the experimental apparatus. The height is also estimated by a one-dimensional model6), and model and experimental values compared. Figure 3 shows the model and experimental values for various gravity conditions. The model values aligned well with the experimental data.

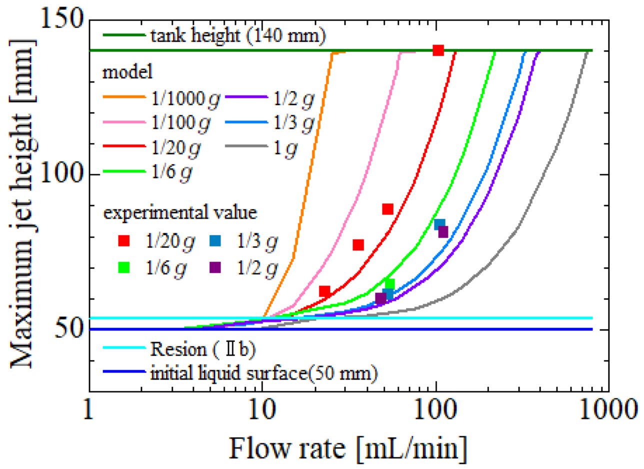

Figure 3. Comparison of jet tip heights derived from the model and experimental results.

Acknowledgements

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