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微小重力下のジェットミキシングにおける攪拌性能の評価

Mixing Performance by Jet Mixing in Microgravity

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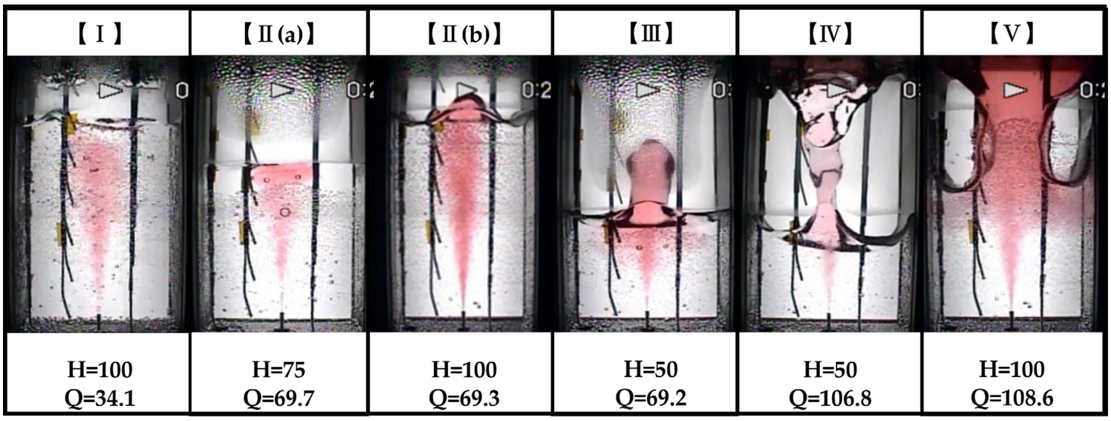
1. Introduction

Long-term storage of cryogenic fluids such as liquid hydrogen and liquid oxygen is required for manned long-distance exploration of deep space. In fuel tank, evaporation from the gas-liquid interface is accelerated by sunlight and heat input from surrounding equipment, and the boil-off gas (BOG) generated from the liquid surface, it is caused pressure raise in the tank and could lead to tank destruction. Conventionally, the direct discharge of BOG has been used as a pressure control method to prevent this destruction. However, this method is not suitable for long-term space exploration due to large fuel loss. Therefore, the development of Thermodynamic Vent System (TVS) to reduce BOG generation is urgently needed[1,2]. An effective way to reduce BOG is to destroy the temperature stratification by mixing cold jet issuing from the bottom of the tank.

Figure 1 shows the flow patterns of jet behavior obtained from our previous experiments[3]. Patterns I ~ II(b) are observed at terrestrial gravity, and flow patterns II(a) ~ V are observed in microgravity: 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 Ⅱ(b); 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. In this paper, microgravity and terrestrial



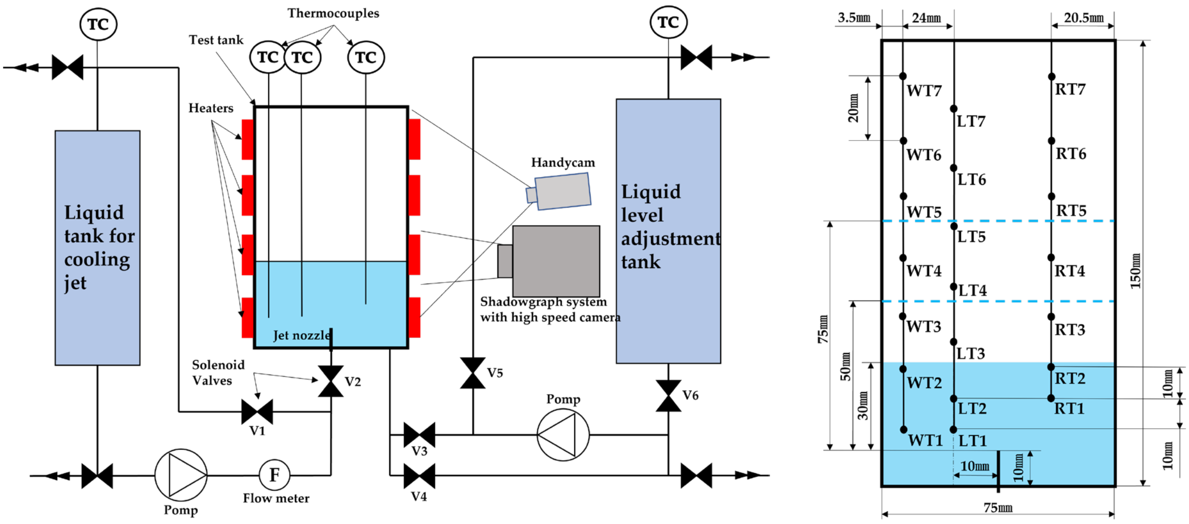
H: Initial liquid surface height (mm), Q: Flow rate (mL/min)

Figure 1. Flow pattern of jet behavior in microgravity.

gravity experiments were conducted to investigate the behavior and the effect of jet mixing on the liquid in the tank.

2. Experimental apparatus

Figure 2(a) shows the schematic diagram of the experimental apparatus. The apparatus consists mainly of a test tank, a liquid tank for cooling jet, a bulk liquid level adjustment tank, a system schlieren, a data logger, a test tank, a flow meter, pumps, thermocouples, a pressure gauge, a jet liquid tank, a liquid level adjustment tank, hand valves and solenoid valves. FC-72 is used as a test fluid. A total of eight ceramic heaters, four on each side, were installed on the wall of the test tank to reproduce the heat input. To observe of jet behavior, Shadowgraph method with a high-speed camera and a Handycam are installed. The Shadowgraph system is for detailed observation, and the Handycam is for observation of entire of the test tank.



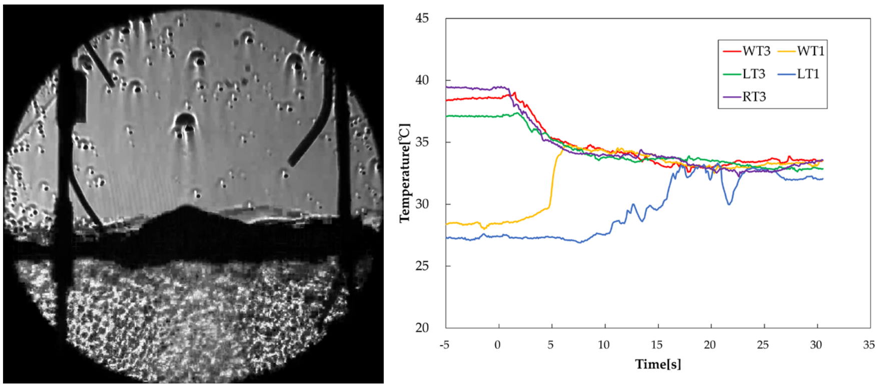
(a) (b)

Figure 2. Experiment set-up: (a) Schematic diagram of the experimental apparatus, (b) Thermocouples location in the test tank

Details of the location of the temperature measurement point by thermocouples in the test tank are shown in **Figure 2(b)**. Thermocouples were installed at seven points near the inner tank wall and at seven points on either side near the center, for a total of 21 points. Experiments were conducted at initial liquid surface heights of 30 mm, 50 mm, and 75 mm. Micro- and reduced gravity are performed by aircraft. 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, 40, 60, 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.

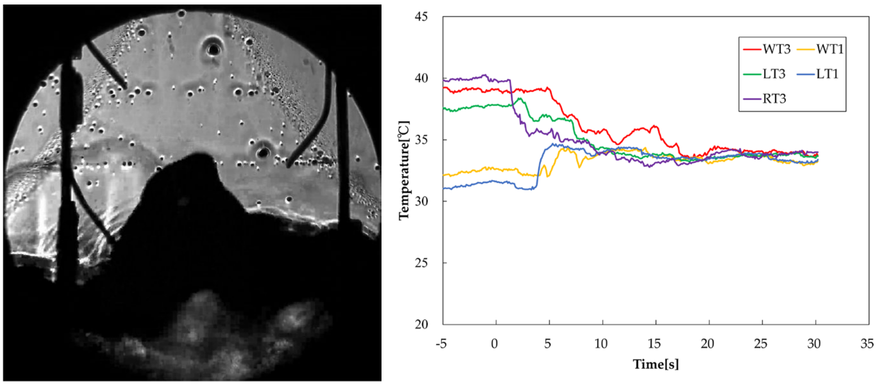
3. Result

Figures 3 and 4 shows the behavior of the jet and the temperature transition in the bulk liquid in the tank at 60 mL/min of the jet flow rate in 1 g and 1/6 g. The temperature measurement points are WT1, WT3, LT1, LT3, and RT3 as shown in **Figure 2(b)**. It was found that the maximum jet-tip height in reduced gravity is higher than that in the terrestrial condition. The temperature transition is clearly shown that as the gravity level decreases, the temperature drop of WT3 is delayed and the temperature rise of LT1 is faster. This is because the jet tip height becomes higher due to the reduced gravity, the jet mixing performance along the liquid surface decreases, and the liquid mixing at vertical direction also weak.



(a) (b)

Figure 3. Result at 60mL/min under 1 g: (a) jet behavior, (b) temperature transition near the liquid surface.



(a) (b)

Figure 4. Result at 60mL/min under 1/6 g: (a) jet behavior; (b) temperature transition near the liquid surface.

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