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小型超音速飛行実験機における酸化剤タンク内模擬推薬熱流動挙動に関する研究

Study on Thermal-Hydraulic Behavior of Simulated Propellant in Oxidant Tank of Small Hypersonic Flight Experiment Aircraft

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1. Introduction

Recently, the next generation supersonic transport and Spaceplane have been studied. The Aerospace Plane Research Center of Muroran Institute of Technology is developing the small-scale supersonic flight experiment vehicle as a flying test bed for technical demonstration in high-speed flight environment. The propellant tank is shown in Fig. 1. In the small-scale supersonic flight experiment vehicle, liquid supplying system for Bioethanol and LOX by pressurant gas has been studied. Since LOX is a cryogenic liquid, the pressurant gas is cooled by LOX and the inner wall of the tank when the propellant is supplied. When the pressurant gas is cooled, the amount of gas required for pressurization increases. The shortage of pressurant gas makes it impossible to maintain the pressure inside the tank, which adversely affects the propellant supply. However, excessive gas loading will cause the pressurant gas tank to become excessive, which will adversely affect the weight of the vehicle. Therefore, it is necessary to predict the amount of pressurant gas loaded [1)].

The purpose of this paper is to develop a design technique for a propellant supply system for the cryogenic propellant tank of the Small Hypersonic Flight Experiment aircraft. In this study, liquid discharge experiments using simulated propellant will be conducted. Using the results obtained, we aim to realize the liquid discharge characteristics by CFD analysis using a pressurized gas supply system that takes into account the thermal flow in the tank.

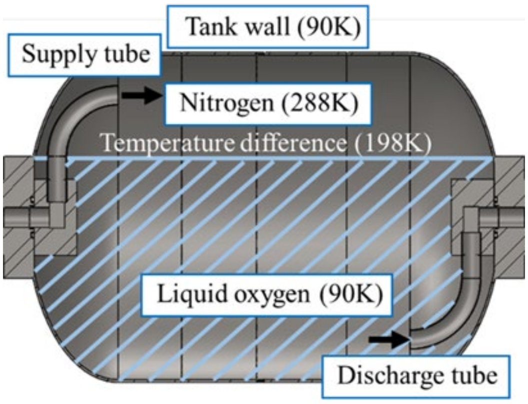

Fig. 1 Propellant tank

2. Experimental Method

Fig 2 shows the measurement points of the internal temperature of the test tank, with the numbers starting from the bottom. The experimental piping is shown in

Fig 3, and experimental conditions A and B are shown in Table 1. 0.2 L/sec is the current flow rate for flight model. In order to verify the thermal-hydraulic behavior in a cryogenic propellant tank, an experiment using a simulated propellant was conducted. In this experiment, we used a test tank (216.3 mm in diameter, 311.3 mm in length, and 8.8 L in filling capacity). The material of the test tank was SUS304 because cryogenic liquid was used as propellant. A heat insulator was installed to prevent heat input. For the simulated propellant, liquid nitrogen with a close saturation temperature was used instead of LOX. And liquid nitrogen is also safer than LOX. Helium gas was used as the pressurizing gas. The liquid nitrogen was filled into the test tank from a self-pressurizing liquid nitrogen container. After the filling was completed, the inside of the tank was pressurized with helium gas, and the liquid nitrogen started to be discharged. PLC (programmable logic controller) was used for the pressure control system. Bang-bang control was used to regulate the pressure (2). When the pressure gauge reaches the lower limit of the target pressure, the electromagnetic valve opens. The electromagnetic valve is set to close when the pressure gauge reaches the upper limit. The measurement items were the temperature of the fluid inside the test tank (16 points), the temperature of the outer wall (3 points), the pressure inside the test tank, the pressurized gas flow rate, the pressurized gas temperature, and the liquid discharge temperature. A T-type thermocouple (sheath outer diameter: 0.5 mm) was used for temperature measurement. The liquid discharge flow rate of liquid nitrogen was calculated from the change in weight using a digital bench scale.

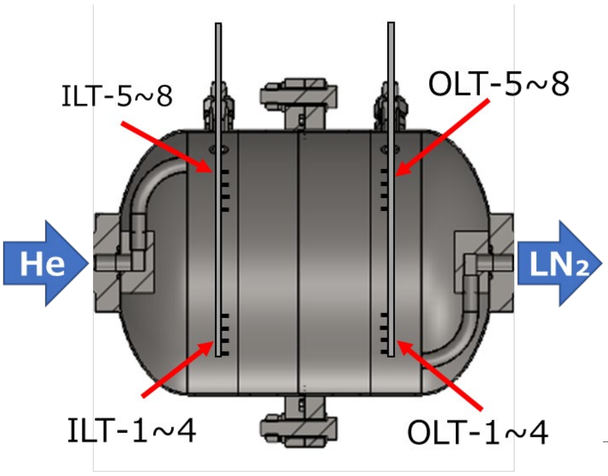

Fig.2 Temperature measurement point

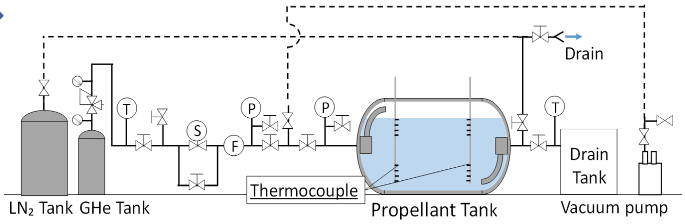

Fig.3 Test system

Table.1 Experimental conditions

	A	B
Flow rate [L/sec]	0.3	0.2
Target Pressure [MPa]	0.2	
Upper Limit [MPa]	0.205	
Lower Limit [MPa]	0.195	
Upstream Pressure [MPa]	0.4	

3. Analysis Method

The analytical conditions are shown in Table.2. Table.2 shows the average values obtained from the experimental results. The thermal-hydraulic behavior in the tank is obtained using ANSYS FLUENT. The VOF method is used to simulate gas-liquid two-phase flow. And the liquid discharge characteristics are analyzed by considering the thermal flow in the tank.

As the initial conditions, tank temperature is 80 K, a tank pressure is 0.2 MPa, and a liquid level is 180 mm. The analytical domain is the inside of the test tank and the solid wall, and these are treated two-dimensionally. The discharge flow rate of liquid nitrogen is inputted at the outlet, and the pressurized gas temperature is inputted at the inlet. These values are given as time variations from each experiment. The pressure inside the tank is given at a constant 0.2 MPa. Therefore, we simulate the situation of liquid discharge inside the tank. The basic equations are the equation of motion, the equation of energy, and the conservation equation of volume fraction (VOF). The flow field is assumed to be laminar. Phase change is not considered. The density, specific heat, heat transfer coefficient, and viscosity depend only on temperature in the gas and - liquid phase. To evaluate the analytical model, we compare the analytical and experimental results for temperature.

Table.2 Analytical conditions

	A	B
Flow Rate [L/sec]	1.71	0.95
Helium Temperature [K]	291.49	290.37

4. Temperature comparison and discussion

The temperature results of the experiment and analysis are compared. The temperature change at the top of the tank for codition A is shown in Figure 5, and the temperature change at the bottom of the tank is shown in Figure 6. The temperature change at the top of the tank is shown in Figure 7, and the temperature at the bottom is shown in Figure 8. The points in the graphs are the experimental results, and the solid lines are the analytical results. Figure 5-8 shows that the temperature is kept below 80 K at the bottom of the tank (OLT1-4). The temperature measurement point at this point is below the free surface. However, when comparing the two, the temperature of the analytical results is higher than the experimental results. And the time when the temperature starts to rise is faster. In Figs. 5 and 7, the temperature at the top of the tank (OLT5-8) rises at the same time as the liquid is discharged in both the experimental and analytical results. This is because the incoming helium gas is kept at room temperature, and the temperature difference with the liquid nitrogen is very large. The temperature of OLT5-8 rises because the incoming helium gas is kept at room temperature. Comparing the upper part of the tank, the experimental results show that the temperature rises slowly immediately after the liquid is discharged. However, the analytical results show that the temperature increase is more rapid. The same can be seen in the graph at the bottom of the tank. Therefore, the analytical results are more affected by the temperature of the pressurized gas than the experimental results. This is because that the phase change of liquid nitrogen is not considered in the analysis. The phase change of liquid nitrogen has the effect of absorbing heat and lowering the surrounding temperature. Therefore, the heat absorbed when the liquid nitrogen vaporizes and the vaporized nitrogen gas is mixed with the pressurized gas, the temperature is lowered. Therefore, there is a temperature difference between the experiment and the analysis. The experimental and analytical results in the liquid phase are kept constant around 80K. If we look at the analysis results of condition A and condition B, we can see that they both give similar results. Therefore, in this analysis, the discharge flow rate has no effect on the results.

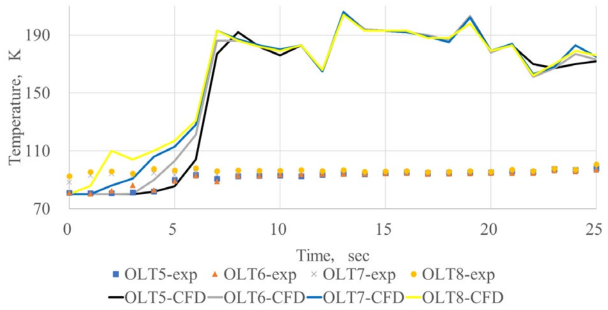

Fig. 5 Experimental condition A. Temperature at the top of the tank.

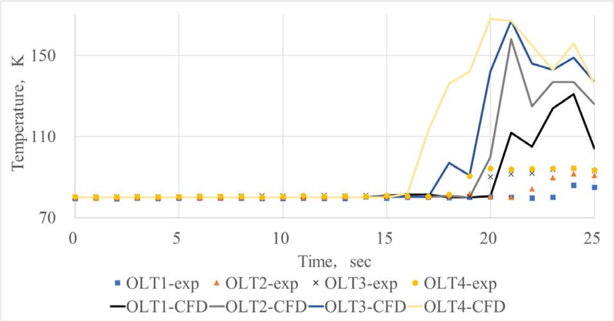

Fig.6 Experimental condition A. Temperature at the under of the tank.

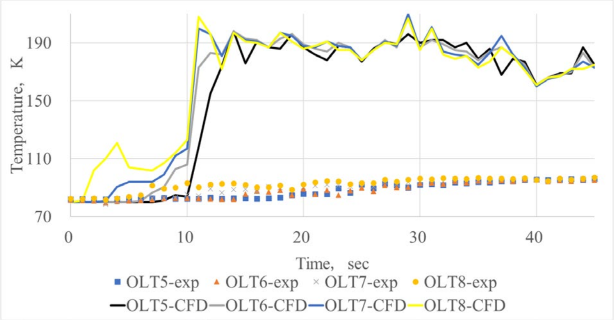

Fig.7 Experimental condition B. Temperature at the top of the tank

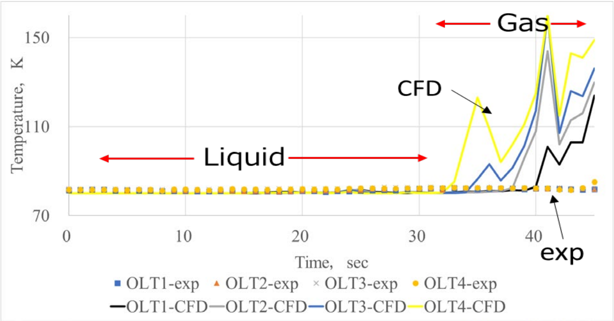

Fig.8 Experimental condition B. Temperature at the under of the tank.

5. Conclusion

We compared the temperature changes between the experimental and analytical results. In the liquid phase, the results were in general agreement. However, in the gas phase, good agreement between the experimental and analytical results could not be obtained. One possible reason is that phase change was not considered. When a liquid vaporizes, it has the effect of lowering the surrounding temperature, which is expected to reduce the rapid increase in temperature obtained in the analysis. In the future, we will consider phase change in the analysis. In addition, a three-dimensional analytical model will be constructed for a more rigorous evaluation.

References

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