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国際宇宙ステーション沸騰・二相流実験での二相流体ループのシステム特性

System Characteristics of Two-Phase Flow Loop in Microgravity Flow Boiling Experiments Onboard International Space Station

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Two-phase flow loop cooling system is required for increasing heat transfer rate, heat transfer distance, and cooling heat flux in thermal control of space structures. The understandings on thermo-fluid dynamics of gas-liquid two-phase flows with phase change under microgravity is necessary for the design of the system. Especially, the circulation mass flow rate of the refrigerant must be kept against the change in vaporization rate leading to large pressure loss to avoid boiling crisis. In order to clarify the heat transfer and flow characteristics of gas-liquid two-phase flows with boiling and condensation under stable microgravity condition, two-phase flow experiments had been carried out as a JAXA project named TPF experiment in Japanese Experimental Module "KIBO" of International Space Station (ISS). The detail information on TPF experiment was reported by Ohta, et al. In this report, the system characteristics of the two-phase flow loop is introduced.

A schematic diagram of the experimental apparatus of TPF experiment is shown in Fig. 1. The loop is a pump driven two-phase flow loop, in which the fluid pressure is maintained by mechanical accumulators with bellows. Since the back pressure of the accumulators was opened to the cabin environment, the system pressure can be kept around the atmospheric pressure. Perfluoro-hexane which is the main component of the fluorocarbon FC-72 was selected as the working fluid. The boiling point of perfluoro-hexane is 57.1 ºC. The experimental loop has two mechanical gear pumps and two volumetric flow meters, one is for low flow rate and the other is for high flow rate. The gear pump is driven by a motor whose rotation speed can be controlled at a constant rate by a control voltage. Turbine flow meters were used due to the high measurement accuracy and compactness. The inlet condition of the test section was set by the heat input in the preheater. The experimental setup has two kinds of heating section with the inner diameter of 4 mm in parallel; a copper heating tube and transparent glass heating tube. Boiling heat transfer coefficient and critical heat flux can be measured in these heating sections, and boiling flow behaviors can be visualized in the glass heating tube. At the downstream of each heating section, an adiabatic observation section with the same diameter channel is connected.

Pump performance curves for the gear pump for high flowrate are plotted in Fig. 2 with black solid lines. These lines were obtained in the preliminary component test on the ground. The flowrate was measured by varying the outlet pressure under the condition with constant control voltage of the pump, i.e., constant rotating speed. It can be seen that the decrease in flowrate with increasing the pump head is small. Measured results of the functional verification test in the TPF experiment onboard ISS are plotted with a green solid line and triangular symbols. Triangular symbols show the results of the liquid circulation test under steady conditions when the pump control voltage is increased from 0.5 V to 4.0 V in 0.25 V steps. The green line is a traversable line of the data during the experiment including a heating test with boiling. Triangular symbols show that the pump head increased rises with increasing the flowrate. The curve means the pressure loss of liquid single-phase flow through the loop. The increase in the pump head indicated by the broken line was due to boiling in the heating tube. It was confirmed that the flowrate could be kept stable even when the pressure loss increased due to boiling.

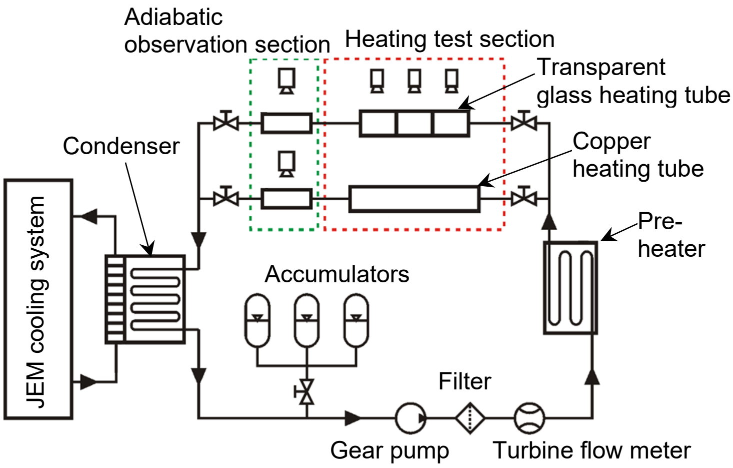

Fig. 1 Schematic diagram of two-phase loop for TPF experiment onboard ISS.

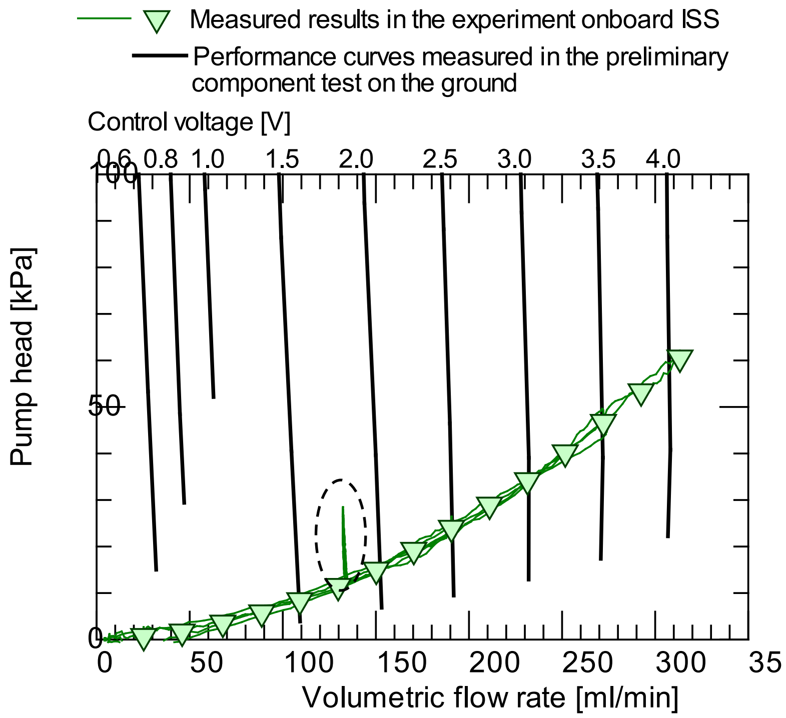

Fig. 2 Flowrate characteristics in TPF experiment onboard ISS plotted on the performance curves of the pump for high flowrate.

Another important aspect is the response of pressure and flowrate to sudden changes in the flow condition. Figure 3 shows a transient change from the start of heating at the metal heating section under the inlet subcooled liquid condition. The upper figure shows the saturation temperature at the outlet pressure of the heating section and wall temperatures of the heating tube. The numbers of #1 to #10 mean the measure position from the inlet in the axial direction. When a heating starts from a subcooled liquid, there is a delay in the onset of nucleate boiling. Lager delay leads to the higher wall superheat and larger amount of superheated liquid. If the delay is large, vapor generation rate will be quite large due to the heat capacity of superheated wall and liquid. Such large vaporization rate affects the stabilization of the system pressure and the circulation flowrate. In this case, at 157 s, the pressure at the outlet of the heating section suddenly rose by 24 kPa due to the increase in volume by vapor generation and also due to the increase in frictional pressure loss by increasing the volumetric velocity. After 15 seconds from the pressure rise, the pressure reduced and stabilized by the accumulator operation. Although the mass velocity reduced due to the pressure rise, the reduction ratio was less than 3 % and smoothly recovered after 15 seconds without pulsatory motion.

It had been confirmed that the experimental setup could realize boiling and condensation flows under flowrate and pressure conditions.

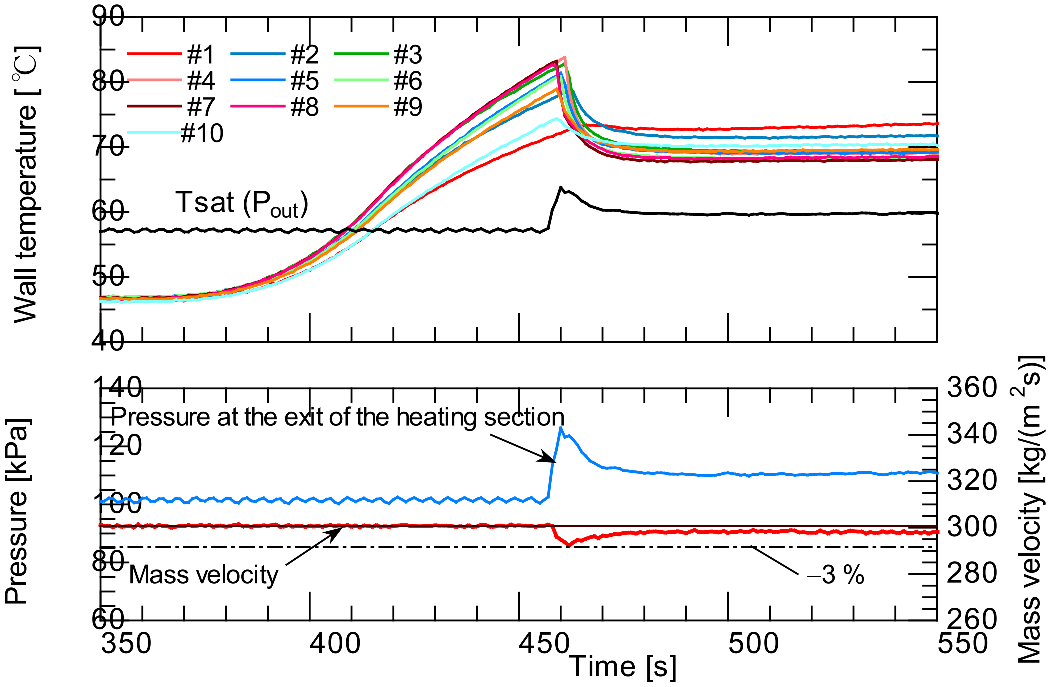

Fig. 3 Change in circulation flowrate in TPF experiment onboard ISS
at a boiling inception in the metal heating tube under the inlet subcooled liquid condition.
The upper figure shows the transient temperature change of the heat transfer wall.

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