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Thermal Control System for Space Experiment on Two-Phase Boiling Flow -II ; Manufacture and Test of the Condenser system

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Abstract

A condenser system is manufactured and tested for ISS program on two-phase boiling flow experiments promoted by JAXA according to the analysis of thermal management in the experimental system. Eight rectangular copper tubes of which circular channel of 6mm in diameter are connected directly by U tubes and arranged in parallel on the given ISS cold plate. The maximum pressure loss of the tube is 7kPa in the experimental condition. FC72 and water of 23ºC are used as working fluid for boiling experiment and cold plate, respectively. Heat of 400W is able to transport to cold plate from FC72 steam at 45kg/h of water flow and higher liquid subcooling than 10K at the exit of condenser tube. Those test results have satisfied the requirements for condenser system in the ISS microgravity experiments on two-phase boiling flow.

1. Introduction

It has been widely known that boiling heat transfer is one of the high thermal transportation technology using phase-change phenomena. Recently, a hybrid-car and an electric car have been intensively developed for CO2 reduction and conversion of fossil fuels. Boiling heat transfer is strongly expected as a high heat flux cooling technology for the power electronics in IC power inverter used for an electric car. Also, it is very important heat transport technology in a space facility. However, we have no sufficient information on the heat transfer with phase-change in microgravity environment.

The project on two-phase boiling flow experiment has been carried out as one of the ISS experiments promoted JAXA for these several years. The name of project is “ISS experiments on interfacial behaviors and heat transfer characteristics in boiling two-phase flow” and the project leader is Prof. Haruhiko Ohta, Kyusyu University. The project team is organized in JAXA by Kyushu Univ., Kobe Univ., Hyogo Prefectural Univ., Tokyo Univ. Science, Shibaura Inst. Tech., IHI, IA, JAMSS and JSF. In the practice of experiments, the maximum available power must be 400W. The heat generation in the boiling test section including heat supplied into the working fluid must be transported to ISS thermal management system through the cold plate given by ISS cooling system.

Prior to the ISS practice, the experimental system and procedures must satisfy the safety requirements through precise ground experiments. In the ground experiments, a condenser system was designed and manufactured according to the thermal analysis. In the present paper, the authors introduce the condenser system and the test results.

2. Ground Experimental System

Outline of ground experimental system on boiling two-phase flow for ISS practice. Two boiling sections are assembled in the system. The one is a transparent mini or microchannel with gold heating film coating for observing vapor behaviors and another one is a copper tube with micro heaters to obtain thermal data. FC72, Fluorinert, is used for the working fluid. Heat is applied into the working fluid in the test section and the pre-heater. In the ISS practice, the experimental system is composed in the multi-purpose rack assembled in the ISS experimental module “Kibou”. The available heat is 400W in the maximum due to the thermal capacity of multi-purpose rack for the experiments.

The heat applied into the working fluid must be transported ISS cooling system through ISS cold plate by a condenser system. The requirement for a condenser system is listed in the **Table 1**.

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Table 1 Requirements of Condenser System

Items	Requirements
Working Fluid	FC72
Maximum Thermal Transport	400W
Cold Plate : Cooling Water Flow Rate	<45 kg/h
Cold Plate : Inlet Water Temperature	23 °C
Dry Quality of Fluid at Condenser Inlet	1.0
Liquid subcooling at Condenser Exit	> 10 K
Pressure Loss of Condenser Tube	< 10 kPa

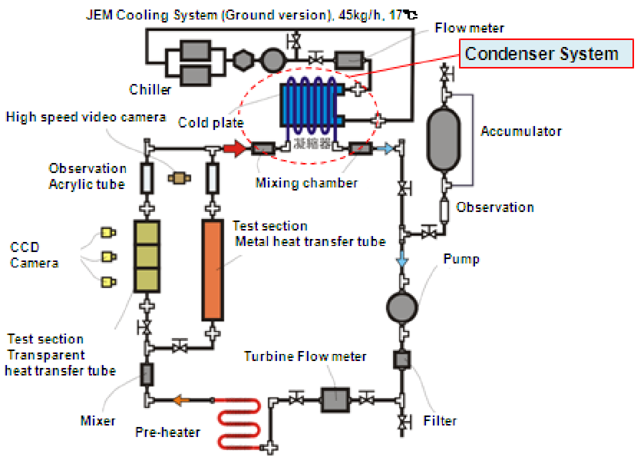

Fig.1 Outline of ground experimental system on boiling two-phase flow for ISS practice

3. Condenser System

Condenser system is shown in **Fig. 2**. Eight condenser tubes are placed in parallel on the cold plate and connected with U plastic tubes.

A piece of tube is a rectangular copper rod of 11mm × 11mm in cross-section and 330mm in length with circular channel of 6mm in diameter as shown in **Fig.2**. The condenser tubes are placed strictly with glue of which name is ECCOBOND and the thermal conductivity is 0.75WmK. The thickened of glue is supposed less than 0.3mm. The condenser system is enveloped with thermal insulation materials.

Ground test loop for condenser system is shown in **Fig.3**. Working fluid, FC72, circulates the condenser loop from a constant heating bath shown in **Fig.3**. Steam of FC72 is supplied into the condenser tube from a steam generator at a quality of 1.0. Cooling water of 23ºC flows into the cold plate and heat is exchanged between cold plate and condenser tube. Heat loss from condenser tube is calculated the fluid flow rate and temperature difference between inlet and exit of the tube. The working fluid is condensed completely and turns to liquid at exit of the condenser tube. Heat gain of cold plate is also calculated by water flow rate and temperature difference between inlet and exit of the cold plate.

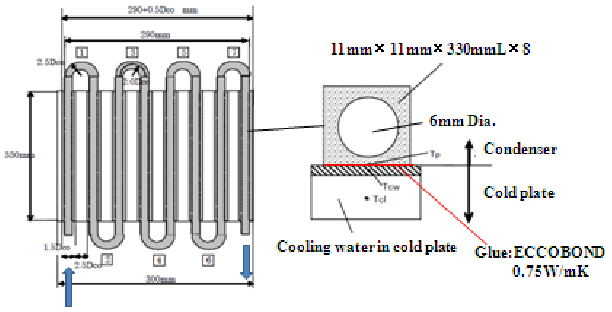

Fig.2 Details of condenser system

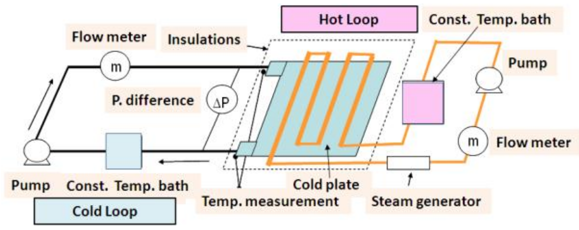

Fig.3 Ground test loop of condenser system

4. Test results and Discussion

Heat balance between condenser tube and cold plate is shown in **Fig.4**. Cooling water is supplied at flow rate of 45kg/h.

Heat loss of FC72 and heat gain of cold plate increases linearly with flow rate of FC72 but leak of heat loss is observed at higher liquid flow rate than 0.20kg/min. The experimental result shows good heat balance until heat loss of 400W that is the maximum available heat input in the ISS experiments.

Liquid subcooling at condenser tube exit is shown for the cooling water flow rate of cold plate in **Fig.5**. According to the test results, the flow rate of test fluid, FC72, is given as 0.25kg/min in the present experiment on boiling for the maximum heat transport of 400W. Here, the subcooling of test fluid is 28K at condenser tube exit for the given flow rate of cooling water of 45kg/h (0.75L/min) and this is sufficiently satisfied the requirement of ISS experiment. For the liquid subcooling of 10K at the tube exit, pre-heating needs at the entry of boiling test section. For the higher fluid flow rate, 0.51kg/mini and 0.76kg/min for example, the dry quality of the test fluid is estimated 0.46 and 0.20, respectively, as shown in **Fig.5**.

In the practice of ISS experiments, it must be considered the effect of gravity on the efficiency of the condenser system. This is a big problem in the condenser system. However, we have hardly the actual data or information on condensed phase-change phenomena in micro-gravity. The present ISS experiment will give us very important in information on heat transportation through condenser.

The test was conducted for the vertical orientation of

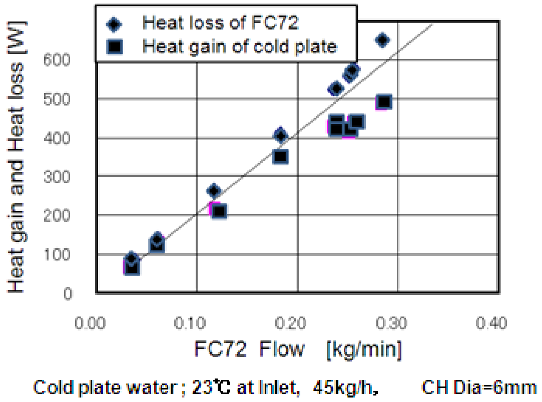

Fig.4 Heat balance of condenser system

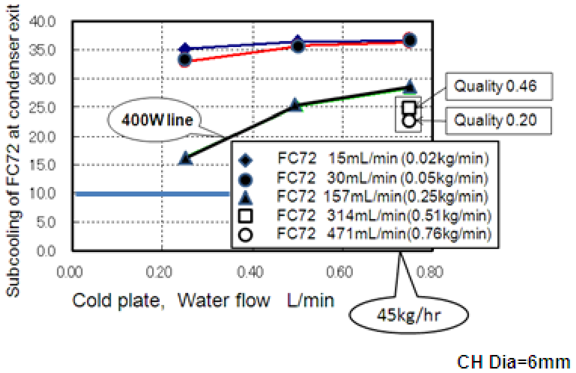

Fig.5 Liquid subcooling of FC72 at exit of condenser tube

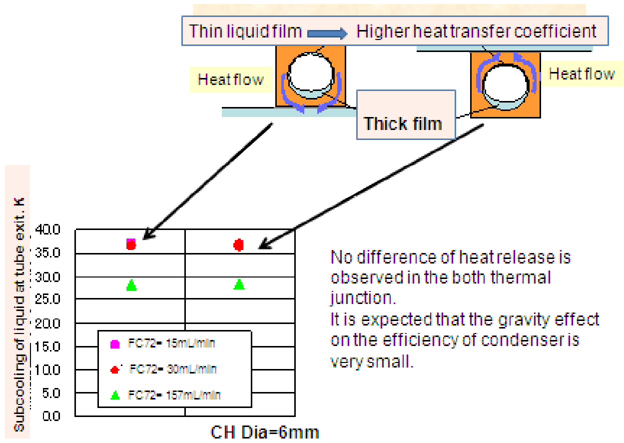

Fig.6 Effect of gravity direction on heat transfer in condenser system at 45kg/h of cooling water

condenser tube and cold plate to investigate the effect of gravity direction on heat transfer of the condenser system as shown in **Fig.6**. It is considered that the thickness or configuration of liquid film in the condenser tube is strongly affected by the gravity direction. The thin liquid film is considered to have superior heat transfer coefficient.

However, no remarkable differentials have been observed between both cases in heat transfer efficiency of the condenser system as shown in **Fig.6**. The heat is considered to be conducted mainly to the cold plate through the copper section. As the results, it is expected in ISS practice that the effect of gravity direction on the heat transfer efficiency is very small in this case of condenser system.

The test was performed for the condenser tubes of 4mm and 6mm in diameter. The maximum pressure loss in the experiments is 18kPa for the small tube of 4mm in diameter and 7kPa for another tube at 400W of heat release. The condenser tube of 6mm in diameter is employed in this experiment and the data are indicated for the condenser tube in the present paper.

5. Conclusions

A condenser system was designed and tested for JAXA ISS program on two-phase boiling flow experiment according to the analysis of thermal management in the experimental system. Eight rectangular copper tubes of which circular channel of 6mm in diameter were connected with U tubes and were placed strictly on the ISS cold plate. The maximum pressure loss of the condenser tube was 7kPa and satisfied the requirement of condenser tube in the experiments. FC72 and water were used for working fluid for boiling experiment and cold plate, respectively.

Heat of 400W was transported to the cold plate from the condenser tube at 45kg/h of water flow. The liquid subcooling of FC72 was higher than 10K at the exit of condenser tube.

No effect of gravity direction on the heat transfer in condenser system was observed according to the experimental results on vertical orientation of the condenser system.

Those test results satisfy the requirement for condenser system in the ISS microgravity experiments on two phase boiling flow.

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