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TCPB DEVICE: DESCRIPTION AND PRELIMINARY GROUND EXPERIMENTAL RESULTS

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ABSTRACT

The TCPB (Temperature-Controlled Pool Boiling) device is developed to perform pool boiling heat transfer studies by the temperature-controlled technique on Earth and under micro-gravity conditions aboard the Chinese recovery satellite. Its aim is to investigate the heat transfer in the nucleate and transition pool boiling regimes. This paper describes the design of this device in detail. The preliminary ground experimental results are also presented and analyzed, which show that the technical and scientific expectations can be fulfilled.

INTRODUCTION

Boiling is recognized as an effective technique to exchange high heat fluxes from heated bodies and is widely used in the on-earth technology in component heating and cooling. The high efficiency also makes it a suitable technique for space applications, in which very efficient, compact and lightweight devices are required. Potential space applications cover not only thermal management and cooling of electronic devices of high generation density, but also fluid handling and control, orbit storage and supply systems for cryogenic propellants and life support fluids, and future power systems.

Experimentation on boiling in micro-gravity started in the late 50s of the 20th century. The investigation in microgravity suffers for unique and stringent constraints in terms of size, power and weight of experimental apparatuses, and of number and duration of the experiments. Therefore, despite the quite wide activity carried out in the past decades, only a partial and in some aspects contradictory knowledge of the boiling heat transfer phenomena has been attained so far. For more detailed information on this subject, one is referred to the review papers by Straub[1] and Di Marco & Grassi[2].

The present program is a research effort on the heat transfer in the nucleate and transition pool boiling regimes in microgravity. TCPB is an acronym for "Temperature-Controlled Pool Boiling", which indicts that the surface tempera-ture of the heater will be controlled throughout the experiments. One flight is expected on the Chinese recoverable satellite in the near future. This paper describes the design of this device in detail. The preliminary ground experimental results are also presented and analyzed, which show that the technical and scientific expectations can be fulfilled.

TEST APPARATUS

General Description

There will be several experiments flown in the same mission, and then a common platform, which is developed by other group in NMLC (the National Microgravity Laboratory/CAS), is used for power control, data acquisition, and image recording. Detailed information of the common platform will be found elsewhere. Then only the boiling rig and electronics are described in detail here.

Wire Heater

A platinum wire of 60 μm in diameter and 30 mm in length were simultaneously used as a resistance heater and a resistance thermometer to measure the temperature of the heater surface, with the advantage that because of its low thermal capacity, it reacted almost without any delay on changes in temperature and heat transfer, respectively. The ends of the wire were soldered with copper poles of 5 mm in diameter to provide a firm support for the wire heater and low resistance paths for the electric current.

Electronics

The feedback electronics used in this study were similar to those used in constant-temperature hot-wire anemometry (Fig. 1). The op-amp measured the imbalance in the bridge and provided an output of whatever voltage was needed to keep the ratio R1/Rw equal to the resistance ratio on the referenced side of the bridge.

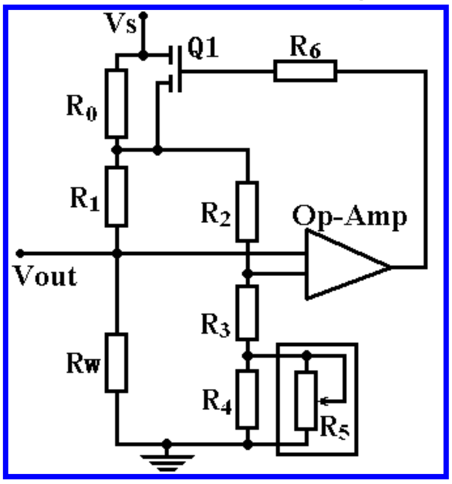

Fig. 1 Schematic of the electronic feedback loop.

The heater resistance, and thus the heater temperature, was kept constant by varying the resistance of the changeable resistance network (R5). This resistance network consists 16 parallel resistors and a 16-channel analog switch, which is controlled by a SCM (single-chip- microcomputer). The output of the circuit was the voltage required to keep the heater at a set temperature. The set temperature points were located uniformly in the axis of *lg*ΔTsat, where the wall superheat ΔTsat = Tw-Tsat. The temperature of the heater could be varied by approximately 400K. The resistor R0 parallel-connected with a MOSFET (Q1) was used to provide a small trickle current through the heater, resulting in a voltage across the heater of about 90 mV even when the op-amp was not regulating.

Space Boiling Rig

Shown in Fig.2 is a schematic of the boiling rig used in this program. The boiling chamber with 80×80×95 mm^3 in inside dimension was made of duralumin. The chamber was pressurized in a airproof container of 200×200×300 mm^3 in dimension and the ambient pressure in the container could be maintained at about 1atm during the flight. Then the bellows and the surrounding housing allowed the pressure in the chamber to be approximately constant although no measure was adopted to control it due to limitations in mass, size, electric power, and energy consumption. The chamber was filled with nominally 700ml of degassed R113. No measure was adopted to control the bulk fluid temperature due to the same limitations. It was assumed the bulk fluid temperature could be maintained at the ambient temperature aboard the satellite throughout the experiments, which will be last 40 minutes. Two platinum resistance thermometers centered within the boiling chamber were calibrated to within 0.5K and provided a measure of the bulk fluid temperature. Three copper-constantan thermocouples were located near the heater to measure the distribution of the temperature in the near field around the heater. The absolute pressure within the boiling chamber was measured using a pressure transducer with a range of 0–3 atm and an accuracy of 0.15%FS (full scale). Eight LEDs (light-emitting diode) were used to light the boiling chamber through a window at the chamber bottom. A CCD video camera (WAT-660D, 537×597 pixels) was used to obtain images of the motion of vapor bubble or film around the heater, which was recorded by a VCR in the common platform at a speed of 25 frame/s. The voltage across the heater and the electric current through the whole bridge were sampled at 10 Hz, while other variables 1 Hz. Since the total resistance of the referenced side of the bridge is more than 6000 times of the sum of the heater and R1, the measured value of the electric current can be considered as that through the heater.

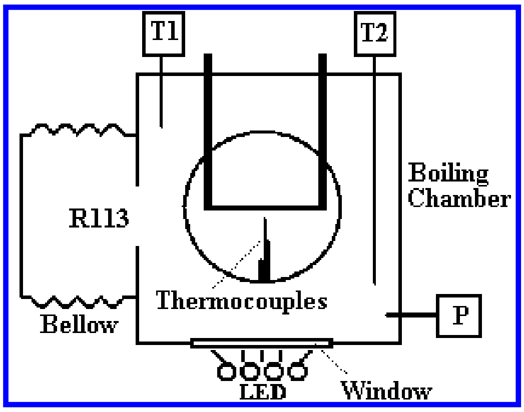

Fig. 2 Schematic of boiling rig.

Ground Boiling Rig

Two simple ground rigs were developed in order to prepare scientific experiment and test performances in the laboratory using two kinds of heating, namely temperature- and voltage- controlled methods. The former was similar with the space boiling rig, except a potentiometer replacing the referenced side of the bridge shown in Fig. 1. In the latter one, a d.c. generator was used to supply the electric energy for the heater. A resistor of 1.5 Ω was connected in series with the heater in order to prevent its burnout.

PRELIMINARY GROUND EXPERIMENTAL RESULTS

Results of the preliminary ground experiments were shown in Fig. 3~5. The pressure in the boiling chamber is 1 atm, and the temperature of the bulk fluid is 16°C. Then the subcooling temperature is $\Delta T_{sub} = T_{sat} - T_{bulk} = 31.7$ K. It was observed that four regimes existed in the experiments, namely single- phase natural convection, nucleate boiling (Fig. 6), two mode boiling or coexistence of nucleate and film boiling (Fig. 7), and film boiling (Fig. 8). The first regime, single-phase natural convection, occurs at low heat flux. The heat transfer coefficient is relatively low in this regime. Eventually the superheat becomes large enough to initiate nucleation at some cavity on the surface. If the voltage is controlled, which is approximately equivalent to control the heat flux, a sudden decrease of the surface temperature occurs due to the increase of the heat transfer coefficient with phase change. If the temperature of the surface is controlled, the phase change at nucleation does not change the surface temperature, but rather increase the heat flux suddenly.

It is observed that the point jumps to the curve of steady two mode boiling in the first up process with temperature-controlled method. This is caused by the perfect wettability of R113 with the surface of the platinum wire. It is also

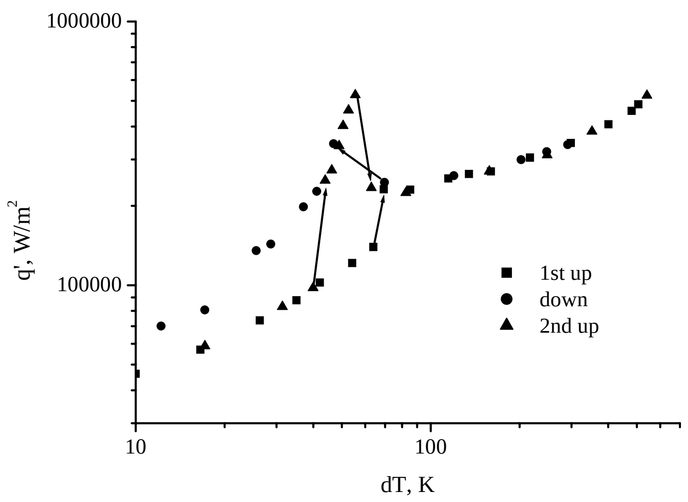

Fig. 3 Boiling curve with temperature-controlled method using the ground rig.

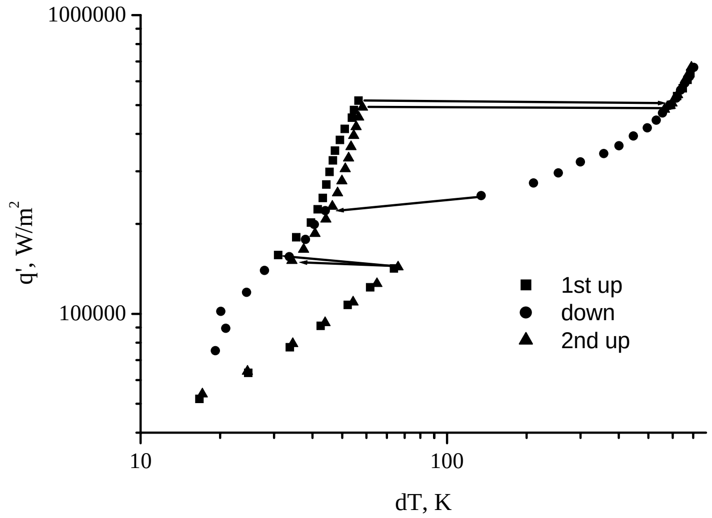

Fig. 4 Boiling curve with voltage-controlled method using the ground rig.

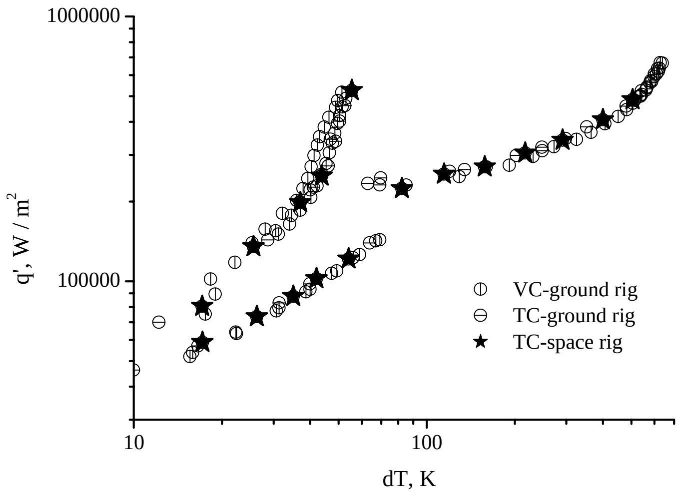

Fig. 5 Boiling curve with temperature-controlled method using the space rig.

found that the onset point of nucleation by the two methods were approximately the same in two methods of heating control, except the second up process with temperature controlled method. For the latter case, vapor could not condenses fully in some cavities on the surface, and thus cause the nucleation occurred at a lower superheat, just like that the boiling process can be maintained in much lower superheat when the heat flux or surface temperature decrease.

Fig. 6 Nucleate boiling.

Fig. 7 Two mode boiling.

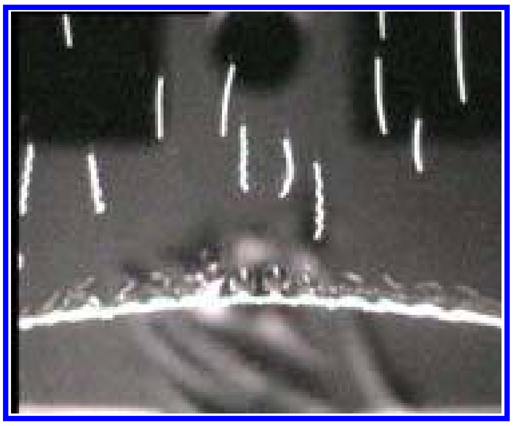

Fig. 8 Film boiling.

The boiling curves obtained by different heating methods and by different experimental rigs are consistent with each other except the hysteresis phenomena (Fig. 5). This fact indicts that the technical and scientific expectations can be fulfilled. The CHF (Critical Heat Flux) was 5.26×10^5 W/m^2, while the prediction by Inoue's correlation was 6.8×10^5 W/m^2. The difference was within 23%. It ought to be pointed that the experiments with the temperature-controlled method could be given an accurate value of the temperature corresponding to CHF, but not the value of CHF. It is accidentally occurred in our experiments that the experiments using the space boiling rig gave an accurate values of both CHF and its corresponding temperature.

Finally, the three two-phase boiling regimes, nucleate and film boiling have been investigated by a great number of investigators, while fewer works were reported on the two mode boiling in literature[4~8]. Thus there is the need for further investigation on two mode boiling.

CONCLUSIONS

A TCPB (Temperature-Controlled Pool Boiling) device is developed to perform pool boiling heat transfer studies by the temperature-controlled technique on Earth and under microgravity conditions aboard the Chinese recovery satellite. Its aim is to investigate the heat transfer in the nucleate, transition, and film pool boiling regimes. This paper describes the design of this device in detail. The preliminary ground experimental results using the laboratory boiling rigs and the space boiling rig show that the technical and scientific expectations can be fulfilled.

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