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# SURFACE TENSION EFFECTS ON MICROGRAVITY BOILING

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Nucleate and pool boiling in microgravity presents many challenges due to the lack of gravity driving the bubble departure. This paper continues on a previous presentation which presented an instrument to test the effects of varying materials, and therefore the surface roughness, and their contribution to heat transfer. Previous experiments by others show that in a microgravity environment, buoyancy is not a contributing factor in bubble departure. Surface roughness drives this departure and affects the heat transfer. To better understand the effects of surface roughness on boiling, a device has been designed to test multiple surface materials against a common liquid. The instrument allows for multiple samples to be tested using a common set of instrumentation. The instrument is being developed for a CubeSat platform. This paper presents the terrestrial testing process of the instrument along with the results of these tests. The instrument only needs to be integrated to a satellite bus for orbital demonstration and these changes will be outlined. The results of these tests will improve the understanding of the physics of boiling in microgravity.

## I. PAST WORK

The design of a microgravity boiling experiment to measure the heat transfer properties of a heated cylindrical sample was suggested by the authors in previous work[1]. The concept design includes six specimens within a fluid which can be integrated into a nano-satellite and return the experimental data. This paper describes the hardware development and initial testing of the suggested design.

## II. INSTRUMENT

### II.I Chamber

With minimal design change from the concept design, the boiling instrument was cut to allow for all six samples to be supported. To account for the pressure increase within this tightly constrained system, excess volume in the system was filled with a soft silicon closed cell foam. The system should be able to withstand 2 Bar of pressure, a reasonable design constraint based on the experimental pressures described later in this paper. The pressure sensor changed packaging, due to availability, and now attaches based on a 1/16 National Pipe Thread (NPT).

The chamber is made of 7075-T6 aluminium. The inner, clear tube used to support the specimen within the chamber is made of polycarbonate. Stainless steel fasteners are used to hold the assembly together.

### II.II Test Sample

For this first round of testing, only one sample, Figure 1, was prepared and installed. The sample consists of an inner metal film resistor, a thermocouple, Kevlar string and an outer metal sample. These parts were glued together with highly thermally conductive epoxy to form one sample. The sample was glued into place within the chamber using general purpose epoxy, sealing the resistor and thermocouple wires.

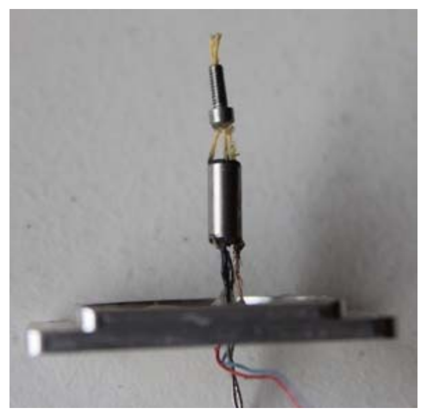

Fig. 1: The test sample mounted to the base of the chamber with the upper suspending cords attached. Electrical leads for current and temperature are seen passing through the base.

### II.III Assembly

Assembly of the chamber was completed submerged in distilled water, allowing for complete immersion of all parts and ensuring no captive air, Figure 2. The top, with the pressure sensor, and bottom, with the sample, were bolted in a sandwich around the containment tube. These were sealed with o-rings to the bulkheads.

Fig. 2: Submerged chamber assembly

## III. INSTRUMENTATIATON

### III.I Fully integrated instrumentation

The prepared chamber was outfitted with electronics. To complete initial testing, voltage, current, pressure, and temperature need to be measured. A custom printed circuit board (PCB) was designed to have the capabilities of the fully functional experiment.

To monitor the power, a battery monitor chip was integrated on the PCB. A solid state relay for each sample, controlled by the micro-controller unit (MCU), connects the power source fed through the monitor chip, to the heated sample. The pressure sensor is fed a regulated excitation voltage and is monitored using an integrated analog to digital converter (ADC) with built-in gain amplification. Each thermocouple has a dedicated thermocouple integrated circuit (IC) with built-in ice-point compensation. Finally, a camera module and LEDs were incorporated to get the supporting images of each experiment.

### III.II Test instrumentation

Not all of the features designed were activated for this initial testing and external resources were used. This allows for a simpler test setup and more control of the variables.

An external power supply was used to pass the power to the resistor. This supply displayed its voltage and current draw on screen which was recorded by the test operator at the appropriate time.

The thermocouple was monitored with a process controller. This controller had a display screen to show the current measurement, but computer interface was preferred.

Fig. 3: The experimental chamber set up with the pressure sensor attached to the PCB with its needed ADC.

Due to the complex excitation and measurement requirements of the pressure sensor, the custom embedded controller designed for full experiment operation was used in initial testing, Figure 3. This sensor and measurement system were calibrated together to eliminate as much error as possible. Calibration points were created by holding the sensor at the same altitude as a nearby scientific weather station and using its barometric sensor measurement as a standard. Then, to get higher pressure points, a column of water was added vertically to the sensor to increase the hydraulic pressure to the sensor. A series of measurements were taken at each test point to allow for a confident measurement. A calibration curve was formed based on these measurements and has an effective range of 1 to 2 Bar of pressure, sufficient for the initial testing.

A computer was used to gather the digital measurements of the pressure and temperature recorded by each sensor. Initially, testing used independent software to gather the data from both the pressure and temperature sensors. After the initial operation, an integrated computer control software was formed to ensure the captured data was synchronized.

## IV. EXPERIMENTAL TESTING

### IV.I Pressurized capsule

After the test configuration was integrated in a submerged environment, the first round of testing started. To understand the properties of the instrument, the supply voltage to the heater was set to a constant value for each test. Each experiment was performed until an approximate steady state case was reached without operating the system for long periods of time. The temperature reached this case in around 20 seconds.

 

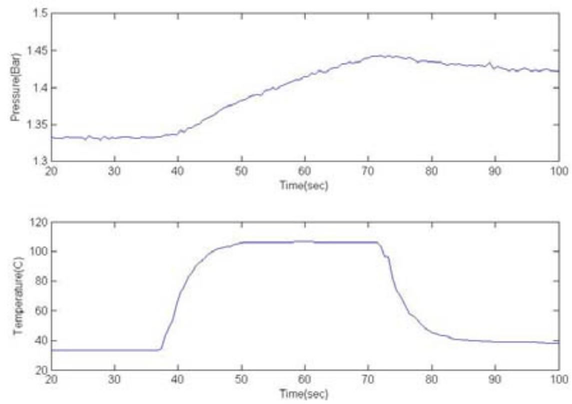


Fig. 4: This figure shows a data set of the heated sample with the pressure increase as expected with a contained system. The open container test removes the pressure response seen on the above figure.

Difficulty was found in determining the heat flux properties desired due to a coupling of the increased pressure as heat was added to the system. The sample temperature crept up as the water temperature and the chamber pressure increased as each experiment was performed. To ensure a proper understanding of the experiment, and to allow for imaging in this infant state, the experimental configuration was changed to remove the pressurized response.

Most important about this first round of testing are that the chamber demonstrated its capability of higher pressure and the sample responded as anticipated.

IV.II Open Container

To create a more controlled environment to qualify the experimental configuration, the bottom bulkhead and its sample was removed and suspended in a pool of open distilled water. This allowed for the experimental pressure to be held constant and the problem was more constrained.

A series of tests were performed while holding the voltage at a constant value. The power will heat the sample until the sample reaches its maximum heat transfer rate, holding the system at a near steady state condition.

As testing commenced, many observations were made. Bubble formation started before the temperature feedback reached a boiling temperature. The only direct temperature feedback was the embedded thermocouple within the sample. The identified boiling was from the bottom of the sample at the entrance point of the resistor lead wires, Figure 5.A. After further heating, bubble jets formed from this region, though the temperature remained below the boiling point.

5.A 5.B

Fig. 5: These show the bubble formation stages seen in initial testing. The left figure (A) shows the bottom left localized heating issue. The right figure (B) shows bubble formation on the heated sample wall.

As the heat was increased, bubble formation on the sample formed as anticipated, Figure 5.B. This is exciting as it shows the proper power levels to achieve the nucleate boiling phase.

In the attempt to reach the bubble departure regime of nucleate boiling on the full surface, the power was further increased. A familiar odor of burnt electronics was noticed in the area of the experiment. The current draw of the resistor dropped through some experiments while the voltage was held constant. This power drop caused an immediate temperature drop and the test was over, Figure 6. The resistor suffered permanent damaged due to overheating internally.

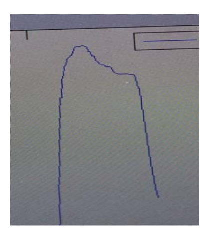

Fig. 6: As the current dropped of the damaged heated sample, the temperature profile showed a sharp reduction in heat.

 

## V. RESULTS AND OBSERVATIONS

### V.I Considerations

The design flaw identified is the placement of the resistor.  The bottom lead of the resistor exits the thermally conductive epoxy before the heat transferred to the wire could be dissipated into the epoxy.  This caused localized boiling where this wire exited the epoxy.

Additionally, the metal film resistor rated to 175 degrees Celsius exceeded this rating.  This was caused by the dimensional gap between the resistor and the metal sample filled with the thermally conductive epoxy requiring too much conduction to get the heat to the surface.  The design of the resistor placement should minimize this value to minimize the required resistor temperature to get the sample through the boiling curve desired.

Also, more accuracy with the thermal feedback can be insured by simply ensuring that the thermocouple placement is aligned as designed. By doing this, consistency can be ensured between the various samples.

### V.II Solutions

The design changes to be made before further testing will begin will include the correction of the sample packaging to eliminate the issues described earlier.  By minimizing the gap between the resistor and the metal sample, ensuring the best possible encapsulation of the resistor, and careful placement of the thermocouple, the experiment should meet the experimental objectives desired.

### V.III Future Missions

As this experiment is finalized, anticipated future testing may include suborbital or parabolic flight opportunities.  Additionally, an orbital CubeSat platform is being designed to host several test cases using this experimental design.

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Becnel, E. B. and Wessling, Francis. C. (2011). Surface Tension Effects on Microgravity Boiling. *62nd International Astronautical Congress* (pp. IAC-11-A2.2.10). Cape Town, SA: International Astronautical Federation.