TWO-PHASE MICRO-CHANNEL HEAT SINK FOR SPACE CRAFT THERMAL CONTROL

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ABSTRACT

The increasing requirements of high power generation and lightweight for the next generation spacecrafts in order to accomplish new NASA missions of the moon and Mars exploration lead to ever-increasing heat generation at the component, module, and system levels. The excessive heat must be effectively dissipated, as the accuracy, reliability and life span of many devices and systems used in space are strongly affected by their temperature. Development of novel thermal control subsystems with significantly improved capacity and efficiency are therefore of critical importance. The primary objective of the project is to research, design, and test a two-phase micro-channel heat sink cooling loop that is capable of dissipating high-heat-flux from electronic and mechanical devices in microgravity environment. While working on this project for the past semester testing of the cooling loop has yet to take place due to the time required to locate and manufacture components. However, much of the design and manufacturing has been completed which can be used for continued research of the effects of orientation with respect to the gravity field on the thermal performance of a two-phase micro-channel heat sink cooling loop.

INTRODUCTION

It is recently projected by National Aeronautics and Space Administration (NASA) that the dissipative heat flux levels from lasers and other high power devices in spacecrafts will be as high as 100 W/cm^2. The dissipative heat has to be effectively removed, as the reliability and life span of these devices are both strongly affected by its temperature as well as its immediate thermal environment. The primary objective of this project is to study the effects of gravitational orientation on the thermal performance of a two-phase micro-channel heat sink cooling loop.

Due to the time required to design, fabricate and order all the components required to begin testing, there has been no time to fully construct the cooling loop and test stand. However all the components of the cooling loop have been purchased or designed and manufactured, and the final design of the test stand is nearly complete. Continued research will provide the knowledge that can be used to aid in the development of a two-phase micro-channel heat sink cooling loop intended for spacecraft thermal control applications.

Figure 1 illustrates the concept of two-phase micro-channel heat sinks [1-5]. Typically fabricated from silicon or a high-thermal-conductivity metal such as copper, micro-channel heat sinks contain a series of parallel micro-size channels having characteristic dimensions ranging from 10 to 1000 micrometers. These micro-channels serve as passages for flow boiling of liquid coolant such as fluorochemicals, refrigerants, and water. In application, a high-power-density device is attached to the base surface of the heat sink. The heat generated by the device is first transferred to the micro-channels by heat conduction through the solid substrate, and then carried away by the flow boiling of liquid coolant in the micro-channels.

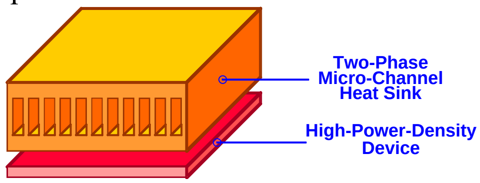


Figure 1. Two-phase micro-channel heat sink.

The basic function of the loop is to condition the liquid coolant and then supply it to the heat sink. In addition, the loop should contain components that reject the heat removed from the high-power-density device to the ultimate sink of the system. Figure 2 shows a schematic of a stand-alone two-phase micro-channel heat sink cooling loop that rejects heat to the ambience. Essential components of such a loop include the pump, pipes, control valves, condenser, coolant reservoir, and heat exchanger.

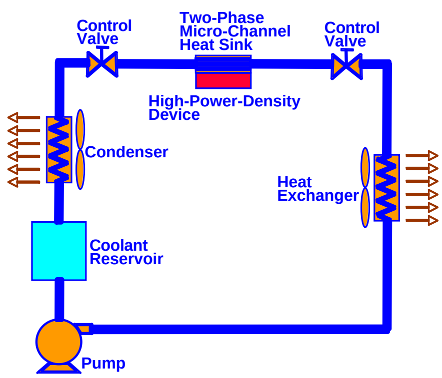


Figure 2. Schematic of cooling loop.

Despite its potential as a high-performance technique applicable to spacecraft thermal control, little has been known about the characteristics of the two-phase micro-channel heat sink cooling loop in space, which is why the focus of the proposed work will be on the effects of orientation with respect to the gravity field on the loop behavior.

Currently, the micro-channel heat sink and cover plate, cooling loop reservoir, and condenser have been designed and fabricated. The pump, coolant, pipe, and valves were also purchased.

METHODS

The fluid chosen to use in cooling loop is made by the 3M Company and is called Fluorinert Electronic Liquid FC-72. FC-72 is clear and colorless, thermally and chemically stable, nonflammable, practically nontoxic, and leaves almost no residue when vaporized. This makes FC-72 safe for use in an occupied area and around electrical components, and makes it ideal for space applications. The boiling point of FC-72 is 56°C at 1 atmosphere which also makes FC-72 ideal for this application because the fluid can be easily vaporized by computer processors which can reach temperatures above 80°C, and the pressure of the cooling loop can be kept low, near 1 atmosphere.

The micro-channel heat sink shown in Figure 3 was designed to be simple for machinability, and designed to be compact to allow the entire cooling loop to fit on a rotatable test stand. The micro-channel section was designed with a channel depth of 1mm, a channel width of 0.4mm, and a wall thickness of 0.4mm. After researching common computer processor dimensions the area of the micro-channel section was chosen to be 35mm by 35mm to mimic dimensions of a processor. Copper was chosen as the heat sink material because it has a high thermal conductivity and it is relatively easy to machine. A thick film heater was originally proposed to be used as the heat source because of its flat shape which mimicked a processor. However, after much searching, no thick film heater was found with the power rating or size required for this application. In previous cooling loop experiments, 1/8th inch diameter cylindrical cartridge heaters were inserted vertically into the bottom of the test section which made the test section very large and not suitable for this application. To solve this problem the heat sink was designed to have four 120V, 120W cylindrical cartridge heaters inserted horizontally into the bottom as shown in Figure 3. Three 0.03 inch diameter holes were designed to be drilled between the heat source and micro-channel interface so thermocouple wires can be inserted to measure the temperature at the entrance, middle, and exit of the heat sink.

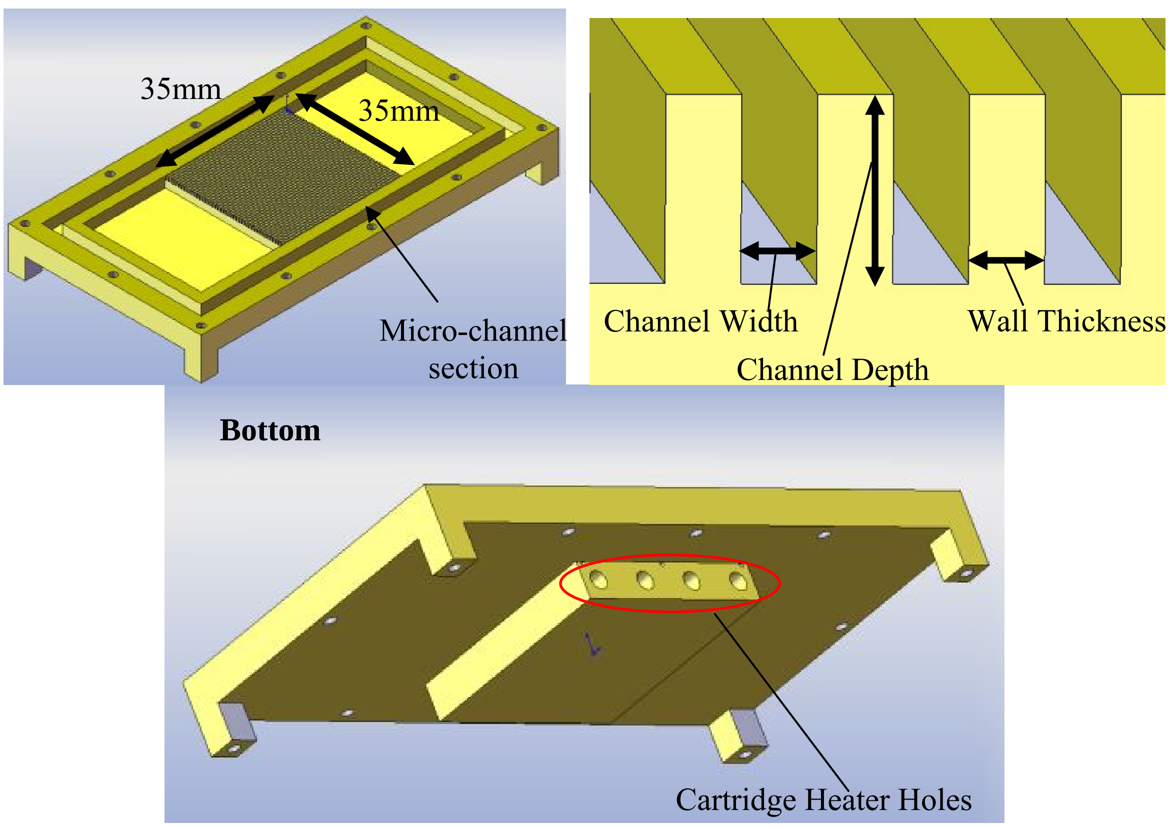


Figure 3. Micro-channel heat sink.

The cover plate shown in Figure 4 for the heat sink was designed to be made out of clear 0.5 inch think polycarbonate. Polycarbonate was chosen because of its translucent property and its ability to withstand high temperatures. By having a translucent cover plate, photographs and ever high-speed video can be taken of the two-phase flow through the micro-channel section so that flow regimes in various gravitational orientation can be observed.

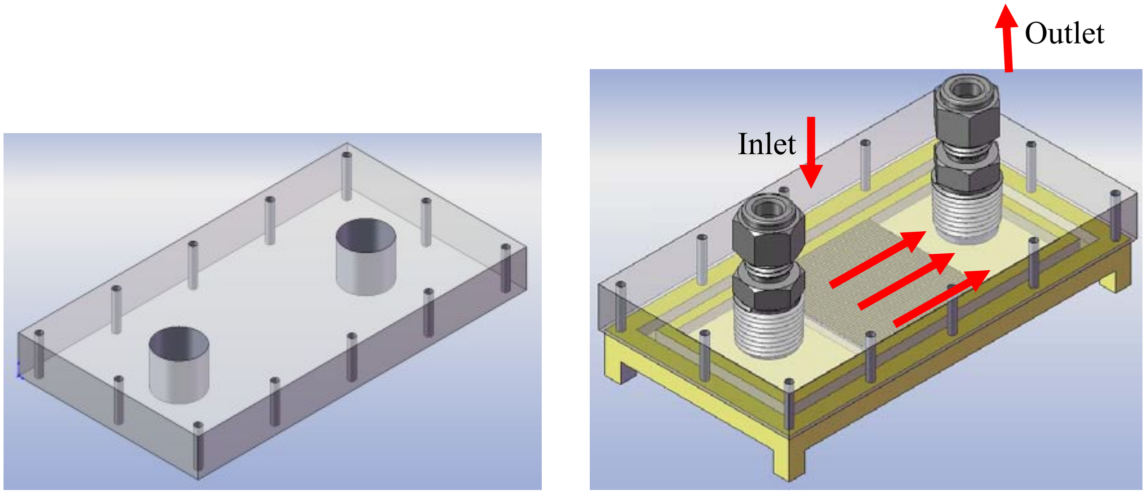


Figure 4. Polycarbonate cover plate.

The cooling loop reservoir shown in Figure 5 was designed be made out of 0.5 inch thick cast acrylic. Cast acrylic was chosen as the reservoir material because of its ability to withstand high temperatures, ease of joining by glue, and translucent property. A translucent reservoir is desirable so the amount of fluid in the reservoir can be easily observed. The reservoir is necessary so the FC-72 can be added easily to the cooling loop. The reservoir is designed to hold 200mL of the cooling loop fluid.

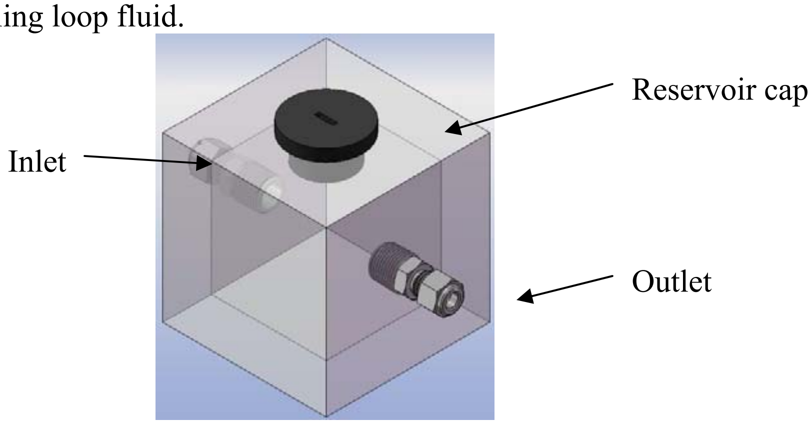


Figure 5. Cooling loop reservoir.

The condenser shown in Figure 6 was designed to cool and condense the FC-72 after being vaporized by the heat sink. The condenser consists of 4 tube passes through copper fins which are cooled through forced convection by a 3.63 inch by 3.62 in 12VDC computer fan which is rated at 60 cubic feet per minute.

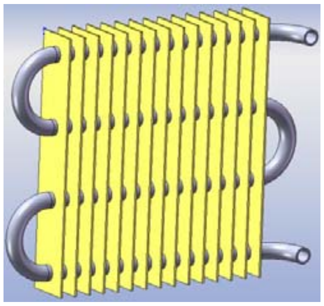
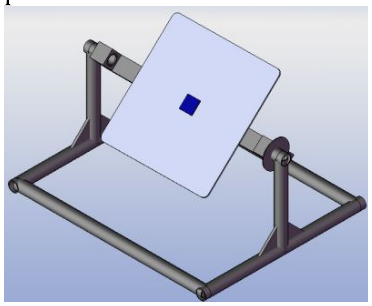


Figure 6. Condenser.

The cooling loop test stand shown in Figure 7 was designed so the micro-channel heat sink could be rotated about two perpendicular axes to vary the gravitational orientation of the heat sink. The entire cooling loop will be mounted to a 1/8 inch thick, 1 square foot aluminum plate. The base of the test stand has already been constructed out of mild steel tubing.

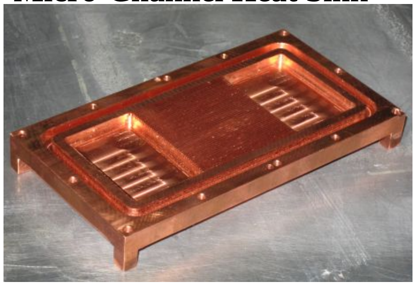


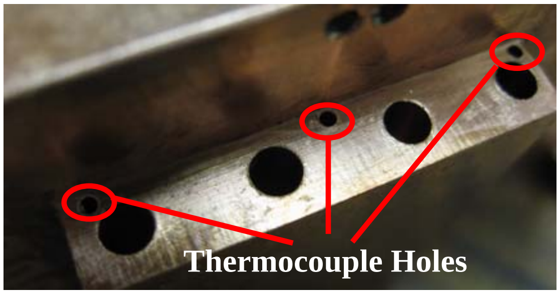
Heat sink centered here

Figure 7. Test stand.

FINISHED COMPONENTS

Micro-Channel Heat Sink

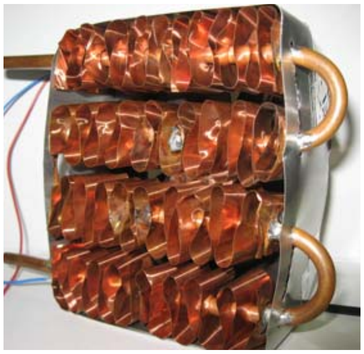


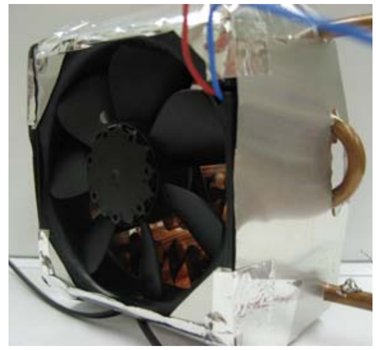


Polycarbonate Cover Plate

Cast Acrylic Reservoir

Condenser **Cooling Fan**





CONCLUSION

Although the primary goal of the research was not met, much of the designing and fabrication was accomplished in only one semester. Another semester will be needed to assemble the cooling loop, finish constructing the stand, and conduct testing.

ACKNOWLEDGMENTS

I'd like to thank the Hawaii NASA Space Grant Consortium for awarding me this opportunity to do hands research that where I've gained new important skills that I will use in professional career which I will begin soon. I also would like to thank my mentor Dr. Weilin Qu who helped me in every step of this project and taught me everything I know about two-phase flow, and giving me the opportunity to do this research. It was a very rewarding experience.

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