

A Freezable Heat Exchanger for Space Suit Radiator Systems

James A. Nabity, Georgia R. Mason and Robert J. Copeland

TDA Research, Inc

Luis A. Trevino

NASA Johnson Space Center

Copyright © 2008 SAE International

ABSTRACT

During an ExtraVehicular Activity (EVA), both the heat generated by the astronaut's metabolism and that produced by the Portable Life Support System (PLSS) must be rejected to space. The heat sources include the heat of adsorption of metabolic CO_2 , the heat of condensation of water, the heat removed from the body by the liquid cooling garment, the load from the electrical components and incident radiation. Although the sublimator hardware to reject this load weighs only 1.58 kg (3.48 lbm), an additional 3.6 kg (8 lbm) of water are loaded into the unit, most of which is sublimated and lost to space, thus becoming the single largest expendable during an eight-hour EVA. Using a radiator to reject heat from the astronaut during an EVA can reduce the amount of expendable water consumed in the sublimator.

Radiators have no moving parts and are thus simple and highly reliable. However, past freezable radiators have been too heavy. The weight can be greatly reduced by placing a small and freeze tolerant heat exchanger between the astronaut and radiator, instead of making the very large radiator freeze tolerant. Therefore, the key technological innovation to improve space suit radiator performance was the development of a lightweight and freezable heat exchanger that accommodates the variable heat load generated by the astronaut. Herein, we present the heat transfer performance of a newly designed heat exchanger that endured several freeze / thaw cycles without any apparent damage. The heat exchanger was also able to continuously turn down or turn up the heat rejection to follow the variable load.

INTRODUCTION

At present, both the astronaut's metabolic heat and that produced by the Portable Life Support System (PLSS) are rejected to space by a sublimator that consumes up to 3.6 kg (8 lbm) of water [1]; the single largest expendable during an eight-hour extravehicular activity (EVA) [2]. This will not be acceptable for long duration

Lunar and interplanetary missions where resupply is difficult. The amount of water lost to sublimation can be greatly reduced by radiating most of the heat load to the ambient environment.

MISSION NEED FOR SPACE SUIT RADIATORS

A space suit radiator can replace the PLSS covering with very little net increase in weight and yet will cut the amount of water needed to cool the astronaut during an EVA by up to 2.7 KG (6 lbs). This will represent a significant cost savings to future missions. As an example, the assembly of the International Space Station (ISS) has required approximately 1920 EVA hrs so far [3]. The cost to transport the cooling water needed during EVAs was about \$20M assuming a cooling water consumption rate of 0.45 kg/h and an approximate launch cost of \$22,000/kg to transport the water to the ISS. A space suit radiator would have lowered this cost by \$15M. However, the costs to transport cooling water increase by about 12X for Lunar and 26X for Mars surface EVAs [4], which will make it prohibitively expensive to carry water just for cooling. In-situ sources of water may be available, but the costs to recover are not known. For Lunar and Mars EVA missions the reduction in water loss is not merely nice, it is essential.

Current plans for Lunar exploration place an outpost and the majority of EVA missions at the poles, which has an ideal environment for the use of a radiator. It will be highly effective, since the sink temperatures of space and the Lunar surface are both cold and not subject to large fluctuations in temperature. Incident solar energy will not heat the radiator surface due its low absorption in the visible spectrum.

FREEZABLE SPACE SUIT RADIATORS

While the advantages of radiators have long been recognized (they can operate effectively in Earth orbit, trans-Lunar, trans-Martian, and in most Lunar and Mars environments), they have a problem that has so far prevented their use on space suits: current simple

designs reject heat at a relatively steady rate in moderately cold to very cold environments. Further, the effective sink temperature will depend on the orientation of the radiator which can change as the astronaut performs the mission, but neither of these will correlate with the rate of heat generation by the astronaut which can vary from 70 to 730 W [5-7]. Without a way to continuously adjust the heat removal rate, the astronaut will alternate between heat stroke and frostbite conditions. Therefore, a key technological problem is to develop a lightweight and freeze tolerant space suit radiator able to accommodate the variable heat load.

The heat rejection from a radiator can be “turned-down” by sequentially allowing tubes that carry the water to the radiator to freeze. When a tube freezes, the temperature of the radiating area around it drops, and the heat rejection rate drops as well. The problem with the freezable radiators developed to date is that they are far too heavy, since they used heavy walled tubes to prevent bursting during freeze/thaw cycles. Further, in past freezable designs, the entire surface of the PLSS had to be thick enough to conduct enough heat several inches to melt the adjacent frozen tubes. As a result, no freezable radiator has been light enough to be used in the PLSS.

Cross, Trevino, and Laubach [8] report a system in which the heat flowing to the radiator was decreased by creating a small gap between the radiator and the water loop. When the heat load was high, the gap was filled with a gas to increase the conductance. When the heat load was low, the gap was vented to space, the heat transfer rate was decreased (vacuum is a very good insulator), and the heat rejection rate dropped. However, the weight of the system was 20 kg (44 lbm) compared to 7.2 kg (15.9 lbm) for the current system. Additionally, because of heat leaks, there was only a ~25% reduction in heat rejection in a cold environment.

RADIATOR AND FREEZABLE HEAT EXCHANGER (RAFT-X)

The RAFT-X space suit radiator [6,7] uses a freezable heat exchanger to transfer heat from the astronaut to the radiator. Since only a small heat exchanger must be made freezable, this space suit radiator is lighter than previous designs. It also uses the conventional water loop to cool the astronaut and life support system components, but provides redundancy in heat rejection, since it is completely independent from the sublimator. Further, there are no moving parts and thus is extremely reliable.

As shown in Figure 1, warm water from the astronaut's liquid cooling garment (LCG) enters a freeze tolerant heat exchanger and transfers heat to the heat pipes. The refrigerant boils in the evaporator section of the heat exchanger and vapor moves up the heat pipe that is located on the radiator panel of the PLSS backpack, which has enough surface area to reject up to 300 W. As heat is rejected by radiation, the vapor condenses

and travels back to the evaporator. There are no moving parts (i.e. pumps) in TDA's spacesuit radiator and the system is completely passive.

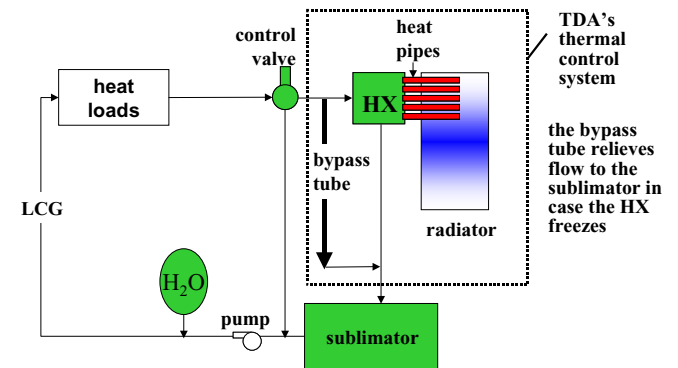


Figure 1. Process flow diagram for the space suit thermal control.

There are a number of advantages to this concept. First, using two separate fluid loops allows the thermal properties of a refrigerant fluid to be advantageously used without altering the LCG. The radiator fluid selection has no impact on the rest of the life support system and to keep the radiator lightweight a refrigerant was chosen that will not freeze within the loop heat pipes even if the PLSS is facing deep space. Second, because the five heat pipe fluid loops are independent from one another and separate from the water loop, a puncture to one of the heat pipes will not be a life-threatening emergency. If the refrigerant in the punctured heat pipe drains out, the water-cooling loop is not affected. The other heat pipes, as well as the sublimator, still remain operational to provide the needed cooling. In fact, the loss of a single loop heat pipe reduces the heat rejection capacity by only 2 to 5%. [7]

In this novel approach only the heat exchanger needs to be freeze tolerant. Making it freeze trap tolerant ensures effective and safe operation at any load. Under low metabolic load, the control valve reduces the water flow to the heat exchanger. In cold environments the heat exchanger drops below the freeze point of water and passively controls the heat rejection rate by allowing the coldest water flow passages in the heat exchanger to freeze. As the water in the heat exchanger freezes, sections of the heat exchanger become inactive, preventing heat rejection to the heat pipes that are in contact with those surfaces of the heat exchanger. If all of the water passages freeze, then the bypass tube (again, see Figure 1) continues to flow some water to the sublimator and thereby provide uninterrupted cooling even when the heat exchanger and radiator transfers little to no heat.

Overall, the RAFT-X space suit radiator (Figure 2) was demonstrated to transfer heat from 300 W down to 90 W, which is a heat transfer turndown ratio of about 2.7, but unfortunately it could not be turned down further without fully freezing the water channel. At lower loads

(< 90 W) the heat exchanger froze completely. While the heat exchanger was undamaged, it was not able to transfer heat until the chamber was warmed to thaw it back out. [7] In space, it would not become operational again until thawed back in the spacecraft. The sublimator remains online in order to complete the EVA without interruption. In summary, this system showed that a freezable heat exchanger could be built, but it was not capable of rapidly freezing and thawing to regulate the radiator, and it was still equal to or slightly heavier on-back than a standard sublimator system.

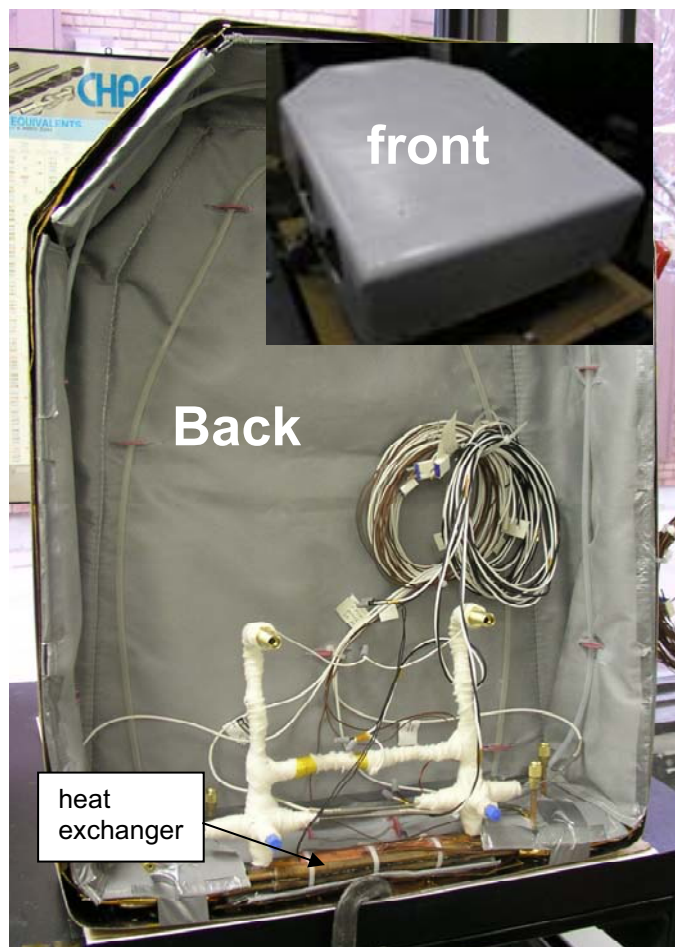


Figure 2. RAFT-X prototype space suit radiator.

A FREEZABLE HEAT EXCHANGER TO PASSIVELY REGULATE HEAT TRANSFER

A new heat exchanger was developed to passively regulate the heat rejection rate to the radiator. The heat exchanger responds quickly and smoothly to match the rate at which heat is rejected to the rate at which it is produced. As the heat load drops, such as during periods when the astronaut is at rest, some of the heat exchanger flow passages freeze to block heat from being transferred to the nearby heat pipes and thereby also to the radiator surface. When the heat load rises the frozen passages rethaw to once again transfer heat at greater capacity. The heat exchanger was designed to accommodate the volume change that occurs when

the water freezes. This proprietary design was proven during freeze tests of the RAFT-X. [6, 7]

CONCEPT OF OPERATION

As shown in the space suit radiator concept sketch (Figure 3), the water from the LCG passes through a small, freezable heat exchanger and loses its heat to the loop heat pipe evaporators, which are joined to the heat exchanger to ensure good conductance. The heat evaporates refrigerant stored in the evaporators. The loop heat pipes transport the heat to the radiator and distribute the heat throughout the radiator surface. The extremely low freeze point of the refrigerant ensures that the heat pipes can not freeze and therefore thin-wall tubing is used for their construction.

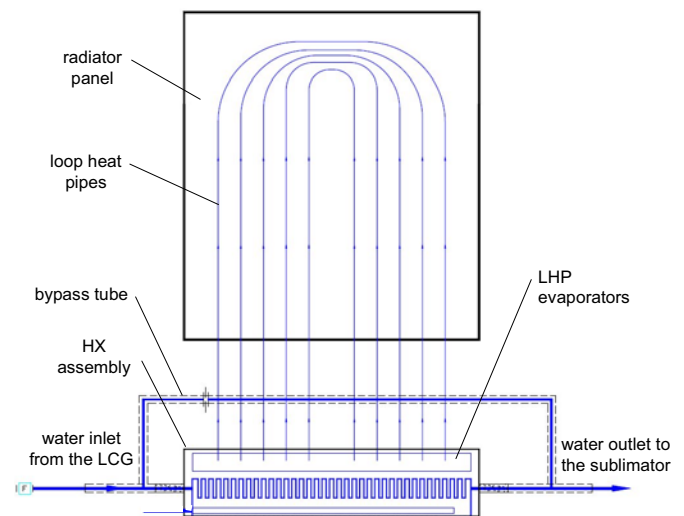


Figure 3. Concept sketch of the space suit radiator.

Of the space suit radiator components (the heat exchanger, the loop heat pipes and the radiator), only the heat exchanger must be freeze tolerant and thus, it is the most important component in the system. Although not shown in Figure 3, the design provides for the needed expansion volume when the water freezes. At low metabolic loads the efficiency of the heat exchanger drops as ice forms within the unit. The build up of ice on the fins reduces the surface area within the heat exchanger and lowers their conductance (the conductivity of ice is only 1/200th that of the fins). Thus, little heat is transferred to the radiator and the astronaut does not freeze. The heat exchanger does this by freezing water in most of the flow channels at low loads, which decreases the active surface area and blocks the flow of heat to some of the heat pipes, thereby limiting the flow of heat to the radiator. Therefore, the heat exchanger effectiveness is proportional to the incoming load, and thus the heat transferred to the radiator tracks the heat generated by the astronaut.