

Design of a Sublimator Driven Coldplate Development Unit

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ABSTRACT

The Sublimator Driven Coldplate is a unique piece of thermal control hardware that has several advantages over a traditional thermal control scheme. The principal advantage is the possible elimination of a pumped fluid loop, potentially saving mass, power, and complexity. Because this concept relies on evaporative heat rejection techniques, it is primarily useful for short mission durations. Additionally, the concept requires a conductive path between the heat-generating component and the heat rejection device. Therefore, it is mostly a relevant solution for a vehicle with a relatively low heat rejection requirement. This paper describes the design of an engineering development unit intended to demonstrate the feasibility of the Sublimator Driven Coldplate concept.

INTRODUCTION

NASA Johnson Space Center has begun several architecture studies for the upcoming lunar lander and lunar outpost. In performing these assessments, an innovative way to perform thermal control was discovered. A manned spacecraft typically uses a pumped fluid loop as its thermal control system. Heat is collected in heat exchangers and coldplates, and then transported around the loop via a pumped liquid coolant. Heat is then removed from the spacecraft via a radiator, an evaporator (or sublimator), or both. Radiators have an advantage of no consumables, but for certain mission phases and locations, evaporative cooling provides the most efficient method for heat rejection.

The approach for a Sublimator Driven Coldplate (SDC) is to combine the heat collection, heat transport, and heat

rejection functions into one piece of hardware. By mounting all of the heat-generating avionics directly on a coldplate-like device that also acts as a sublimator, the rest of the thermal control system can be eliminated as shown in Figure 1. Without the need for a pump, an accumulator, and the coolant fluid itself, significant mass savings can be realized.

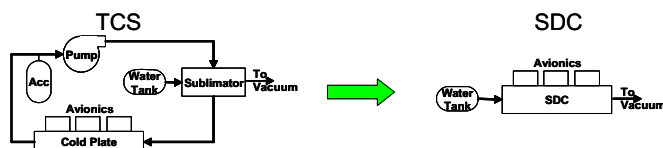


Figure 1. A sublimator driven coldplate can replace an entire pumped fluid loop thermal control system.

REQUIREMENTS

The following requirements were specified in the task description for the SDC CRAVE delivery order:

- The SDC design shall not require any power during nominal operation.
- The SDC shall be capable of rejecting a minimum of 2.5 kW (8530 Btu/hr) for a minimum period of 6.5 hours.
- The SDC shall not exceed a surface area of 4500 in² (2.9 m²) and the maximum dimensional extents shall not exceed 98 inches (2.5 m).
- The SDC maximum surface temperature shall not exceed 43°C (109.4°F) during operation assuming that the 2.5 kW (8530 Btu/hr) is uniformly distributed on the 4500 in² (2.9 m²) available surface area.

- The design of the SDC shall require only a single penetration in the vehicle pressure shell.
- The SDC shall be capable of withstanding a load of 5.0 g's with 133 kg (293 lb) of avionics mounted on the unit.
- The SDC shall use de-ionized water as the sublimator working fluid.

Several obvious implications are evident from these requirements. The required 2500 W (8530 Btu/hr) of power corresponds to a water mass flow rate (liquid in and vapor out) of 3.6 kg/hr (7.9 lb/hr). Coupled with the total duration of 6.5 hours, a total of 23.4 kg (51.4) lb of water (approximately 6.2 gallons) would be required.

Additional factors affecting the design come from knowledge and experience with sublimators. For example, the pressure drop of the vapor exiting the SDC must be kept below the triple point pressure of water so that ice is allowed to form at the porous plate. Additionally, the heat flux into the porous sublimator plate must be kept below a threshold value to prevent breakthrough of the feedwater. For this project a maximum allowed heat flux into the sublimator plate of 10 W/in^2 ($52.9 \times 10^3 \text{ Btu/hr/m}^2$) was used. It is interesting to note that, if uniform heat flux is assumed, only 250 in^2 (0.16 m^2) of sublimator surface area is needed for the total 2500 W (8530 Btu/hr) heat load, which is well below the 4500 in^2 (2.9 m^2) of total surface area allowed.

Besides the sublimator surface area not needing to be as large as the maximum allowed surface area, the actual mounting surface area does not need to be as large as the maximum allowed either. By comparing to typical avionics and coldplates, a more reasonable range for the total surface area was determined to be $0.75 - 1.5 \text{ m}^2$ ($1163 - 2325 \text{ in}^2$). This results in an average heat flux for the heat sources of $1.1 - 2.1 \text{ W/in}^2$ ($5.69 \times 10^3 - 11.4 \times 10^3 \text{ Btu/hr/m}^2$).

DESIGN AND ANALYSIS

The basic layout of a sublimator driven coldplate as depicted by Rathbun¹ is shown in Figure 2. A component mounting surface is shown at the bottom, with the next layer up being the feedwater passage. Fins are shown to help conduct heat from the component mounting surface, across the feedwater passage, and into the porous plate. Feedwater forms an ice layer at the porous plate since it is exposed to vacuum conditions below the triple point. Heat conducted into the ice causes it to sublime, while additional feedwater continuously replenishes the ice layer. A cover forms a vacuum passage with the vapor from sublimation being ducted away through a vapor outlet.

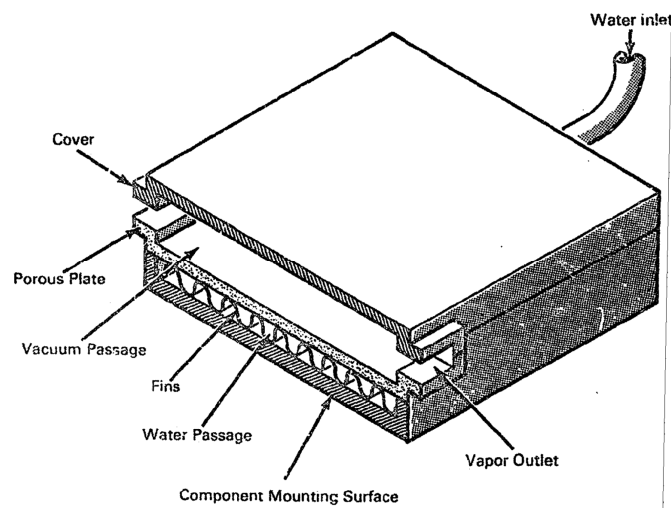


Figure 2. General concept for a sublimator driven coldplate¹.

Early in the project, numerous design concepts were considered. Most of these various ideas are captured by considering two main concepts, which are referred to here as the plate concept and the tube concept. These two concepts are each discussed below.

PLATE CONCEPT

For a large mounting surface, an arrangement such as that shown in Figure 3 could be used. Rather than using a single large sublimator (porous plate) surface with the same surface area as the mounting surface, a number of smaller sublimator surfaces could be used. The figure depicts 9 sublimator surfaces, but fewer or more (e.g., 4, 16, etc.) could also be used. Furthermore, rather than having a separate cover to form a vapor passage, two plates can be arranged together such that the space between forms the vapor passage, as depicted in Figure 4. Avionics boxes can be mounted to both the top and bottom surfaces. Utilizing both surfaces provides the total required mounting surface area with a smaller footprint than if only one side were to be used. The smaller footprint also results in greater rigidity.

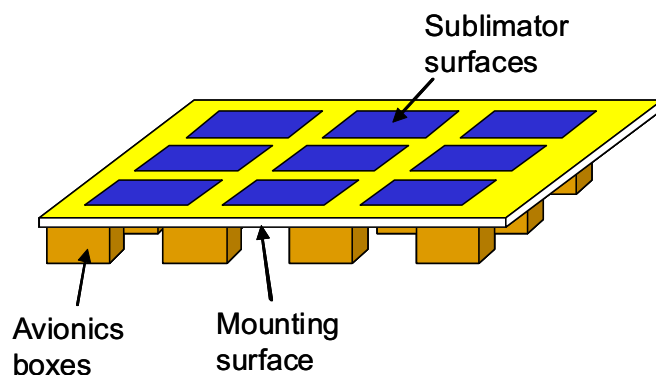


Figure 3. Concept for a sublimator driven coldplate with multiple sublimator surfaces.