United States Patent

[11] **3,613,775**

[72] Inventor **Daniel L. Curtis**
Manhattan Beach, Calif.

[21] Appl. No. **825,812**
[22] Filed **May 19, 1969**
[45] Patented **Oct. 19, 1971**
[73] Assignee **Litton Systems, Inc.**
Beverly Hills, Calif.

[54] **SELF-REGULATING COOLING SYSTEM**
4 Claims, 3 Drawing Figs.

[52] **U.S. Cl.** **165/46,** 62/315
[51] **Int. Cl.** **F28f 7/00**
[50] **Field of Search** .... 244/1 SS; 2/2.1; 165/105, 170, 110, 180, 46; 62/119, 315, 259

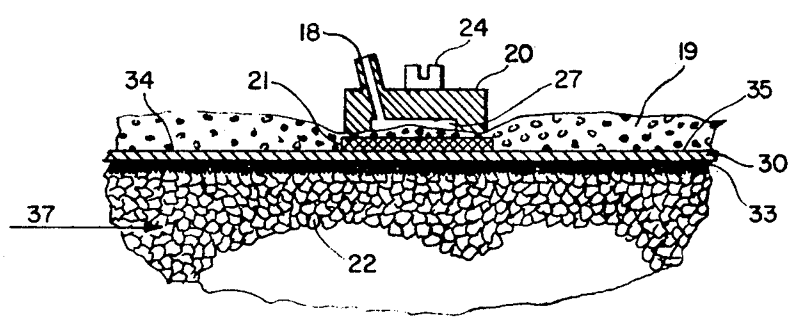
[56] **References Cited**

UNITED STATES PATENTS

3,152,774	10/1964	Wyatt	244/2.1
3,411,156	11/1968	Feher	2/2-1
3,463,150	8/1969	Penfold	244/1 X
3,490,718	1/1970	Vary	165/105
3,170,303	2/1965	Rannenberg et al.	62/98
3,212,286	10/1965	Curtis	62/315
3,197,973	8/1965	Rannenberg et al.	62/268
3,314,475	4/1967	Valyi	165/170

Primary Examiner—Frederick L. Matteson
Assistant Examiner—Theophil W. Streule
Attorneys—Alan C. Rose, Walter R. Thiel and Alfred B. Levine

ABSTRACT: A self-regulating cooling system to remove metabolic heat from the coolant loop in a life support system used in space activity. Coolant passes through a sublimator as part of the coolant loop which also includes a pulse pump and a coolant garment. A separate water storage container provides feedwater to the sublimator where it is sublimated along a surface thermally connected to a heat exchange element through which the coolant flows.



PATENTED OCT 19 1971

3,613,775

Fig.1

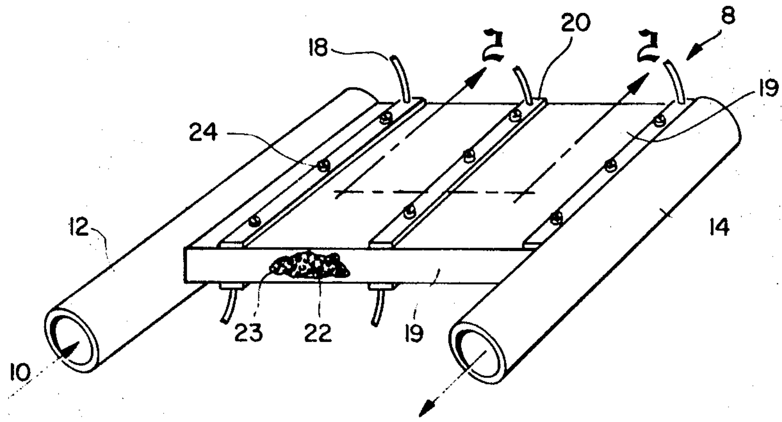


Fig.2

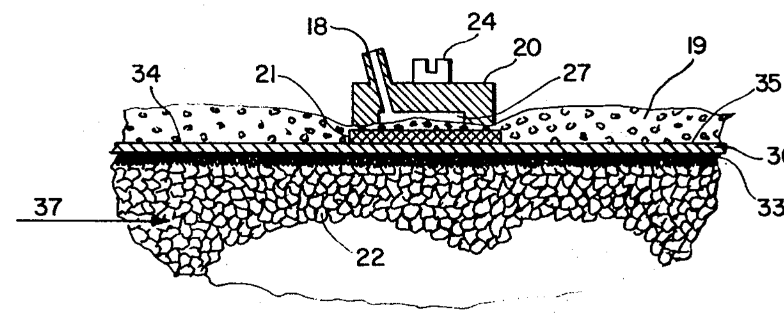
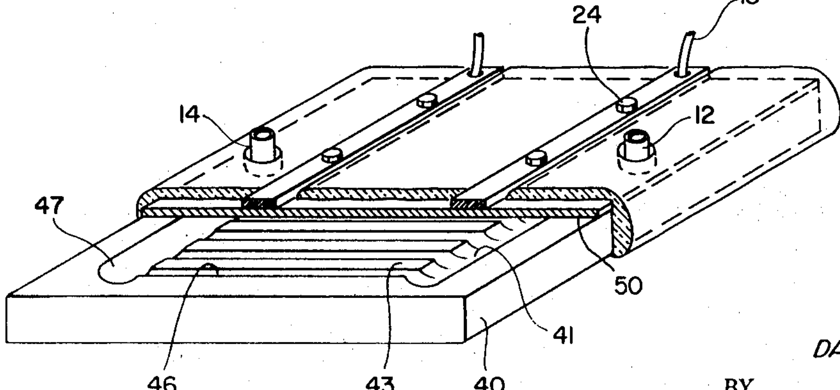


Fig.3



INVENTOR.
DANIEL L. CURTIS

BY Walter R. Thiel

ATTORNEY

SELF-REGULATING COOLING SYSTEM

BACKGROUND OF THE INVENTION

During manned space exploration a life support system is necessary for use in either the space vehicle or the space suit. The life support system must provide for the controlled dissipation of the metabolic heat of the astronaut as well as any heat absorbed due to external radiation such as emanates from the sun. Because of the weight limitations for a backpack that an astronaut can carry on his space suit and the high-launching cost per pound, it is extremely important that the weight of the life support system be kept at a minimum, while still retaining the necessary cooling characteristics.

Previously designed life support systems have generally utilized a dynamic form of cooling. Most of these systems use the evaporation of a liquid into space as the principal means of dissipating heat removed from the astronaut's body by a cooling garment. A coolant flowing through small tubes in the garment carries excess body heat to the cooling device where the heat is removed. These systems have generally involved very heavy and cumbersome equipment and normally include pumps, valves, and coolant reservoirs requiring complex regulation with many valves and mechanical devices.

State of the art systems have evaporated the liquid, usually water, through a sublimation device wherein the water is allowed to evaporate into a vacuum thereby absorbing from the coolant system sufficient heat to supply the heat of vaporization to the water. Upon initial exposure to the vacuum, the water freezes and thereafter sublimes while removing additional heat from the system. Because of the sublimation process, the evaporator is self-regulating, maintaining itself at a temperature of approximately 32° F. If the heat-exchanging portion of the sublimator has good thermal conductivity from the coolant to the sublimating surface then extremely rapid and efficient heat transfer can be achieved.

Conventionally, sublimation-type cooling systems have used a porous metal as the element in the sublimator which supports the ice layer being sublimated and provides the thermal conduction to the ice layer. In such systems, the sublimation occurs in the micropore structure of the porous metal, usually a nickel plate. Thus, any impurities existing in the water would automatically be left behind within this micropore structure at the site where vaporization takes place. Over a relatively short period of time this slow accumulation of solid residue leads to system degradation and performance of the unit is destroyed in a relatively short period of time. To overcome this deterioration in performance, prior systems required a water so pure as to cast doubt on the usefulness of sublimator systems during space missions. Another problem plaguing prior systems was the further deterioration of performance due to the electrolysis of the metals used. To alleviate this problem, porous nickel was used as the sublimating surface, because of the lower susceptibility of the nickel to degradation through electrolysis, even though other metals such as copper have substantially higher heat transfer coefficients. This trade-off resulted in a system having a lower heat transfer coefficient thereby requiring a larger sublimating surface area.

Another basic disadvantage to using porous nickel as the sublimating surface was the considerable length of the thermal path from the sublimation surface to the heat exchanger, thereby resulting in a relatively low-efficiency system. To meet the necessary heat removal requirements it became necessary to construct sublimators which were quite large in size and unduly heavy. These systems were normally characterized by a high-pressure drop across the heat exchanger which needed large and powerful pumps to maintain more flow through the coolant loop. The need for water purity meant that the feedwater system had to be very carefully monitored and where zone temperature control was desired, complex regulation systems were required.

It is therefore the object of this invention to provide a cooling device for a life support system that is self-regulating and which will be considerably lighter and smaller in size than in prior systems.

An additional object of the invention is to provide a cooling system that will not be susceptible to performance deterioration over long periods of operating time and will be impervious to system degradation due to electrolysis of the various metal elements.

Another object of the invention is to provide a cooling system utilizing a sublimation process where it is possible to separate the sublimation region from the water distribution and flow control region while still providing a short thermal path between the sublimation zone and the heat source.

Another object of the invention is to provide a cooling system which will be characterized by a low-pressure drop of the coolant fluid flowing through the heat exchange portion of the system thereby reducing the size of the pumps needed for the coolant loop.

Still another object of the invention is to provide a cooling system wherein the sublimation surface will be characterized by a high-heat transfer coefficient thus resulting in a high-efficiency heat removal system.

Still a further object of the invention is to provide a cooling system which will be readily adaptable to zone temperature controls where different temperatures must be maintained over distinct portions of the life support system.

SUMMARY OF THE INVENTION

The aforementioned objects of the invention are accomplished by channeling feedwater along a felt distributor pad sandwiched between an adjustable pressure pad and a metal sublimating surface. The sublimating surface is covered by a layer of synthetic foam. Initially, feedwater spreads in a thin sheet over the surface of the metal and any water leaving the metal surface and evaporating into the foam covering immediately freezes preventing further migration of the water into the foam. The net result is a thin layer of ice between the metal and the foam covering which will sublimate away as heat is added to the system by a heat exchanger which thermally connects the sublimator and the coolant loop. Feedwater flow to the sublimating surface is cut off when the felt distributor pads freeze. As heat is added, the sublimating ice is replaced by the addition of feedwater. The heat exchange portion of the sublimator is a copper foam or channeled aluminum block through which the coolant liquid or gas flows.

BRIEF DESCRIPTION OF THE DRAWINGS

The specific nature of the invention, as well as other objects, aspects, uses and advantages thereof, will clearly appear from the following description and from the accompanying drawing, in which:

FIG. 1 is a perspective view of one embodiment of a cooling system in accordance with my invention.

FIG. 2 is a portion of a detailed cross-sectional view along lines 2—2 of FIG. 1 showing the details of the sublimating apparatus.

FIG. 3 is a perspective view, partially cut away, of a second embodiment of a cooling system in accordance with my invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIG. 1 a cooling system is illustrated which is suitable for use with a life support system such as the one described in my copending application, Ser. No. 701,244 filed on Jan. 29, 1969 entitled "Life Support System" and assigned to the assignee of the instant application. The coolant 10 from the thermal control portion of the life support system enters conduit 12 in the direction shown and passes through the sublimator 8 to the conduit 14 before returning to the support system. Openings (not shown) are provided in the sides of conduits 12 and 14 to allow the coolant to enter and leave the sublimator 8. Between conduits 12 and 14 the coolant 10, which can be either a gas or a liquid, passes through a heat exchanger shown at the cut away portion 23 of the sublimator 8. The heat exchanger can be any metal having a high coefficient of conductivity and through which the coolant 10 can easily flow such as a copper foam 22 illustrated in FIG. 1. Surrounding the copper foam 22 is a high conductivity solid metal sheet (not shown) which is then covered with an open cell synthetic foam 19 as the exterior surface of the sublimator. On either side of the sublimator 8, several pressure pads 20 are placed in parallel directions and fastened to sublimator 8 with screws 24. Each pressure pad 20 has a water feed line 18 to supply feedwater to a felt strip located along the underside of each pressure pad 20.

The detailed construction of the sublimator may be more clearly understood by referring to FIG. 2 which is partial cross-sectional view under one of the pressure pads 20 taken along lines 2—2 of FIG. 1. The copper foam 22 is cemented to a copper sheet 30 by a thermally conductive cement 33 applied along the bottom surface of the sheet 30. Several long strips of felt 21 are placed adjacent the sheet 30 with the foam 19 disposed to cover the Teflon felt strips 21 and the copper sheet 30. The pressure pads 20 are aligned over the felt strip 21 and the screws 24 adjusted to apply pressure over the foam 19 thereby compressing the foam and the felt strip 21. The pressure pad 20 is constructed so as to provide a water feed channel 27 through which feedwater entering from the water supply line 18 can be supplied to the entire length of the felt 21 lying beneath the pressure pads 20. The felt strips 21 act as distributors to evenly spread the feedwater over the sublimating surfaces 34 and 35 which lie along the upper side of the copper sheet 30.

The pressure screws 24 are initially adjusted to limit the maximum flow of water through the channel 27 and onto the felt strips 21. Normally, once the pressure screws 24 are initially set they need not be adjusted thereafter. Teflon felt is ideally suited as a flow controller because it is one of the few materials in felt form that is anhygroscopic. While most other nonmetallic materials would slowly absorb water thus causing the material fibers to swell resulting in water blockage, Teflon material will not absorb any water nor will it swell.

During the operation of the sublimator 8 shown in FIGS. 1 and 2, feedwater enters each pressure pad 20 through the water feed line 18 and passes through channel 27 where it is allowed to seep through the foam 19 into the felt strip 21. The feedwater initially seeps through the Teflon strip 21 and spreads along the adjacent sublimating surfaces 34 and 35 on the copper sheet 30. Because of the vacuum which exists in space, any water leaving the sublimating surfaces 34 or 35 and passing into the foam 19 will immediately freeze, forming a porous ice layer on the underneath side of the foam 19 which prevents further water migration into the foam layer. The net result is that the water is forced to spread almost uniformly over the sublimating surfaces 34 and 35. As the temperature of this surface drops to approximately 32° F. by virtue of the water vaporization from the foam 19, the water along the entire sublimating surface will freeze and eventually the ice front will extend into the felt strips 21. As soon as the outside of the felt strip 21 freezes, water flow from channel 27 onto the sublimating surfaces 34 and 35 ceases.

Coolant flowing through the life support system through the aforementioned conduits 12 and 14 will pass through the heat exchanger, in this case, an open cell copper foam 22. The direction of the general flow of the coolant is represented by arrow 37. It should be noted that the actual flow will be a somewhat circuitous path through the foam. Any heat contained in the coolant will be transferred by the copper foam 22 through the thermally conductive cement 33 and the copper sheet 30 to the ice existing along the sublimating surfaces 34 and 35. Heat reaching the sublimating surfaces 34 and 35 from the heat exchanger will cause some ice to sublimate away. As the ice lying on the surface of the felt strips 21 sublimates, feedwater will again flow from the felt strip 21 onto the surfaces 34 and 35 until the ice layer is again replenished.

The system is self-regulating because as the heat entering from the heat exchanger unit rises, the sublimation process will speed up thus causing a proportionally greater intake of feedwater from the channel 27. Because there are many sublimation regions in parallel existing along the length of the Teflon felt strip 21, the net result is a uniform flow of feedwater into the water feed line 18 and through channel 27 which will vary in direct proportion to the heat input to the system.

Another embodiment of a sublimator system is illustrated in FIG. 3. The elements common to both embodiments are labeled with the same numeral designations. As illustrated, the sublimator is constructed similarly to the above-described embodiment, the exception being that the heat exchange element is an aluminum block 40 having coolant input and output manifolds 41 and 47 respectively, connected by a plurality of parallel channels 46 through which the coolant passes from one manifold to the other. Coolant is supplied to the manifolds from the life support system, as in the previous embodiment, by an input conduit 12 and an output conduit 14. The parallel channels 46 are separated by a corresponding number of aluminum fins 43, illustrated in the cutaway portion of the figure. For purposes of simplicity the channels 46 are not shown except for the portion of the heat exchanger where the sublimating surface is cut away. The aluminum heat exchanger is constructed by machining the manifolds 41 and 47 and the channels 46 into an aluminum plate and then braising an aluminum plate 50 over the machined surface. The result is a solid aluminum block with the manifolds 41 and 47 and the parallel channels 46 contained therein. Constructing the heat exchanger into a unitized block obviates the necessity for a separate metal plate as a sublimation surface since the sides of the aluminum block are ideally suited for this purpose.

In operation, the embodiment of FIG. 3 will operate substantially identically to the embodiments of FIGS. 1 and 2. However, rather than taking a labyrinthine course through a metal foam the coolant will flow through the parallel channels 46. Tests have shown both embodiments to be extremely efficient and equally effective.

It should be apparent from the above description of the sublimator operation that the major portion of sublimation occurs over the open sublimation surfaces which are adjacent the felt strips and not from felt strips themselves. Because only a small fraction of the sublimation process actually takes place in the Teflon felt strips, and because this sublimation will take place only along the external surface of the strips, any residue which is deposited upon sublimation will not influence the flow of feedwater through the strips onto the sublimating surfaces. Therefore, the purity of the feedwater used in the sublimator system will not be as critical as it was in prior systems. Tests have shown that feedwater of reasonable purity, such as the commercial grade Arrowhead Puritas Distilled Water (solid residue–1.5 PPM) is sufficient for efficient operation of the system.

Because the system described above uses copper elements as a heat exchanger rather than a metal having a much lower heat transfer coefficient, it is possible to design a system having an equivalent thermal capacity with substantially smaller and lighter components than previously was available. Also, the sublimation in the instant system takes place along a surface rather than in a metal foam material, and a much shorter thermal path is provided from the heat exchanger to the sublimating surface.

An additional advantage of my sublimator system as exemplified by both embodiments, is that the sublimator system can be easily adapted to provide a wide range of temperature control. The thermal capacity of the sublimator can be simply controlled by controlling the feedwater into each pressure strip. Where plurality felt distributor strips are located on the top and bottom surfaces of the heat exchanger, varying the number of felt strips in the "on" condition (i.e., feedwater flowing therethrough) will vary the amount of sublimation and thus the heat rejection possible from the heat exchanger. Control can be simply effectuated by means of a simple set of on-off valves in the feedwater circulation system.

Tests run on comparable systems have shown that the present sublimator system constructed in accordance with my invention is capable of a heat transfer coefficient in excess of 300 BTU's hr/ft²/° F. as compared with 160 BTU's hr/ft²/° F. for a conventional system of comparable design. In addition, the present system is substantially lighter and smaller in volume and is not susceptible to performance deterioration over long periods of operating time. The present system is characterized by a pressure drop across the heat exchanger which is approximately one-third that of conventional systems. Because of the reduced size and weight of the system the lines and control valves needed can be correspondingly smaller and simpler. This advantage becomes especially important where the system is contemplated for use with a remote control unit such as might be used in a portable life support system to be carried by an astronaut with a control box located on his chest and the sublimator located in a back pack.

With the simplicity of this system, the sublimator is particularly suited for use with the thermal control system of a space suit life support system and can equally well be utilized in existing and proposed spacecraft thermal control systems. The system is also readily adaptable for use with either a liquid or gas heat exchanger.

I claim my invention is:

1. A self-regulating cooling system adapted for use in low-pressure environments comprising:
   a. a heat exchanger for removing heat from a coolant circulating therethrough;
   b. a metallic sheet having a surface region for sublimating ice intermittently forming thereon from feed water, said metal sheet thermally connected to said heat exchanger for receiving heat therefrom;
   c. a layer of open cell foam of low thermal conductivity covering said sublimating surface for passing water vapor and for supporting a porous ice layer formed in regions therein from feed water vaporizing in a low-pressure environment, portions of said ice layer intermittently forming on said sublimating surface and forming in said layer of foam sublimating away through the layer of open cell foam to the low-pressure environment in response to heat from said metallic sheet;
   d. at least one felt strip positioned between said metallic sheet and said layer of open cell foam for spreading feed water over said sublimating surface region of said metallic sheet and for controlling the operating temperature of the cooling system about the freezing point of water, said felt strip having a surface area in contact with said metallic sheet which is substantially smaller than the total surface area of said metallic sheet, said felt strip spreading feed water over regions of said sublimating surface not covered by a layer of ice, the flow of feed water onto said sublimating surface ceasing whenever ice forms at the water-emitting surfaces of said felt strip and resuming whenever ice formed at the water-emitting surfaces of said strip sublimates away in response to heat from said metal sheet; and
   e. feed water distribution means positioned in juxtaposition with said felt strip for supplying feed water to said felt strip; said feed water distribution means including means for controlling the maximum possible rate of flow of feed water from the water-emitting surfaces of said layer of open cell foam.

2. Cooling system of claim 1 wherein said heat exchanger includes a copper foam through which a coolant passes.

3. The cooling system of claim 1 wherein said heat exchanger includes;
   a. a metal block having input and output manifolds for passing a coolant; and
   b. a plurality of parallel disposed channels connecting said input and output manifolds for passing a coolant, the coolant in said channels being in thermal contact with said metallic sheet;

4. The cooling system of claim 1 wherein said felt strip is an anhygroscopic material.