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FURLABLE HEAT EXCHANGER

3,496,995

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3 Sheets-Sheet 1

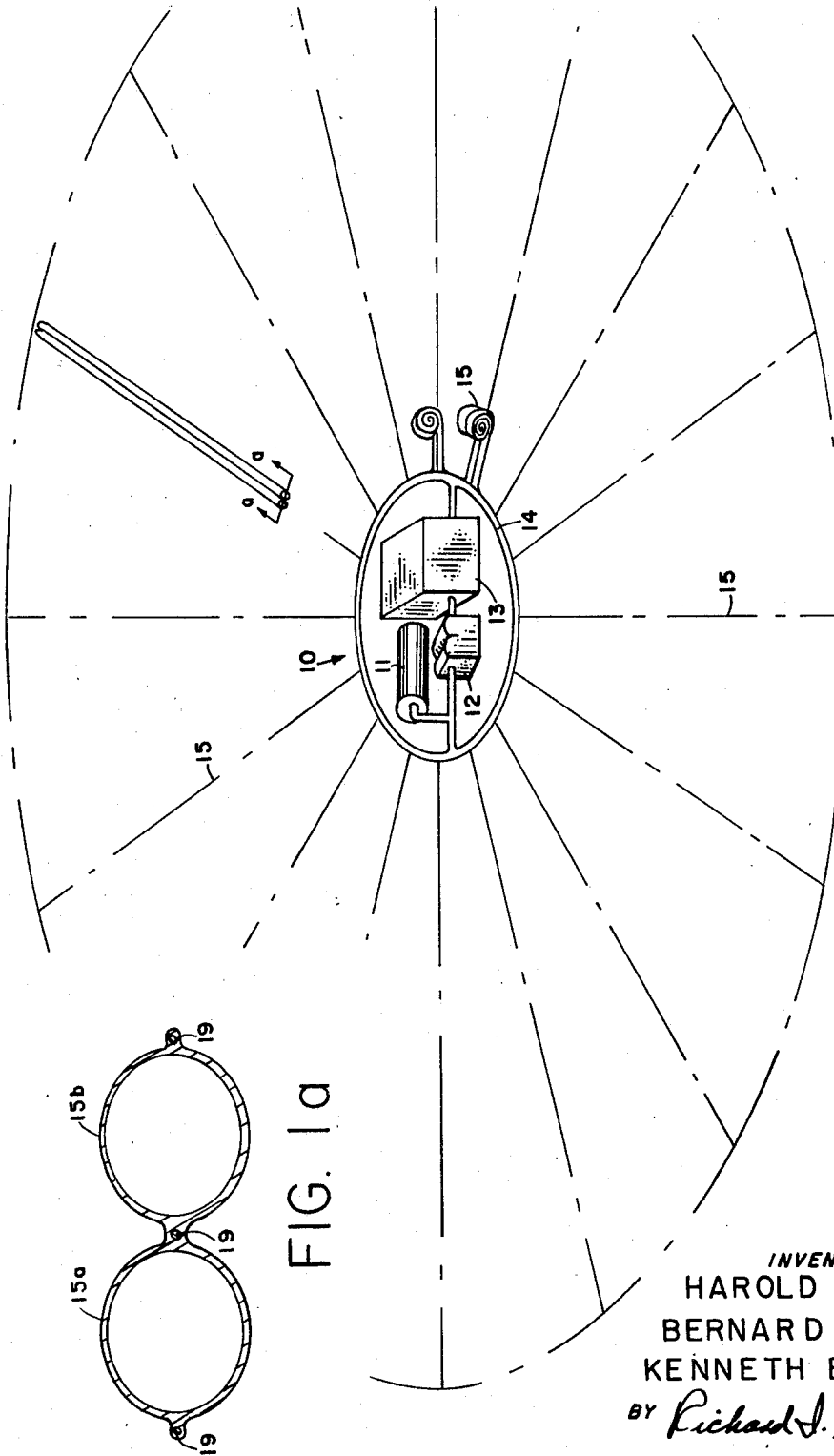


FIG. 1

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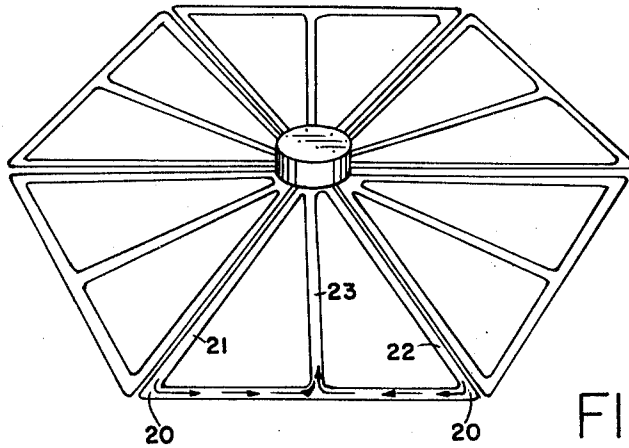


FIG. 2

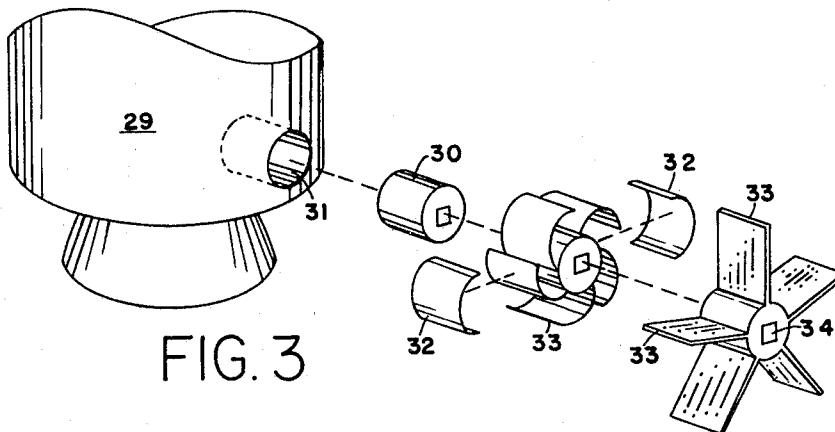


FIG. 3

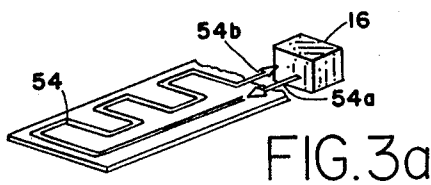


FIG. 3a

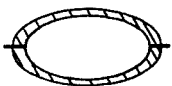


FIG. 5b

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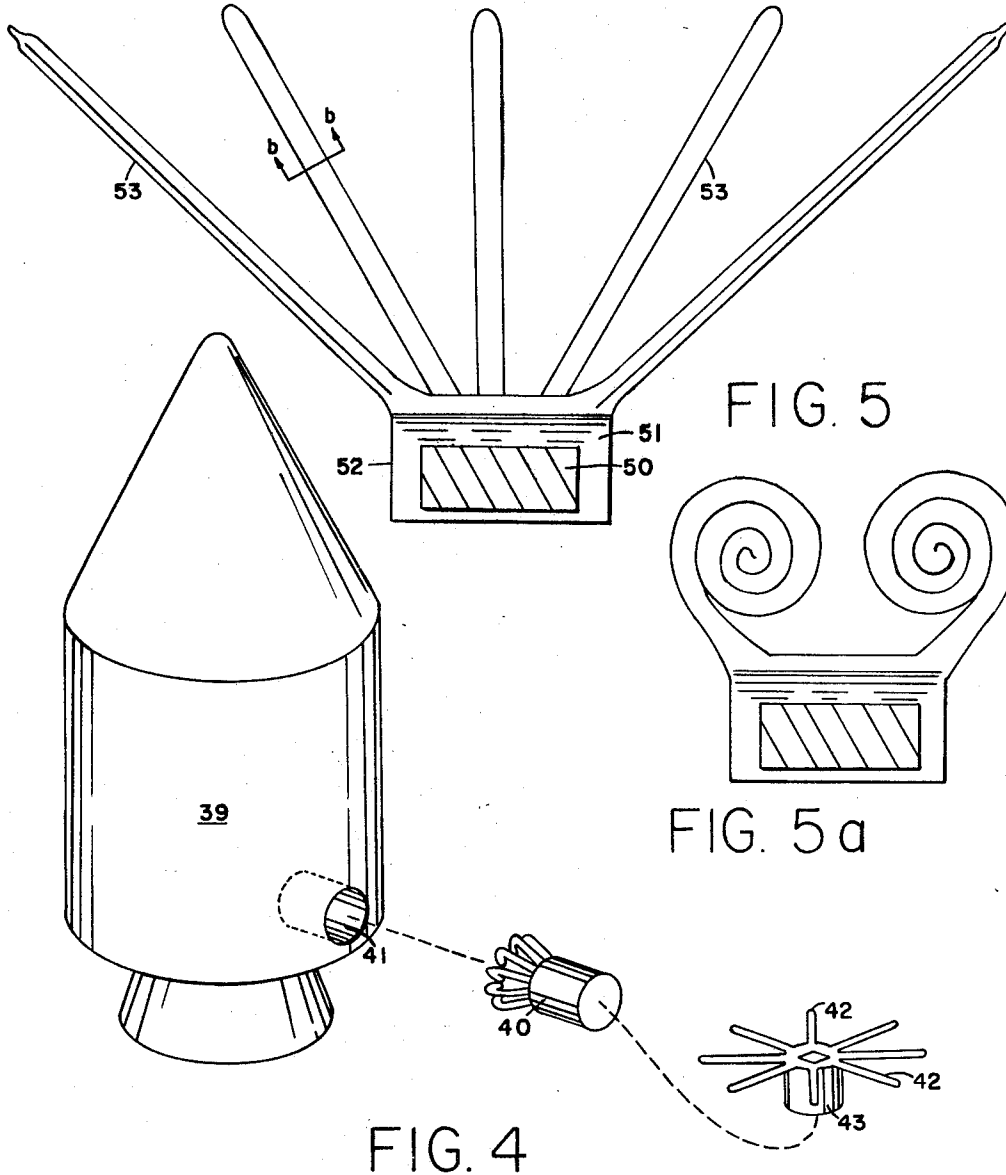
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FURLABLE HEAT EXCHANGER

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Int. Cl. F28f 5/00

U.S. Cl. 165—46

12 Claims

ABSTRACT OF THE DISCLOSURE

This disclosure relates to collapsible heat exchangers which are transported by missile vehicles to an outer space environment where they are then automatically unfurled to present large areas of surface for heat transfer. The feature of collapsibility permits large surface heat-exchange areas to be packaged in relatively small volumes during the travel period from launch pad to the space or alien planet destination, and then unfurl to occupy its full operational size.

BACKGROUND OF THE INVENTION

This invention relates to thermal heat exchangers and more particularly to furlable heat exchangers which can be packaged to occupy a small space when in an inoperative position, but whose heat transfer surface area can be increased by unfurling preparatory to becoming operative. These forms of heat exchangers have particular application in outer space and other alien environments.

One of the major problems with space power generators utilizing thermal cycles has been the amount of radiator surface required for waste heat rejection. In transporting these generators to space environmental regions, their "on board" size and weight restrictions must, of necessity, be minimal. However, since low radiator temperatures are essential to high efficiency of such heat exchangers, the total heat transfer surface area, when operative, must be rather large. Though we recognize that heat transfer will occur from these heat exchanges by radiation or convection, or both, we will nevertheless henceforth refer to these surfaces as "radiators." Of course, if the heat exchangers are employed in a space vacuum, no heat exchange takes place by convection.

In order to minimize on board launch vehicle volume as power packs are carried into space, we have discovered that a furlable radiator can be fabricated which would adequately meet both the size and heat exchange requirements. The radiators contemplated by this disclosure are packaged in a collapsed (i.e. furled) condition, and packed snugly around and integrally connected to the heat generator system. During the launch phase of the space vehicle, in-transit cooling for this limited period can be provided by using the heat capacity of the associated materials; for example, the heat-sink capacity of the adjacent launch vehicle structure and skin, and the self-contained coolant. When the high "g" and high atmospheric drag portion of the flight profile is passed, the radiator and self-contained power generator may be deployed overboard from the spacecraft whereupon the radiator arms are unfurled and allowed to occupy as much space as is required by the design. Depending on the heat rejection requirements, these radiator arms may extend anywhere from a few feet in length to fifty or more feet in length. When such radiators are employed in vacuum environments, the heat transfer will occur through radiation; on the other hand, should the radiator

be in a gaseous environment, heat transfer will occur by both radiation and convection.

Accordingly, it is among the various objects of this invention to provide a heat exchanger which presents a large surface area for heat transfer in its operative condition, but which can be furled and packaged into a small volume while it is inoperative.

It is a further object of this invention to provide a heat exchanger which is readily collapsible but which will automatically unfurl its heat transfer portions into operative position at a predetermined time.

It is a still further object of this invention to provide a furlable heat exchanger wherein the heat transfer or so-called radiator surfaces are held in an extended position through the action of pressurized circulating coolant and the unfurlable characteristics of the structure itself.

Another object of this invention is to provide a furlable heat exchanger which dispenses with the need for a mechanical circulating mechanism but which instead utilizes a change-of-state coolant.

These and other objects will become more apparent in light of the following disclosure, when taken in conjunction with the various drawings in which:

FIGURE 1 illustrates a self-contained power package and furlable heat exchanger with self-coiling arms;

FIGURE 2 depicts another embodiment of a furlable heat exchanger;

FIGURE 3 illustrates a still further form of a furlable heat exchanger in sequential deployment from a spacecraft;

FIGURE 3a illustrates in schematic form a typical pattern of coolant flow through one of the several heat transfer members of the heat exchanger of FIGURE 3;

FIGURE 4 illustrates a still different embodiment of a furlable heat exchanger in a sequential deployment from a spacecraft;

FIGURE 4a depicts in schematic form a typical pattern of coolant flow through one of the several heat transfer members of the heat exchanger of FIGURE 4; and

FIGURES 5, 5a and 5b illustrate a further embodiment of a furlable heat exchanger for use in gravitational environments.

PREFERRED EMBODIMENTS

Referring now with greater particularity to FIGURE 1, there is shown therein a self-contained, interconnected power package 10 comprising a storage tank 11 for the storage of coolant, a pump 12 and a power supply 13 whose excessive heat loads must be dissipated. Surrounding this power package in substantially coplanar form is a hollow, flexible structure comprising a generally toroidal portion 14 and a plurality of radiator arms 15 flexibly, integrally connected to, and radially extending from this toroidal portion outwardly to a length of fifty or more feet. As seen in FIGURES 1 and 1a, each radiator 15 is comprised of two separated channels 15a, 15b connected in serial fashion at their outer and inner ends respectively. Coolant is circulated from storage tank 11 through pump 12 and power supply 13 into channel 15a of one of radiator arms 15 where it flows in serial fashion through the channels of the remaining radiator arms and finally returns to the storage tank in a conventional manner. As this coolant flows through the arms 15, cooling by radiant heat transfer or convection or both (depending on the environmental circumstances) occurs from the surface of the collapsible arms which remain extended by virtue of the pressure of the coolant fluid circulating through these channels. At such time as pump 12 stops, pressure is lowered, and arms 15 will, because of spring wires 19, begin to furl. This in turn will cause

the coolant fluid remaining in the arms to regress into storage tank 11.

An essential concept of this invention is that in those instances where the heat exchanger may have alternate periods of non-use, the radiator arms should furl automatically. In order to provide this feature, the radiator arm material can have embedded therein lengths of spring wire 19 as shown in FIGURE 1a. When no coolant is circulating, the self-coiling feature of wire 19 will furl radiator arms 15 as shown in the drawing. When the device is operative however, and fluid coolant is circulating, the coolant flow pressure will overcome the spring-constant of wires 19 and unfurl radiator arms 15 to their extended form.

It is obvious that any number of coolant circulating schemes can be provided. For example, in the embodiment of FIGURE 2 the outboard ends 20 of alternate arms 21, 22 are connected to an intermediate arm 23 so that the outboard channels receive hot coolant which flows into this intermediate return line and exhausts into the coolant reservoir (not shown). A heat exchanger of this nature then assumes the form of a closed polygonal geometric shape which in the case of FIGURE 2 is hexagonal.

In FIGURES 3 and 4, there is depicted in schematic view other forms of this invention. Referring to FIGURE 3, a furled heat exchanger 30 enclosed with a cover 32 is discharged overboard from cavity storage 31 in space vehicle 29. At a predetermined time thereafter, covers 32 are cast off and the heat exchanger arms 33, integrally and flexibly connected to cylindrical pump housing 34, are unfurled to a fully deployed radial position. As schematically illustrated in FIGURE 3a, each of the arms 33 contains a channel 54, the inner end 54a of which receives coolant discharged from pump 16 carried within housing 34, while the other end of this channel 54b communicates with conventional fluid circuitry within housing 34 for circulating the low temperature coolant into a reservoir and through the power package where its temperature is raised before it is pumped outboard into the arms again for cooling. It is to be understood that housing 34 may contain the power package from which heat is extracted, or alternatively, this power package can remain inboard of the space vehicle and have the coolant fluid connected therefrom to the pump and radiator arms.

Referring to the embodiment shown in FIGURE 4, there is schematically shown another form of heat exchanger 40 being discharged overboard from cavity 41 of space vehicle 39. The heat transfer arms 42 are flexibly connected to one end of cylindrical housing 43 and when fully deployed, extend radially therefrom. Adjacent arms are channeled for coolant circulation as shown in FIGURE 4a. Each of the previously described embodiments illustrate heat exchangers in which a liquid coolant having a high vaporization temperature is employed and which accordingly requires a mechanical pumping mechanism for circulation.

In FIGURES 5 and 5a however, there is illustrated in schematic form an unfurlable heat exchanger in which no mechanical pumping mechanism for circulating coolant fluid is necessary, so long as gravitational influences are present. The device depicted in FIGURE 5 is comprised of a power package 50 surrounded by a fluid reservoir of coolant 51, both contained within a suitable housing 52 from which upwardly extend a plurality of furlable heat transfer arms 53. The arms 53 (sectionally shown in FIGURE 5b) consist of a single channel and are initially furled into a coil. In operation, heat from the power supply causes the liquid coolant to boil and vaporize; the coolant vapor, as it expands, flows into the arms and unfurls them. As this vapor cools, it condenses on the interior walls of the radiator arms as a liquid and flows back into the reservoir where it is heated and enters into this change-of-state cycle again. It is necessary in the design of this form of heat exchanger, however, to assure that the unfurlable arms are inclined upwardly from the coolant

reservoir to permit the condensate to flow into the reservoir under gravitational influence.

The heat exchanger material of the embodiments disclosed is preferably a metallic foil (e.g. aluminum, steel, copper or the like) for readily conducting heat energy from the circulating coolant to the surface of the heat transfer arms. A further characteristic which is intended in the preferred embodiments of these heat transfer arms is that where applicable they be self-coiling, i.e. when there is no coolant pressure or flow, these arms should automatically furl. It may be that the material selected will itself exhibit this "memory" feature; if not, then spring-wire may be embedded into these arms to product such a self-coiling feature.

The coolant fluid may be any liquid or gas suitably appropriate for the environmental use; however, in the embodiment of FIGURE 5 which requires no mechanical circulation, the coolant employed must be a liquid and this liquid must vaporize at some temperature below that of the environment the heat exchanger is in, in order that the heat exchanger operate in its intended mode. The term "liquid" is also intended to embrace metals, so long as they are in a fluid state when used in a coolant capacity.

Generally the major mode of heat transfer of these exchangers will occur as radiation emitted from the arms. However, when used in alien environments, radiant energy from solar sources may at times also be incident on the radiator surfaces and will accordingly be absorbed. The net rate of loss of thermal energy then is the difference between the rate of emission from radiator surfaces, and the rate of absorption from external sources to these surfaces. To some extent it is possible by a proper selection of spectral characteristics to control this net rate of heat loss by controlling the range of wave lengths of energy to be emitted, as opposed to the range of wave lengths which are to be absorbed. In order to employ these parameters to best advantage, this invention contemplates coating the radiator arms with any of a number of inorganic substances to obtain a favorable absorptivity to emissivity ratio. As an example, these coatings may be aluminum phosphate, potassium silicate, or sodium silicate. The coatings recited as examples may be pigmented to yield an optimum absorptivity to emissivity ratio in order to radiate those wave lengths of thermal energy desired to be emitted, while at the same time providing reflectivity for those wave lengths of thermal energy which are not desired to be absorbed.

We have thus disclosed several novel forms of heat exchangers for use in environments alien to earth, and have accordingly achieved our objectives of providing an operative power package and radiator system which can be easily transported through space and yet adapt itself, automatically, by change in size to operate efficiently and effectively. Though we have particularly described our invention in terms of specific radiator orientation with respect to the hub of the power package, we do not desire or intend to be thus limited. It should be obvious, now, in light of our disclosure, that any number of various geometries of flow and radiator orientations can be provided to meet the demands of varying circumstances since these disclosures are merely illustrative of our invention.

While the invention has been described with respect to cooling, it would be obvious to employ the principles in radiation heat absorption applications.

We claim:

1. A heat exchange system comprising: at least one heat exchange arm; means for furling said heat exchange arm; and means for unfurling said heat exchange arm including means for circulating fluid.

2. The structure of claim 1 wherein said means for circulating fluid includes pumping means for pumping fluid into said heat exchange arm whereby the pressure of the circulating fluid causes said heat exchange arm to unfurl.

3. The structure of claim 2 wherein said means for

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furling said heat exchange arm includes a spring arranged therein whereby said heat exchange arm will furl when the pressure of the circulating fluid is lowered.

4. The structure of claim 3 further including a reservoir of heat transfer fluid for accommodating the fluid when said heat exchange arm is in its furled condition.

5. A self-contained power package comprising: a power supply, means for circulating fluid through said power supply, and a furlable heat exchanger including at least one furlable channel which unfurls upon application of circulating fluid thereto.

6. The structure of claim 5 wherein said furlable heat exchanger further includes a reservoir of heat transfer fluid in communication with said furlable channel for accommodating the heat transfer fluid when said channel is in its furled condition.

7. The structure of claim 6 wherein said furlable heat exchanger includes means for circulating the heat transfer fluid through said channel in its unfurled condition.

8. A heat exchange system comprising: at least one furlable radiator arm and a cooling fluid whereby when said cooling fluid boils the vapor expands causing said radiator arm to unfurl.

9. The structure of claim 8 and further including a fluid reservoir wherein said radiator arm is inclined up-

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wardly so that said vapor upon cooling condenses and flows out of said arm into said reservoir.

10. The structure of claim 8 wherein said radiator arm is biased to a furled condition.

11. A self-contained power package comprising: a power supply, a coolant fluid in communication with said power supply, and at least one furlable radiator arm biased in a furled condition, such that when said coolant boils the vapor will expand and cause said radiator arm to unfurl.

12. The structure of claim 1 wherein at least one surface of said heat exchange arm is coated to achieve maximum net radiative heat absorption or dissipation.

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165—47, 86; 244—1