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WASHINGTON, D.C. 20546

REPLY TO
ATTN OF: GP

November 6, 1970

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U. S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code USI, the attached NASA-owned U. S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U. S. Patent No. : 3,502,141

Government or Corporate Employee : U.S. Government

Supplementary Corporate Source (if applicable) : NA

NASA Patent Case No. : XMS-04268

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:
Yes ☐ No ☒

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of Column No. 1 of the Specification, following the words ". . . with respect to an invention of . . ."

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Enclosure
Copy of Patent cited above

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METHOD OF IMPROVING HEAT TRANSFER CHARACTERISTICS IN A NUCLEATE BOILING PROCESS

Filed Dec. 23, 1965 2 Sheets-Sheet 1

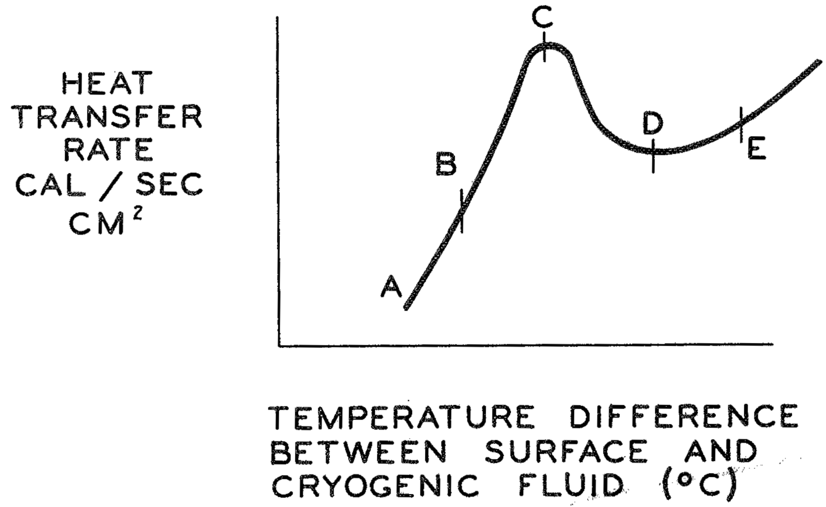
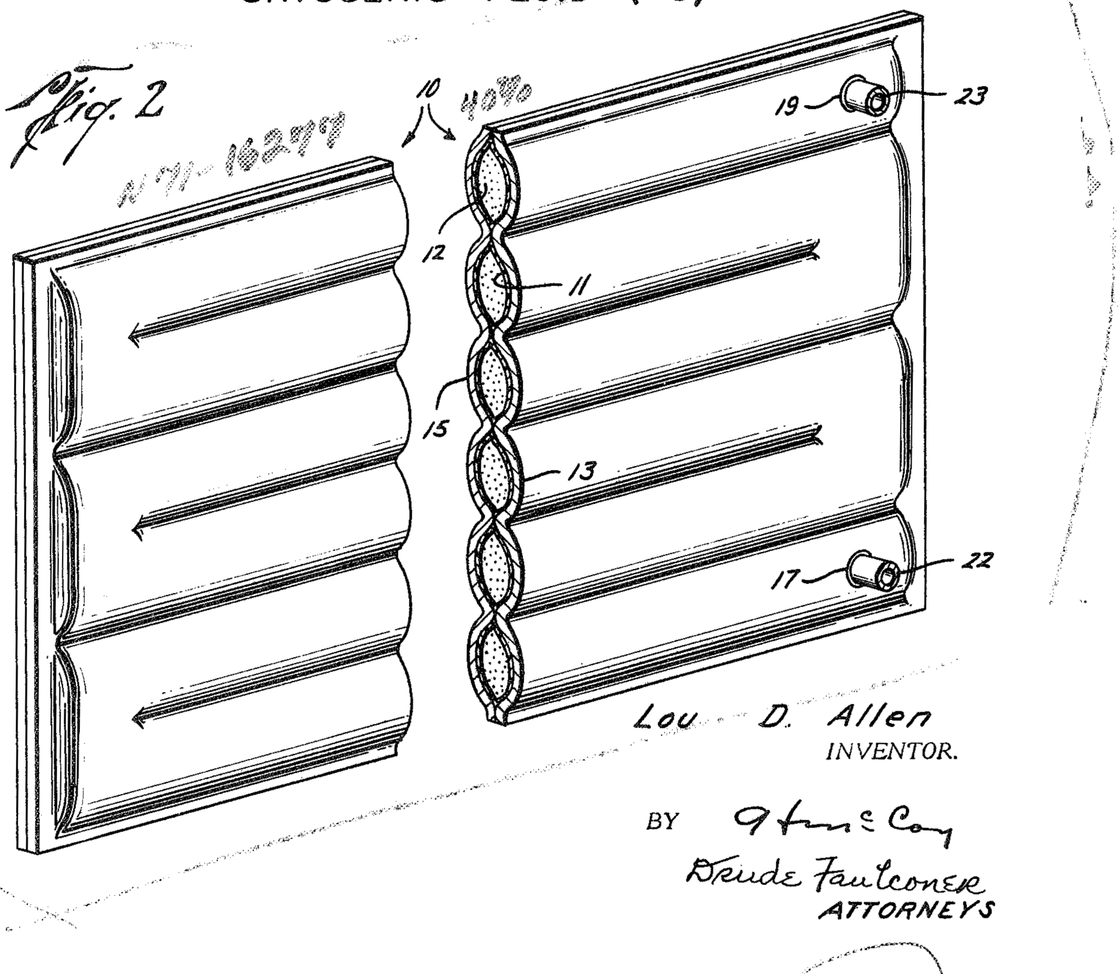


Fig. 1

Fig. 2



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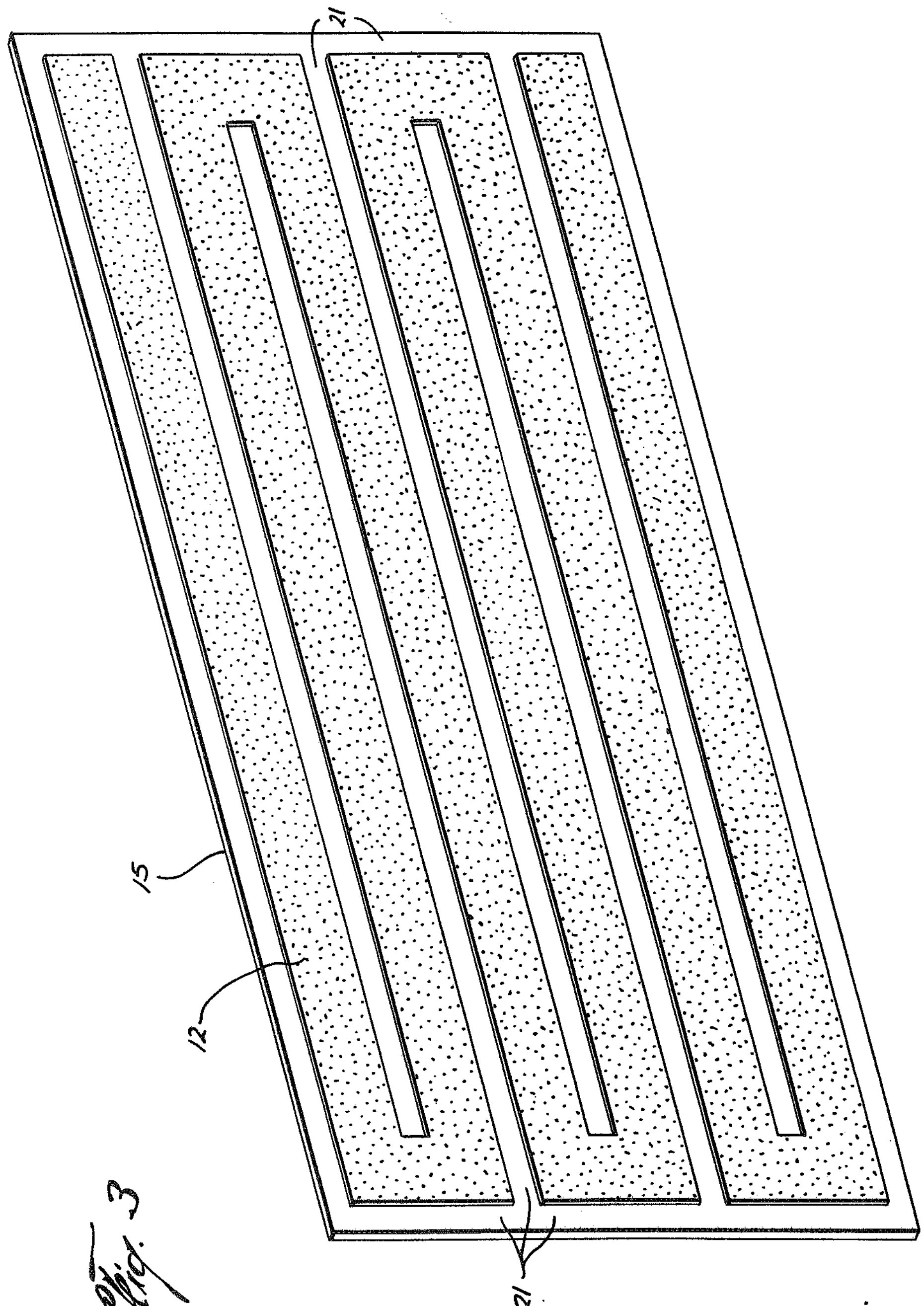

Fig. 3

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United States Patent Office 3,502,141
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3,502,141

METHOD OF IMPROVING HEAT TRANSFER CHARACTERISTICS IN A NUCLEATE BOILING PROCESS

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Int. Cl. F28f *13/18, 19/02*
U.S. Cl. 165—133 5 Claims

ABSTRACT OF THE DISCLOSURE

A method of reducing the cooldown time and enhancing the steady heat transfer characteristics of a circulating cryogenic cooling system comprising coating the surfaces, within the system, exposed to the cryogenic cooling liquid with high molecular-weight, plastic-resin material having a thickness in the range of .001 to .004 inch and roughening the exposed surface of the plastic-resin material to establish a random pattern of pits and indentations. A cryopanel so processed is also disclosed.

The invention herein described may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This invention relates to a method for substantially reducing the cooldown time of an object cooled by a nucleate boiling process, and more particularly relates to a method and means for reducing the cooldown time of a circulating cryogenic cooling system, and for enhancing the steady-state heat transfer thereto once it has reached its operating temperature.

In order to predict accurately how a new piece of equipment or material will perform in space, it is first subjected to a series of ground tests which simulate those conditions normally expected to be encountered in space flight. One such test involves subjecting the new article to extremely low temperatures. This is done by placing the article in a simulation chamber which utilizes a cryogenic cooling system to reproduce the desired temperature. Common cryogenic systems of this type consist basically of several metallic panels (commonly called cryopanels) which have passageways therein through which a cryogenic substance such as liquid nitrogen is circulated. In the large cyropanels a tremendous amount of heat must be transferred in order to cool these panels to the desired low temperatures, and accordingly the cooldown time for these panels is considerable (running into several hours). This "dead" time is undesirable, not only from the lost time aspect, but also in terms of the expense involved.

The present invention provides a means which not only substantially reduces this cooldown time, but one which also greatly enhances the steady-state heat transfer to the panel once the desired temperature is reached. This substantial increase in overall efficiency is accomplished by first coating the internal surfaces of the passageways in the panels with a minute layer of a permanent insulative-like material and then roughening the exposed surfaces of the insulative material to establish a random pattern of pits or indentations therein for a purpose that will be more fully explained below. This insulative material must be one that can be bonded or otherwise permanently secured to the panel, and must exhibit thermal properties which allow the metal substrate to expand and contract without affecting the bond between the insulative material and the substrate. One group of insulative materials which possess the desired characteristics

are high molecular-weight, plastic-resin materials such as polymerized halogenated ethylenes. To further explain the actual results and the surmised theory as to why these results occur, it is helpful to refer to the drawings in which:

FIG. 1 is a representative curve showing the rate of heat transfer from a warm body to a cryogenic liquid as a function of the temperature difference between the surface of the body and the liquid;

FIG. 2 is a perspective view, partly in section, of a cryopanel made in accordance with the present invention; and

FIG. 3 is a perspective view of one-half of the cryopanel of FIG. 2 before final assembly.

Since the present invention relates to the complex field of nucleate boiling, it is considered that a brief description of the phenomena associated with this type boiling will be helpful in both the explanation and the understanding of the more detailed description of the present invention set forth below. When a warm body is placed in contact with a much colder fluid (such as a cryogenic liquid), heat is transferred from the body to the liquid by a series of different heat-transfer mechanisms. The rate of heat transfer that normally occurs during this cooling process has been plotted against the temperature difference between the body and the liquid, and is shown by the curve in FIG. 1. The portion of the curve lying to the right of point E depicts the high rate of heat transfer which occurs during the early stages of cooldown, and is believed to result from the force convection heat transfer between the body and the liquid.

After a short time, this high rate of heat transfer decreases to a relatively low rate. This low rate region occurs between points D and E on the curve of FIG. 1, and is commonly called the stable vapor, or film boiling region. It is so called because it is thought that during this phase the warm body becomes essentially encased by a relatively quiescent and slowly moving film which has a very low thermal conductivity, and since the heat transfer from the body to the liquid must take place across the film, the rate of heat transfer is accordingly low.

As the cooling process continues, the vapor film becomes unstable. It is believed that the instability of the film in this region is caused by the vapor film being constantly dissipated and reformed at a rapid rate. This unstable region is shown by that portion of the curve which lies between points D and C, and is referred to as the region of unstable or partial film boiling. During the partial film boiling phase the rate of heat transfer steadily increases until point C on the curve is reached where the maximum rate of heat transfer occurs. This point is called the "critical ΔT," or the point at which nucleate boiling commences. Nucleate boiling continues until the body is substantially the same temperature as the cryogenic liquid. This phase of the cooling process takes place between points C and B on the curve, and is termed the nucleate boiling region. Final cooling of the body occurs between points B and A, and is due to natural convection.

From the above brief description of the phenomena associated with the nucleate boiling process, it can be seen that it would be desirable to broaden the critical ΔT region where maximum heat transfer exists, so that higher heat transfer rates could be maintained over longer periods of time. From previous experiments in this field it has been determined that this region can be broadened by applying a thin coating of insulative-like material to the surface of a warm object to be cooled before it is submerged into the cooling liquid. Although the theory involved is not certain, it appears that the thin coating changes the surface-liquid interface conditions so that the time required to reach the nucleate boiling point or critical ΔT is shortened. This, in effect, enlarges the critical ΔT region on either side of point C in FIG. 1. The insulating effect that the thin coating has on the heat transfer is far outweighed by the positive effect it has in inducing nucleate boiling at an earlier stage in the cooldown cycle. This is true, however, only if the thickness of the coating material is kept in a defined range, as will be more fully discussed below.

In early experiments a variety of materials such as petroleum jelly, asbestos, and clear varnish were attached or coated onto solid metallic cylinders. These cylinders were then submerged in liquid nitrogen, and the cooldown times for the cylinders were recorded. In each case the cooldown time was less than the cooldown time of an uncoated cylinder. However, upon further observation it was found that these coatings had a tendency to break up, melt, or the like, whenever the cylinders were raised back to room temperature. Also, as briefly mentioned above, the thickness of the coating material must be maintained in a narrow range in order to produce the desired results. This is due to the fact that if the layer is too thin no noticeable changes occur in the cooling process, and if it is too thick the actual insulating effect of the layer offsets any other advantages gained thereby.

The desired thicknesses of the above mentioned materials are very difficult, if not impossible, to maintain when the coated body is subjected to repeated cooling cycles. Still further, severe problems exist in properly bonding or securing the desired thicknesses of these temporary coatings to the metal surfaces in such a way that they will not erode or chip away during repeated cooldown cycles. The latter is especially true where the surface to be coated is an internal surface of a passageway through which the cooling liquid is circulated. All of these previously tested materials, if applied to internal passageways, would undoubtedly flake, erode, or the like, into the stream of cooling liquid, and thereby not only severely damage delicate circulating pumps, but also render the passageways unsuitable for repeated use. All of these factors make such materials totally unsuitable for practical applications in known cryogenic cooling systems.

The present invention allows the highly desirable cooldown properties of a thin coating of insulative-like material to be utilized in a circulating cryogenic cooling system, and at the same time overcomes all of the above mentioned problems. In the present invention, a minute layer of a high molecular-weight plastic-resin material such as a polymerized halogenated ethylene, e.g., polytetrafluoroethylene (commonly known as Teflon), is permanently bonded to the surface of the warm body to be cooled and is roughened by sandblasting, or the like, for a purpose explained below. From experimentation, it has been determined that the thickness of such plastic-resins should be maintained in the range of 0.001 to 0.004 inch. This roughened layer of insulative-like material not only provides a means for substantially reducing the cooldown time of the body, but also is one which is not adversely affected by repeated cooldown cycles. Also, this layer of insulative-like material substantially enhances the steady-state heat transfer of the body after it has been cooled to the desired temperature, as will be shown below.

In the initial tests first utilizing a permanent, insulative-like material, a small, uncoated stainless steel plate was immersed in a Dewar of liquid nitrogen to determine the time required for the plate to cool to the temperature of the liquid nitrogen. The uncoated plate was cooled in approximately 21 seconds. After a 1.5 mil coating of polytetrafluoroethylene was bonded to the plate, the cooling time was reduced to 15.6 seconds (a 26% reduction). Although this amounted to a substantial reduction in cooldown time, it was recognized that these results had been obtained under ideal conditions (i.e., all of the small area of the plate was exposed to the cryogenic liquid at

the same time). Since these conditions could not be duplicated in a practical cooling system, it was reasoned that the reduction of cooldown time in such an actual system would be substantially less than the 26% reduction obtained above, and could be as low as 5%, which would hardly justify coating the cooling system. Upon further study it was theorized that the surface of the polytetrafluoroethylene was of such smooth texture that only a minimum of nucleate boiling sites (those sites—indentations, pits, etc., at which nucleate boiling takes place) were provided thereon. To test this theory, a number of holes were punched in the polytetrafluoroethylene layer, and the plate was again immersed in the liquid nitrogen. The plate cooled down in 13 seconds. Encouraged by these results, the number of nucleate boiling sites on the layer of polytetrafluoroethylene was further increased by sandblasting the layer in a random pattern. The plate then cooled down in 4.5 seconds, giving a truly remarkable reduction in cooldown time of 79%, indicating that the above procedure could be used with great advantage in an actual cooling system.

A cryopanel which illustrates the practical aspects of the present invention is shown in FIG. 2. The panel **10** is constructed as follows. A thin insulative layer **11**, **12** of polytetrafluoroethylene (ranging from 0.001 to 0.004 inch, preferably from 0.0015 to 0.002 inch), cut in the pattern shown in FIG. 3, is first bonded to each of two 20-gauge steel sheets **13**, **15**, respectively. This can be done with a platen press-bonding technique well known in the bonding art. Next, the insulative layer **11**, **12** on each sheet is roughened by sandblasting, or the like, to establish a random pattern of pits or indentations some of which perforate the layer and exposed the steel sheet. These pits serve as nucleate boiling sites during the cooldown process, as explained above. Inlet opening **17** and outlet opening **19** are then cut through both sheet **13** and the layer **11** thereon. Sheet **15** is next positioned on sheet **13** so that the uncovered area **21** on sheet **15** identically coincides with the uncovered area on sheet **13** (unshown) The two sheets are then joined by an electronic beam weld along their uncovered areas. Inlet tubing **22** is attached to opening **17** and compressed gas is injected under high pressure from a source (not shown). This high pressure gas will permanently deform the sheets along the unwelded, insulative covered areas to form a continuous S-shaped passageway such as shown in FIG. 2. Outlet tubing **23** is then connected to opening **19** so that fluid passing through panel **10** can be recirculated.

To demonstrate the davantages of a cryopanel made in accordance with the present invention over an uncoated cryopanel, both cooldown and steady-state heat transfer tests were conducted. The two cryopanels used in these tests were geometrically identical. The internal flow passages of one cryopanel were coated with a 2 mil thick layer of polytetrafluoroethylene and roughened in the manner described above, while the flow passages of the other cryopanel were uncoated. Both cryopanels were constructed of 20-gauge stainless steel, and were painted with a high emissivity paint. Each was 18 inches long, 12¼ inches wide, and weighted 5.5 pounds. Several thermocouples were attached at identical locations on each of the two panels. The panels were then mounted parallel to each other and were thermally insulated from the mountings. A bank of quartz tube lamps was positioned midway between the panels to provide a heat flux for the steady-state heat transfer studies. The thermocouple outputs were relayed through a 150° F. reference junction oven and into a data system where the data could be recorded in digital form. The entire test setup was placed in a vacuum chamber to eliminate heat transfer by convection.

Liquid nitrogen was admitted to each of the panels at the same time, and the temperature at each thermocouple was constantly recorded until a temperature of −280° F. was reached. This is the temperature at which most space simulation chambers are designed to operate. A comparison of the data showed that the cryopanel made in accordance with the present invention had an average cooldown time of 24% less than that of the uncoated panel—a significant reduction in cooldown time. Also, it should be recognized that the reduction in cooldown time could further be improved by more extensive engineering of the cryopanels, e.g., manifolding the cryogenic liquid so that it is admitted to the cryopanel at a multiplicity of points.

To determine the effect of coated cryopanel on steady state heat transfer, the bank of quartz tube lamps was actuated and an equal heat load of 5810 watts was imposed on each of the two cryopanels after they had reached the cooldown temperature of −280° F. The average temperature of the uncoated panel during the period that the heat was applied was −188.5° F., while the average temperature of the coated panel was −248° F. These results indicate that the coated cryopanel is able to maintain a temperature of 59.5° F. less than the uncoated cryopanel under identical conditions.

To further compare the overall steady-state heat transfer of the coated and uncoated panels, the following equations are given:

$$q_c = U_c A_c (\Delta\theta)_c \quad (1)$$

$$q_u = U_u A_u (\Delta\theta)_u \quad (2)$$

where

q_c is the heat load on the Teflon coated cryopanel,
q_u is the heat load on the uncoated cryopanel,
U_c is the overall heat transfer coefficient for the coated panel,
U_u is the overall heat transfer coefficient for the uncoated panel,
$(\Delta\theta)_c$ is the difference between the coated cryopanel skin temperature and the liquid nitrogen temperature,
$(\Delta\theta)_u$ is the difference between the uncoated cryopanel skin temperature and the liquid nitrogen temperature,
A_c is the coated cryopanel area,
A_u is the uncoated cryopanel area.

Experimentally, q_c was made equal to q_u so that

$$U_c A_c \ (\Delta\theta)_c = U_u A_u \ (\Delta\theta)_u$$

and since $A_c = A_u$

$$U_c \ (\Delta\theta)_c = U_u \ (\Delta\theta)_u$$

which results in

$$U_c = \frac{(\Delta\theta)_u}{(\Delta\theta)_c} U_u \quad (3)$$

Equation 3 shows the steady-state relationship which interrelates the overall heat transfer coefficients of the coated and uncoated cryopanels.

By using the data obtained in the above mentioned test with the known temperature of liquid nitrogen (−320° F.), $(\Delta\theta)_u = 131.5°$ F. and $(\Delta\theta)_c = 72°$ F. so that using Equation 3

$$U_c = \frac{131.5° \text{ F.}}{72° \text{ F.}} U_u$$

$$U_c = 1.83 U_u$$

showing that under identical conditions for the panels tested, a coated panel in accordance with the present invention can transfer almost twice as much heat as an uncoated cryopanel of the same size.

Although the invention has been illustrated in conjunction with a space simulation cryopanel, it should be realized that it can be utilized in other environments such as other nucleate boiling cooling systems, cryogenic transfer lines, or the like, and that the invention as set forth is intended to cover all changes and modifications which do not constitute a departure from the spirit and scope of the invention.

What is claimed and desired to be secured by Letters Patent is:

1. In a nucleate boiling process for cooling an object with a liquid, the method of reducing the cooldown time of said object comprising:
   - coating those surfaces of said object which are to be exposed to said liquid with a layer of high molecular-weight, plastic-resin material having a thickness in the range of 0.001 to 0.004 inch.; and
   - sandblasting the exposed surfaces of the plastic-resin layer to establish a random pattern of perforations forming nucleate boiling sites.

2. The method of claim 1 wherein said high molecular-weight, plastic-resin material is a polymerized halogenated ethylene.

3. The method of claim 2 wherein said polymerized halogenated ethylene is polytetrafluoroethylene.

4. In a circulating, cryogenic cooling system, a cryopanel comprising:
   - a metallic panel having an internal passageway therethrough for circulation of a cryogenic liquid;
   - a layer of a high molecular-weight, plastic-resin material having a thickness in the range of 0.001 to 0.004 inch bonded to the surfaces of said internal passageway, said layer having a random pattern of perforations forming nucleate boiling sites; and
   - inlet and outlet means in said panel communicating with the respective ends of said passageway in said panel whereby cryogenic liquid admitted through said inlet will pass through said passageway and out said outlet means.

5. A cryopanel in accordance with claim 4 wherein said high molecular-weight plastic-resin material is a polymerized halogenated ethylene.

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U.S. Cl. X.R.

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