RELIEVED-CHANNEL, BONDED HEAT EXCHANGER

Inventors:  J. Clair Batty, North Logan, UT (US); Scott M. Jensen, Logan, UT (US)

Correspondence Address:
Utah State University
Pate Pierce & Baird
570 Research Park Way, Suite 101
North Logan, UT 84341 (US)

Appl. No.: 12/417,552
Filed: Apr. 2, 2009

Related U.S. Application Data
Continuation-in-part of application No. 11/743,555, filed on May 2, 2007.
Provisional application No. 61/042,205, filed on Apr. 3, 2008, provisional application No. 60/861,583, filed on Nov. 29, 2006, provisional application No. 60/836,901, filed on Aug. 9, 2006.

Publication Classification
Int. Cl.
F28D 15/04 (2006.01)
F28D 9/00 (2006.01)

U.S. Cl. 165/104.26; 165/157

ABSTRACT
A panel assembly for exchanging heat with an ambient environment maintains minimal temperature differential by virtue of operation as a heat pipe apparatus. Panels of a composite material having excellent structural strength and structural stiffness but comparatively modest thermal conductivity are machined as mirror images of one another. Two orthogonal arrays of parallel channels are machined in the faces of two panels, each intersection of channels forming and bounded by pedestals having a lower, broader base with a narrower upper portion extending from a shoulder of the base portion of the pedestals. The pedestals, in turn, form the bounds of the channels, each having a deeper and a narrower aspect extending along the bases of all the pedestals. Channels have a broader aspect extending along near the tops of the pedestals.
SECTION B-B

FIG. 10
SECTION C-C

FIG. 11
DETAIL B

FIG. 15
RELIEVED-CHANNEL, BONDED HEAT EXCHANGER

RELATED APPLICATIONS

[0001] This application claims the benefit of co-pending U.S. Provisional Patent Application Ser. No. 61/042,205, filed on Apr. 3, 2008 and incorporated herein by reference. This application is also a continuation-in-part of co-pending U.S. patent application Ser. No. 11/743,555, filed on May 2, 2007, also incorporated herein by reference, which claims the benefit of U.S. Provisional Patent Application Ser. No. 60/861,583 filed Nov. 29, 2006 and the benefit of U.S. Provisional Patent Application Ser. No. 60/836,901 filed Aug. 9, 2006.

BACKGROUND

[0002] 1. The Field of the Invention

[0003] This invention relates to heat transfer and, more particularly, to novel systems and methods for two-phase heat and mass transport.

[0004] 2. The Background Art

[0005] Heat transfer is fundamental to many processes. Engines releasing energy from fuel must routinely reject heat. Meanwhile, electronic and electrical devices that consume electricity likewise require cooling. One particularly demanding environment occurs with spacecraft. Spacecraft contain many electronic instruments. Weight is at a premium, as is space. Meanwhile, the loads required of any structure during launch may be substantial. Thus, the combination of light weight and high strength is difficult to achieve.

[0006] In heat exchange, metals have comparatively high thermal conductivities. By contrast, composite materials such as bonded composites, fiber-reinforced layers, and the like typically have comparatively poor thermal conductivity.

[0007] What is needed is an apparatus and method for heat exchange from a satellite to the surrounding space environment. It would be an advance in the art to provide heat exchangers having comparatively light weight, high structural strength, high structural rigidity and stiffness, and yet having comparatively superior heat transfer capacity.

BRIEF SUMMARY OF THE INVENTION

[0008] In accordance with the foregoing, an apparatus and method in accordance with the invention may rely on a composite panel formed of fibers in a resin or other matrix. Fibers may be glass, carbon, or other suitable material. Likewise, resins surrounding the fibers may be selected from various hydrocarbons, carbon, and the like.

[0009] In certain embodiments of an apparatus in accordance with the invention, panels may be formed of structurally stiff, structurally strong composite materials. Panels may be machined to excavate channels within the panel. Channels may run at right angles to one another forming residual pedestals between channel intersections. Moreover, channels may be machined at distinct widths and depths. For example, a first, deep channel may be machined at a comparatively narrower width. Thereafter, a comparatively shallower and wider channel may be excavated along the path of the first channel. Thus, a channel may have two depths, each having a corresponding width. For example, the deeper portion of a channel may have a narrower width while the shallower portion of a channel may be relieved, e.g. have a wider width.

[0010] In such a channel, liquids may transport along the narrower portions of channels, requiring less volume for passage. Meanwhile, vapors may more readily pass in the larger (wider) channel portion where a greater volume is required according to the laws of fluid mechanics and boundary layer theory.

[0011] In a method and apparatus in accordance with the invention, two panels may be formed to constitute mirror images of one another. Accordingly, the tops of the pedestals thereof may be layered with a suitable bonding material compatible with the material of the panels as well as with the working fluid that will be used as a heat and mass transport medium therein. The individual pedestals of a pair of panels may then be placed in intimate contact with one another, such that the bonding layer on the top of each pedestal bonds each of the two respective panels together at substantially each and every pedestal.

[0012] In one embodiment of an apparatus and method in accordance with the invention, a panel assembly for exchanging heat with an ambient environment maintains minimal temperature differential by virtue of operation as a heat pipe apparatus. Panels of a composite material having excellent structural strength and structural stiffness but comparatively modest thermal conductivity are machined as mirror images of one another. Two orthogonal arrays of parallel channels are machined in the faces of two panels, each intersection of channels forming and bounded by pedestals having a lower, broader base with a narrower upper portion extending from a shoulder of the base portion of the pedestals. The pedestals, in turn, form the bounds of the channels, each having a deeper narrower aspect extending along the bases of all the pedestals. Channels have a broader aspect extending along near the tops of the pedestals. The tops of the pedestals may be treated with a bonding material and bonded together as panels are placed together as mirror images of one another to make contact at each pedestal. An extremely strong, rigid structure results, capable of surviving launch loads, while still providing excellent heat pipe characteristics. Transport of liquids occurs through the bottoms of narrower portions of channels while vapor returns by way of the broader portions of channels available near the tops of all the pedestals.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The foregoing features of the present invention will become more fully apparent from the following description and appended claims, taken in conjunction with the accompanying drawings. Understanding that these drawings depict only typical embodiments of the invention and are, therefore, not to be considered limiting of its scope, the invention will be described with additional specificity and detail through use of the accompanying drawings in which:

[0014] FIG. 1 is a perspective view of one embodiment of a closed "panel assembly" or heat exchanger formed of two individual panels (e.g., substrates) machined with channels and pedestals for fluid transport therewith;

[0015] FIG. 2 is a perspective view of the apparatus of FIG. 1 illustrating the two mirror-imaged panel units or elements facing one another but separated in an exploded configuration;

[0016] FIG. 3 is a cutaway, perspective view of one embodiment of a single panel element having channels of single depth and single width;

[0017] FIG. 4 is a perspective view of a portion of a panel unit or element of FIGS. 1-2 illustrating pedestals and chan-
nels of distinct upper and lower dimensions, having two distinct widths for channels and two distinct heights for channels and pedestals;

Fig. 5 is a perspective view of the apparatus of Fig. 4, shaded for easier visualization;

Fig. 6 is a top plan view of a single, open, panel unit or element for the apparatus of Figs. 1-2;

Fig. 7 is a side view of the apparatus of Fig. 6;

Fig. 8 is an end view of the apparatus of Fig. 6;

Fig. 9 is a plan view of detail A as designated in Fig. 6;

Fig. 10 is an end, cross-sectional view of section B-B as identified in Fig. 9;

Fig. 11 is an edge, cross-sectional view of section C-C as identified in Fig. 9;

Fig. 12 is a plan view of detail D from the apparatus of Fig. 6;

Fig. 13 is a cutaway top plan view of a lower half of a panel unit or element of a panel assembly in accordance with the invention of an apparatus in accordance with the invention, having interrupted, individual arrays of pedestals;

Fig. 14 is a cross-sectional, end view of section A-A of the closed panel assembly from Fig. 13;

Fig. 15 is an end, cross-sectional view of detail B of the closed panel assembly from Fig. 14;

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

It will be readily understood that the components of the present invention, as generally described and illustrated in the drawings herein, could be arranged and designed in a wide variety of different configurations. Thus, the following more detailed description of the embodiments of the system and method of the present invention, as represented in the drawings, is not intended to limit the scope of the invention, as claimed, but is merely representative of various embodiments of the invention. The illustrated embodiments of the invention will be best understood by reference to the drawings, wherein like parts are designated by like numerals throughout.

Referring to Fig. 1, and to Figs. 1-5 generally, a system 10 in accordance with the invention may include panels 12, such as the illustrated panels 12a, 12b bonded to one another to form a closed panel assembly 10 having enclosed channels 14 therewith. In certain embodiments, a pair of panels 12 may be formed and subsequently bonded together to form a single apparatus 10. Apertures 13 formed in the apparatus 10 may provide an ability to mount the apparatus 10 to a rack, frame, bracket, or the like for implementation in a particular assembly, such as a spacecraft. The apparatus 10 may be embodied in various sizes. For example, in certain embodiments, the apparatus 10 may extend several feet on an edge. By contrast, in other embodiments, the apparatus 10 may extend mere inches on an edge in order to accomplish a specific purpose.

Referring to Fig. 2, the panels 12a, 12b may each be formed to have an array 15 of pedestals 16. As illustrated in detail in Figs. 4-5, the pedestals 16 may be arranged in an array 15 extending throughout an interior portion of a panel 12. Each of the panels 12a, 12b in the illustrated embodiment represents a substantial mirror image of the other. Accordingly, by application of a bond or bonding material to the top of each pedestal 16 in the array 15, mutual, corresponding arrays 15 in each of the panels 12a, 12b may be bonded together at multiple points.

A working fluid operating in two phases in the array 15 may be contained in a comparatively small volume between the pedestals 16, without ballooning or breaking the individual panels 12a, 12b. Large expanses of area exposed to comparatively modest pressures may generate extremely large total forces. Accordingly, maximum stresses at the edges of an apparatus 10 lacking bonding between the pedestals 16 would fail at substantially lower pressures than the apparatus 10. In the illustrated embodiment, bonding of each of the pedestals 16 to a corresponding pedestal of an opposite panel 12, provides for well distributed stress in order to reduce stress in the material of the panels 12.

Referring to Fig. 3, a panel 12, in general may be configured in several ways. U.S. patent application Ser. No. 11/743,555 is incorporated herein by reference and details many operational characteristics of panels 12 assembled as various embodiments of an apparatus 10.

In general, a panel 12 may be molded, cast, stamped, machined, or otherwise formed to have an array of channels 14 extending in various directions. In the illustrated embodiment, channels 14a, 14b are oriented orthogonally with respect to one another. Typically, the channels 14 may each be of substantially the same dimensions. For example, widths, depths, and the like may be uniform throughout substantially all channels 14. This is not a necessity, but may be a practical benefit for manufacturing, operation, temperature uniformity, and the like.

Meanwhile, the excavation or other formation of each of the channels 14 results in the remaining material forming a pedestal 16. Each of the pedestals 16 thus has outer walls 18 bounding the channels 14. Likewise a floor 20 of each channel 14 is the closest surface to the outermost (e.g., environmentally exposed) surface of each panel 12. Accordingly, channels 14 may be formed to create an extremely small distance, selected to be a suitably engineered thickness between an outer surface of the panel 12, and the floor 20 of the channels 14 interior thereto. Thus, the heat transfer distance through which energy must be conducted may be minimized according to suitable engineering parameters.

Referring to Figs. 4-5, pedestals 16 may have upper walls 18a, 18b or upper surfaces 18a, 18b extending along a comparatively narrower portion thereof. Similarly, lower walls 18c, 18d or lower surfaces 18c, 18d bound the larger portions of each pedestal 16. Corresponding channels 14a, 14b are comparatively wider and pass by the upper portions of the pedestals 16. Similarly, lower, comparatively narrower portions of the channels 14c, 14d pass along the bottom portions of the pedestals 16.

By providing substantially increased space or volume near the upper portions of each of the pedestals 16, substantially increased vapor transport may occur throughout the array 15 of pedestals 16, with less obstruction. By the same token, the thickness of the material of the panel 12 between the floor 20 of any individual channel 14, and the opposing outside surface of the panel 12 corresponding thereto may be minimized.

In certain embodiments, it is contemplated that the thickness of the panel between the floor 20 of a channel 14, and the outside surface of the panel 12 may be on the order of tens of thousandths of an inch in certain embodiments. Thus, although the thermal conductivity of the composite material forming a particular panel 12 may be comparatively less than the thermal conductivity of most metals suitable for heat
transfer, the overall thickness is sufficiently small to render the net thermal resistance tractable for suitable heat transfer. In general, the shoulder 24 of a pedestal may be flat, inclined, or otherwise shaped as suitable to promote heat transfer. In certain embodiments, a filleted shape for the shoulder 24 may be appropriate. Likewise, a trapezoidal or inclined surface may serve well. In one embodiment, the shoulder 24 simply represents a flat surface parallel to the top 20 of the pedestal 16.

Defining a longitudinal direction 26, a lateral direction 28, and a transverse direction 30, all mutually orthogonal to one another, one may describe the directions of fluid flow and heat transfer. For example, heat transfer is ultimately to be effected in a transverse direction 30 into and out of panel 12 at selected locations.

For example, in a spacecraft application, heat may be transferred by radiation into the blackness of space from an outer surface of a panel 12. Meanwhile, heat may be transported by convection inside the channels 14 by a heat pipe activity. For example, capillary forces (e.g., surface tension forces) may maintain a flow of liquid along the lower, narrower portions of the channels 14 near the floor 20 of each. Meanwhile, in a generally opposite direction, heat and vapors may return back through the upper portions of the channels 14, such as the paths 14a, 14b illustrated in FIGS. 4-5.

As a practical matter, no overt enforcement of such flow division is needed. Typically, liquids will be pushed out of the free stream of vapor flows, thus relegating liquids to the smaller spaces and paths 14c, 14d by the vapor as a consequence of boundary layer effects. Accordingly, vapor will typically dominate the central flows through the paths 14a, 14b illustrated.

As a practical matter, the apparatus 10 may be formed of any of several materials, including or excluding metal. Bonding may be done by any suitable method, including spot welding, adhesive bonding, or the like. Likewise, a composite material comprised of a fiber reinforcement in a resin matrix may be bonded by a separate adhesive, or simply by a solvent. For example, in FIG. 4, a surface 38 of a layer 40 of an adhesive, resin, or other bonding material 40 may contact a corresponding surface 38 on a pedestal 16 opposite the one illustrated. That corresponding pedestal 16 extends from a corresponding panel 12 placed opposite the panel 12 illustrated in FIG. 4 (see e.g., FIG. 2). Thus, the layer 40 of a bonding agent may be selected to be compatible with the panel materials and the operating fluid operating within the channels 14, in order to provide suitable life for the apparatus 10.

In an alternative embodiment, the layer 40 may be replaced with a layer 40 of solvent softening a portion of the top 22 of a pedestal 16. Accordingly, the pedestals 16 may be placed in a pressurized contact with one another until the solvent has dissipated, leaving the tops 22 of the pedestals 16 bonded to one another.

In certain embodiments, the pedestals 16 may be formed by machining out the channels 14 in a substrate forming the panel 12. In such an embodiment, the substrate may be formed of a suitable metal, a composite material as described hereinabove, or the like. Likewise, in certain embodiments, a non-reinforced panel 12 may be cast, stamped, molded, or the like in order to form the pedestals 16 and channels 14. For example, a comparatively thin layer of a polymeric material, or a reinforced polymeric material may be stamped to form pedestals 16 that are effectively hallow along the outer surface thereof. Such pedestals, may still be bonded together by solvents or a layer 40 of suitable adhesive connecting the tops 22 of opposing pedestals on corresponding panels 12a, 12b in an apparatus 10.

Defining a functional flow direction 30, a functional lateral direction 32, and a functional transverse direction 34, all mutually orthogonal to one another, one may describe the directions of fluid flow and heat transfer. For example, the heat transfer is ultimately to be effected in a transverse direction 30 into and out of panel 12 at selected locations.

For example, in a spacecraft application, heat may be transferred by radiation into the blackness of space from an outer surface of a panel 12. Meanwhile, heat may be transported by convection inside the channels 14 by a heat pipe activity. For example, capillary forces (e.g., surface tension forces) may maintain a flow of liquid along the lower, narrower portions of the channels 14 near the floor 20 of each. Meanwhile, in a generally opposite direction, heat and vapors may return back through the upper portions of the channels 14, such as the paths 14a, 14b illustrated in FIGS. 4-5.

As a practical matter, no overt enforcement of such flow division is needed. Typically, liquids will be pushed out of the free stream of vapor flows, thus relegating liquids to the smaller spaces and paths 14c, 14d by the vapor as a consequence of boundary layer effects. Accordingly, vapor will typically dominate the central flows through the paths 14a, 14b illustrated.

As a practical matter, the apparatus 10 may be formed of any of several materials, including or excluding metal. Bonding may be done by any suitable method, including spot welding, adhesive bonding, or the like. Likewise, a composite material comprised of a fiber reinforcement in a resin matrix may be bonded by a separate adhesive, or simply by a solvent. For example, in FIG. 4, a surface 38 of a layer 40 of an adhesive, resin, or other bonding material 40 may contact a corresponding surface 38 on a pedestal 16 opposite the one illustrated. That corresponding pedestal 16 extends from a corresponding panel 12 placed opposite the panel 12 illustrated in FIG. 4 (see e.g., FIG. 2). Thus, the layer 40 of a bonding agent may be selected to be compatible with the panel materials and the operating fluid operating within the channels 14, in order to provide suitable life for the apparatus 10.

In an alternative embodiment, the layer 40 may be replaced with a layer 40 of solvent softening a portion of the top 22 of a pedestal 16. Accordingly, the pedestals 16 may be placed in a pressurized contact with one another until the solvent has dissipated, leaving the tops 22 of the pedestals 16 bonded to one another.

In certain embodiments, the pedestals 16 may be formed by machining out the channels 14 in a substrate forming the panel 12. In such an embodiment, the substrate may be formed of a suitable metal, a composite material as described hereinabove, or the like. Likewise, in certain embodiments, a non-reinforced panel 12 may be cast, stamped, molded, or the like in order to form the pedestals 16 and channels 14. For example, a comparatively thin layer of a polymeric material, or a reinforced polymeric material may be stamped to form pedestals 16 that are effectively hallow along the outer surface thereof. Such pedestals, may still be bonded together by solvents or a layer 40 of suitable adhesive connecting the tops 22 of opposing pedestals on corresponding panels 12a, 12b in an apparatus 10.

Due to the relative proximity of each of the tops 22 of adjacent pedestals 16, the net effective stress imposed by internal pressures of vapors within the channels 14 may still be supported at sufficiently close intervals to use materials of comparatively modest strength. For example, various polymers may have sufficient strength to operate with various commonly available working fluids having suitable boiling points to operate as heat transfer fluids in the apparatus 10.

In yet another embodiment, the pedestals 16 may be built up by curing. For example, complex or closed volumes may sometimes be formed by coating a substrate with a resin. Curing a portion of the resin by ultraviolet or other triggering means is followed by removal of all uncured resin. The process may be repeated as desired. Thus, a wall may be built up, and an outer surface may be applied, all for the enclosed volume that might otherwise might not be susceptible to molding.

In yet another embodiment, one panel 12 may actually have pedestals 16 built up from a metal base. For example, the panel 12 may be formed as an excavated portion in the central region where the array 15 will be located. The panel may thus be surrounded with a boundary wall of integral material with the substrate or base.

In certain embodiments, an apparatus may be constructed using powdered metal. The metal powder may be distributed in the array portion 15 of a panel 12. A laser directed to specific locations at regular intervals along the portion 15 will define an array of spots of heat. At each of the spots of heat, the powdered metal is melted and thus bonded to the substrate panel 12 or a previously bonded location of melted, powdered metal. Thereafter, excess unmelted powder may be removed. Repeatedly, the panel 12 may be covered with a layer of powdered metal. Repeatedly, in turn, at the same locations, an array of hot spots may be created at regular intervals. Thus, melting additional powdered metal on top of the previous locations of melting builds a column or pedestal at each such location. Channels are left as the powdered metal that was left unmelted is removed.

By repetition of this process, such pedestals 16 were built up to form the full array 15 of pedestals 16 on panel. The pedestals formed by rastering the laser across the powdered metal at regular locations were built up to a suitable height to operate as pedestals 16. For example, pedestals 16 operate to maintain open channel spaces, and also to bond to one another in order to bond to panels 12 together at very frequent, regular intervals.

Rastering a laser across the numerous, built-up pedestals may provide a liquefied surface. Thereupon the panels 12 may be pressed together to bond the metal tops 22 of the pedestals 16 of opposing panels 12 together. The porosity resulting from the irregularities of the melted metals in the pedestals 16 may operate to improve an adherence or capillary adhesion of liquids to the channels 14.

Referring to FIG. 6, a panel 12 formed of a substrate may be formed to have an array 15 of pedestals 16. The panel 16 may be provided with apertures 13 to attach an apparatus 10 formed of two panels 12 in a deployable position.

In the illustrated embodiment, a tool may operate along straight, parallel lines like the cutting element of a milling machine, or like a circular saw. To improve manufac-
turing speed, a saw-like operation may result in overrun portions 42, 44. Likewise, the overrun portions 42 may provide pedestals that are comparatively long and narrow, rather than having a balanced width-to-length aspect ratio of unity. For example, the overrun portion 42 provides for access by liquid and vapor despite the interference of the apertures 13 and the surrounding material required to support them.

The overrun portions 42, 44 do not provide all the advantages of the uniform pedestals 16 of unitary aspect ratio found elsewhere, along the panel 12. However, they still provide access by fluid to those reaches of the panel 12.

FIGS. 7 and 8 illustrated comparative depths of cuts used to form the channels 14 in the panel 12. The dimensions outlined represent those for one embodiment of a test apparatus manufactured in a laboratory for evaluation of the performance of an apparatus 10 in accordance with the invention.

Referring to FIG. 9, detail A shows the overrun portions 42, 44 of cuts forming the various pedestals 16. In the proximity of the apertures 13, the overruns 42 provide access by heat transfer fluid to portions of the panel 12 not accessible in both longitudinal and lateral directions, due to the requirement for material integrity in the vicinity of the apertures 13.

FIGS. 10-12 illustrate dimensions of channels 14 and pedestals 16 in the embodiment of FIG. 6 fabricated as a laboratory test apparatus 10. Notwithstanding the nearly 800 thousandths of an inch that the channels 14 descend into the panel 12, approximately that much additional material is left as a wall. The material remaining between the floor of each of the channels 14, and the opposite surface of the panel 12, may typically be reduced to something on the order of between 10 and 40 thousandths of an inch. Shaping the floor 20 of each channel 14 may provide a balancing of strength and heat transfer.

Referring to FIGS. 13-15, in one embodiment of a panel 12 in accordance with the invention, the array 15 of a panel 12 may actually be provided with periodic barriers 46. For example, the barriers 46a, 46b may be bonded to corresponding barriers 46a, 46b in an opposing panel 12. Thus, the array 25 of pedestals 16 may actually constitute various sub-arrays 15 sealed away from one another. In such an embodiment, each individual portion between adjacent barriers 46a, 46b in the panel 12 may operate as a single heat transport device. Thus, in an environment such as high launch loads, the barriers 46a, 46b may resist or limit the ability of fluids to transfer from end of the panel 12 to another under the influence of acceleration forces.

In general, detail B of FIG. 15 illustrates a shape of pedestals 16 bonded to one another to form the channels 14. The portion 14a is seen as the narrow portion 14a wherein liquid will accumulate to be boiled off eventually by addition of heat into a panel 12. Meanwhile, returning vapor from a boiling portion of the panel 12 will return along the larger cross-section of channel 14c to be condensed at a cooler location on the panel 12 or the panel assembly 10.

Typical dimensions for an apparatus 10 may be on the order of about a foot square. Meanwhile, apparatus 10 prototypes of about 200 mils in total thickness may be 100 mils or less in thickness in a deployed apparatus. Likewise, 30 thousandths of an inch may be a suitable wall thickness between a floor 20 and outer surface. That is, the distance between the bottom 20 of the channel 14, and the opposing outer wall surface of that same panel 12 may typically be separated by as little as 30 mils or less.

In certain prototypes, an effective thermal conductivity for panel material may still yield an effective heat transport equivalent to a thermal conductivity on the order of thousands of watts per meter per degree kelvin. This is superior to the effectiveness of solid copper as a transport mechanism. Meanwhile, the structural stiffness and strength of a graphite fiber composite material such as a carbon-carbon composite has been found to provide a suitably stiff, strong, effective thermal panel for discharge of heat from a spacecraft.

The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative, and not restrictive. The scope of the invention is, therefore, indicated by the appended claims, rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

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

1. An apparatus comprising:
   a panel formed of a composite material comprising a fiber-reinforced matrix;
   the panel, machined to provide a first set of channels, parallel to one another, the channels having a first portion excavated into an inside surface of the panel to extend comparatively closer to an outside surface opposite thereto, and a second portion excavated to extend more shallowly;
   a second set of channels extending orthogonally to the first set of channels and parallel to one another, the channels of the second set having a first portion extending comparatively deeper and closer to an outer surface thereof opposed the second set, a second portion extending a comparatively more shallow, lesser distance toward the outside surface;
   the first panel having a plurality of first pedestals formed by excavation of the channels;
   a second panel having a plurality of second pedestals formed by excavation of the second panel to be positioned opposite and corresponding to the first pedestals;
   a bond formed between first pedestals of the first panel in contact with the second pedestals of the second panel corresponding thereto; and
   a working fluid transported by capillary action in the first portions of the channels, and returning as a vapor through the second portions of the channels.

* * * * *