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(54) PLATE-FRAME GRAPHITE-FOAM HEAT EXCHANGER

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(57) ABSTRACT

A heat exchanger for thermally coupling a first fluid and second fluid is disclosed. The heat exchanger comprises plates comprising cores of thermally conductive graphite foam. A plurality of conduits for conveying the first fluid is formed in each core. Each plate further comprises thermally conductive barriers that sandwich the core, wherein the barriers are substantially impervious to r the first fluid and second fluid. Plates are stacked in a frame such that the frame and plates collectively define a plurality of channels for conveying the second fluid. Heat is exchanged between the primary fluid and the secondary fluid through the graphite-foam cores and barriers.

Heat exchangers in accordance with the present invention can be lighter, have improved ratio of heat transfer surface density to heat exchanger volume, be lower cost, and/or be smaller for a given heat transfer capability than prior-art heat exchangers.

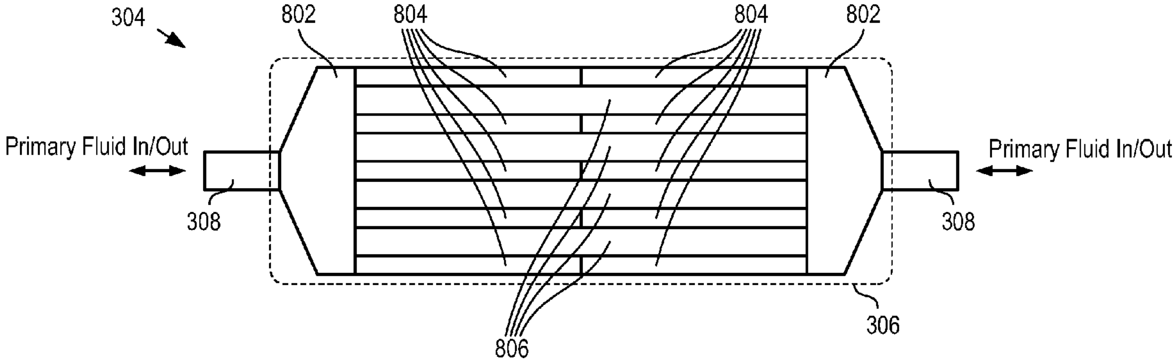
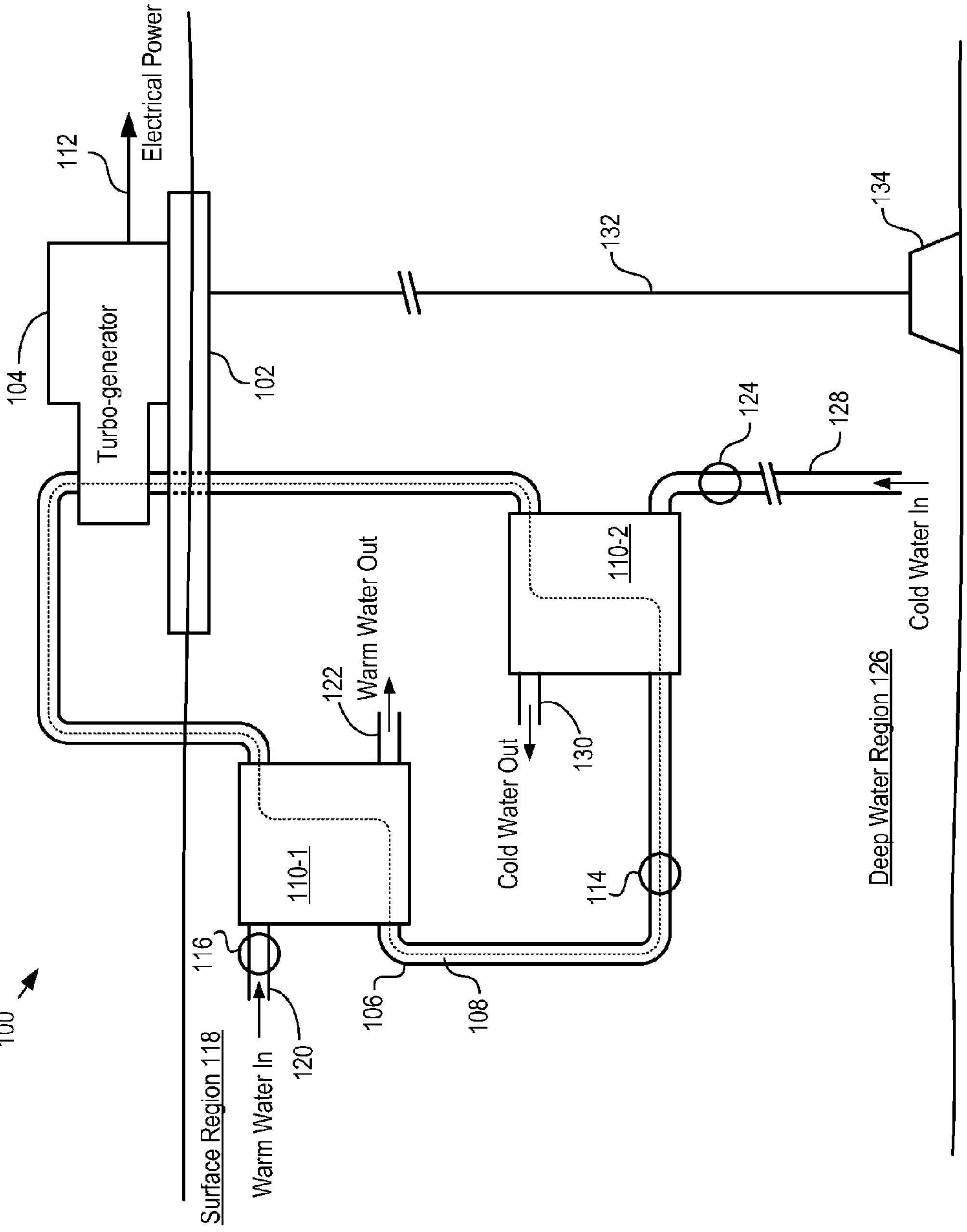


FIG. 1


100
Surface Region 118
Warm Water In
120
116
110-1
106
108
122
Warm Water Out
114
Cold Water Out
130
110-2
Deep Water Region 126
Cold Water In
124
128
Turbo-generator
104
102
112
Electrical Power
132
134

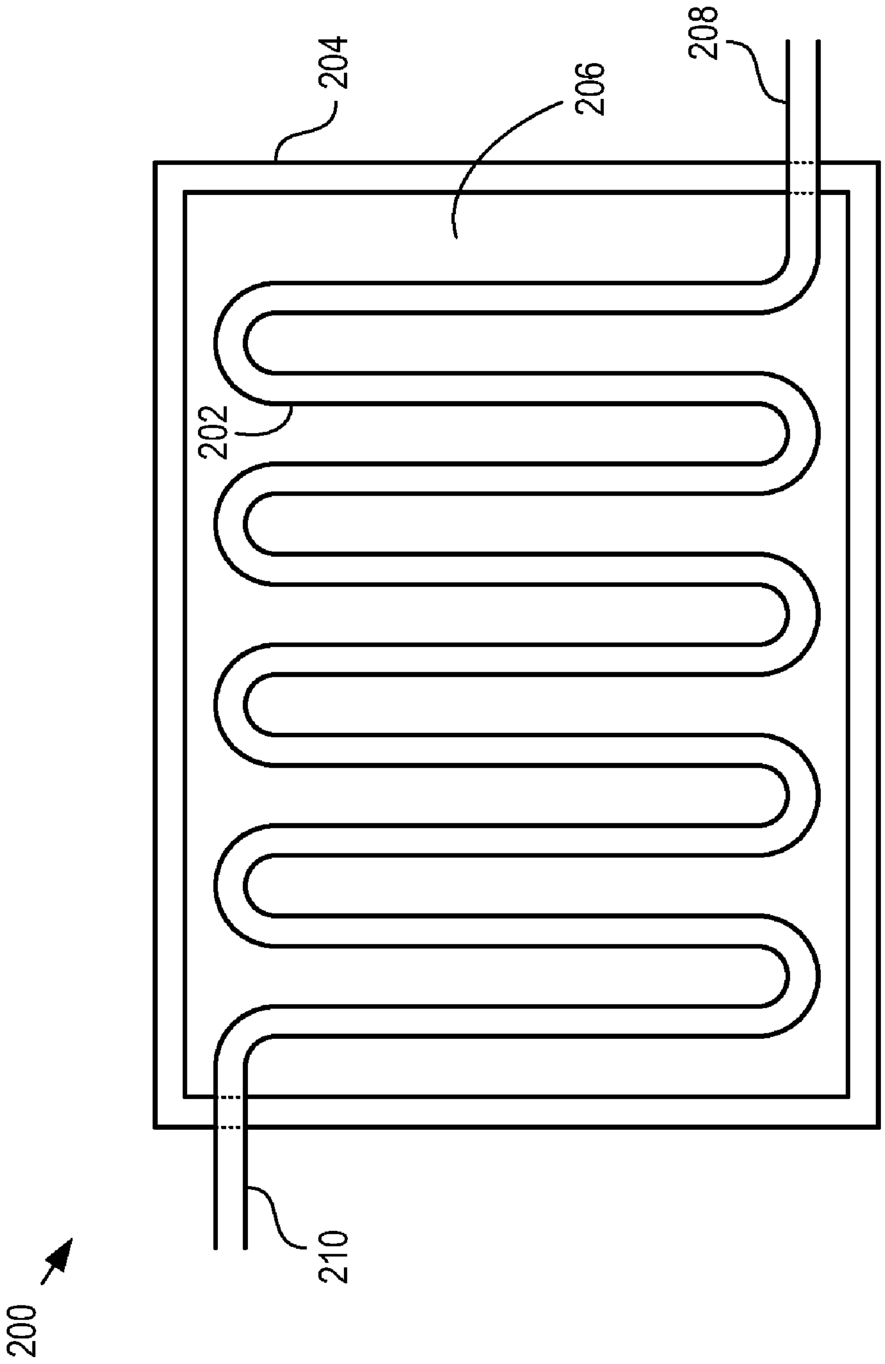


FIG. 2 (Prior Art)

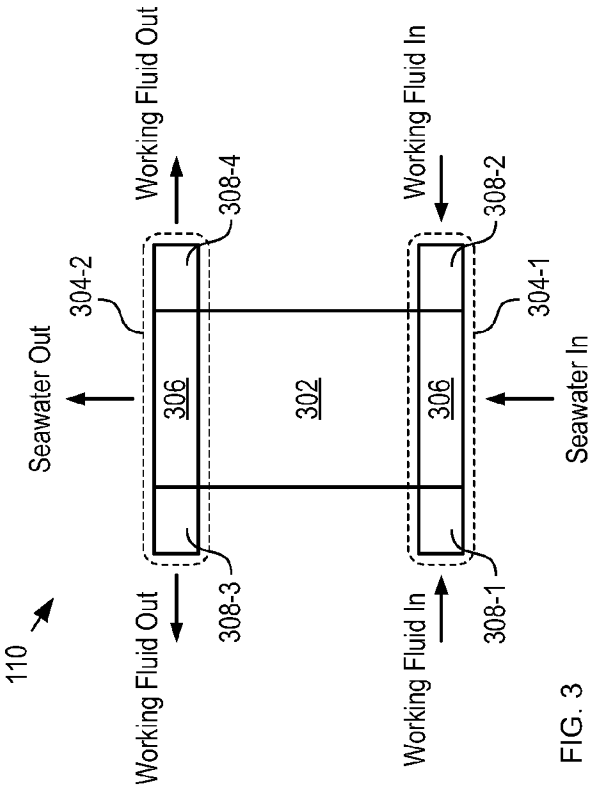

110
Working Fluid Out
Seawater Out
Working Fluid Out
304-2
308-3
306
308-4
302
Working Fluid In
Seawater In
Working Fluid In
304-1
308-1
306
308-2

FIG. 3

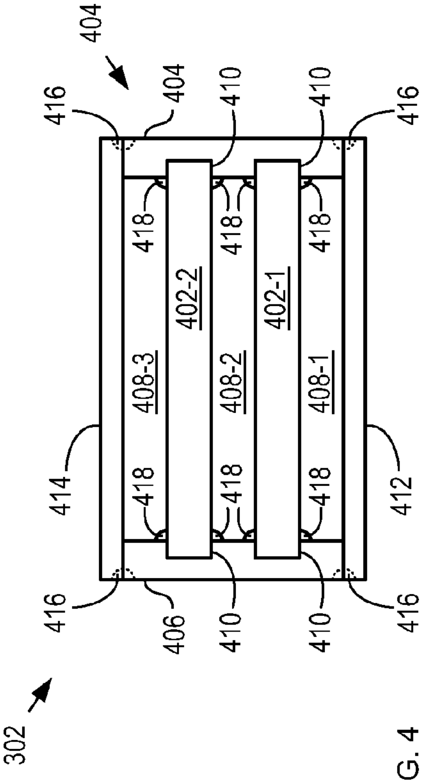

404
416
404
410
410
416
418
418
418
402-2
402-1
408-3
408-2
408-1
414
412
418
418
418
416
406
410
410
416
302

FIG. 4

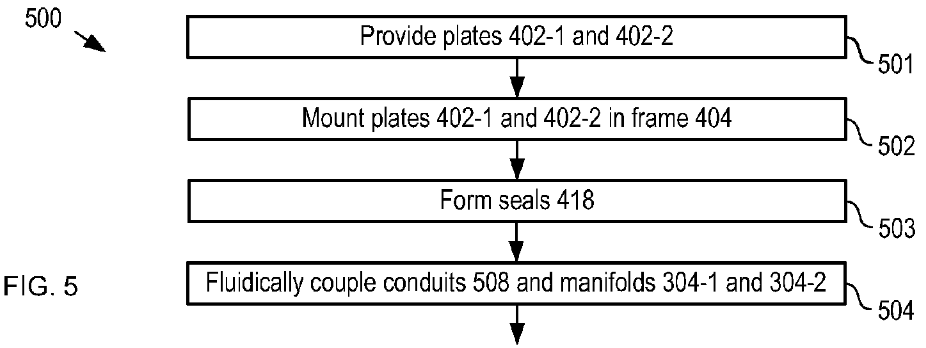


FIG. 5

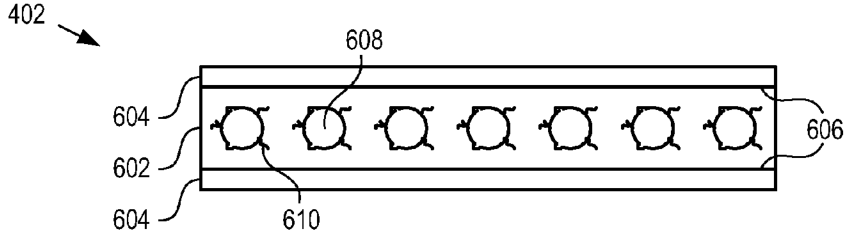


FIG. 6

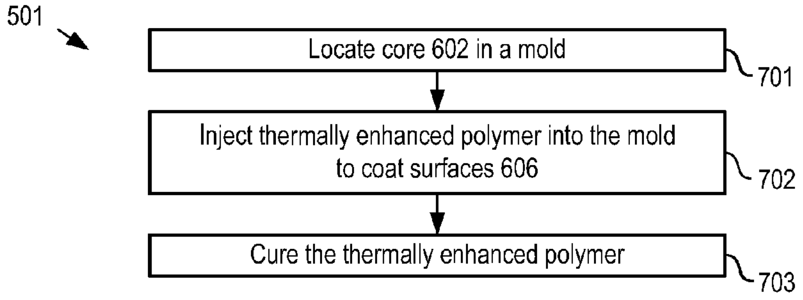


FIG. 7

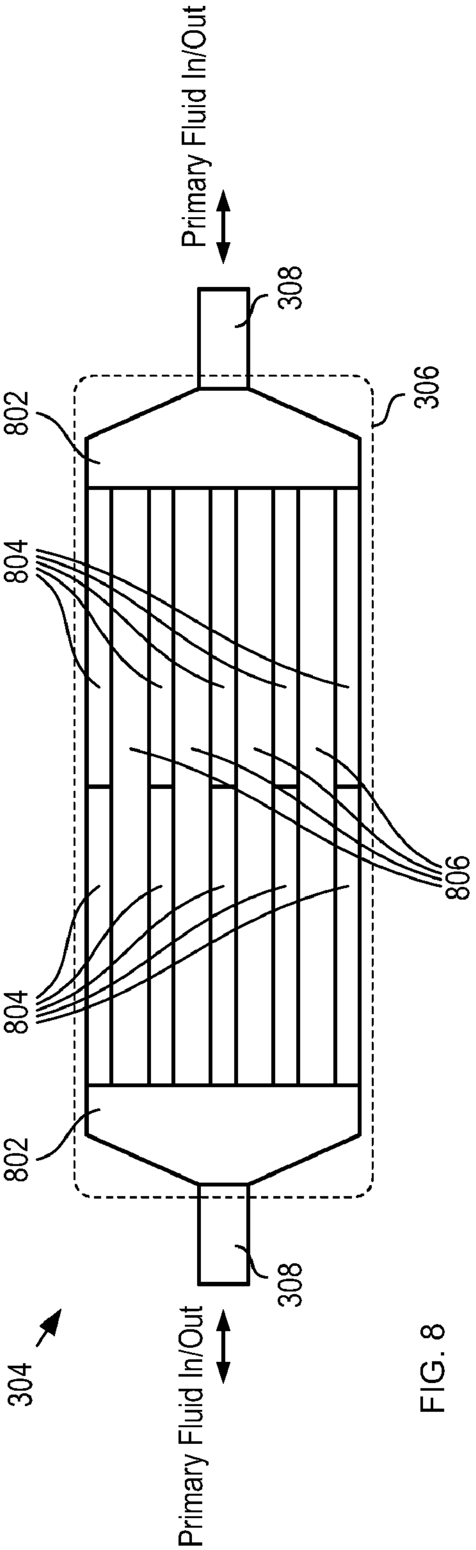

304
Primary Fluid In/Out
Primary Fluid In/Out
308
308
306
802
802
804
804
806

FIG. 8

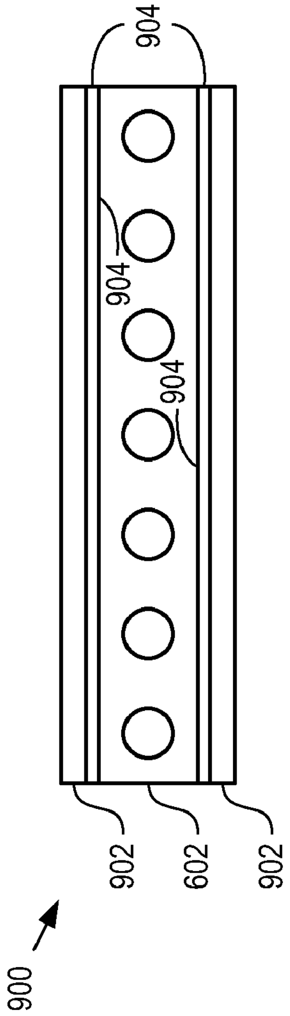

900
904
904
904
902
602
902

FIG. 9

PLATE-FRAME GRAPHITE-FOAM HEAT EXCHANGER

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This case claims priority of U.S. Provisional Patent Application U.S. 61/145,996, which was filed on Jan. 21, 2009 (Attorney Docket: 711-246US), and which is incorporated herein by reference.

[0002] In addition, the underlying concepts, but not necessarily the language, of the following case is incorporated by reference:

[0003] U.S. patent application Ser. No. 12/484,542, filed Jun. 5, 2009 (Attorney Docket: 711-231US).

[0004] If there are any contradictions or inconsistencies in language between this application and one or more of the cases that have been incorporated by reference that might affect the interpretation of the claims in this case, the claims in this case should be interpreted to be consistent with the language in this case.

FIELD OF THE INVENTION

[0005] The present invention relates to energy conversion in general, and, more particularly, to heat exchangers.

BACKGROUND OF THE INVENTION

[0006] Patent application Ser. No. 12/484,542, filed Jun. 5, 2009 (Attorney Docket: 711-231US)

[0007] Large, robust heat exchangers are needed to build a closed-cycle Ocean Thermal Energy Conversion (OTEC) plant. OTEC heat exchangers must withstand prolonged exposure to a primary working fluid, typically ammonia, as well as a large secondary flow of seawater. Further, it is highly desirable, if not necessary, that such heat exchangers provide high overall heat transfer coefficients, exhibit minimal mechanical pumping losses, and are light weight. It is also important that the materials and fabrication costs of these heat exchangers are not excessive.

[0008] In the prior art, heat exchangers are typically either "shell and tube heat exchangers" or "plate-frame heat exchangers."

[0009] Shell and tube heat exchangers commonly comprise a plurality of tubes enclosed within an open volume of a surrounding shell. Typically, the tubes and shell comprise conventional metallic materials. In some cases, shell and tube heat exchangers comprise shells made of more exotic materials, such as composites, graphite foam, etc. Such materials enable a reduction in the weight of a heat exchanger.

[0010] Shell and tube heat exchangers are widely used for liquid to liquid, liquid to vapor, evaporator and condenser applications. In operation, a primary fluid or vapor flows through the tubes. A secondary fluid, typically air, flows around and through the space that surrounds the tubes inside the shell. Heat is exchanged between the fluids/vapors through the walls of the tubes.

[0011] Although shell and tube style heat exchangers are often used for ship/submarine service, they are typically characterized by relatively low heat transfer coefficients. As a result, shell and tube heat exchangers are not well-suited for OTEC applications since they would require undesirably large surface areas. This drawback is further exacerbated by the fact that there is normally only a small difference between seawater and process fluid temperatures.

[0012] Plate-frame heat exchangers are typically constructed of thin metal plates joined together to form a thermal transfer path between the primary and secondary fluid streams. The plates are normally joined using welding, brazing, epoxy, or mechanical attachment. Plate-frame heat exchangers find use in a wide range of liquid to liquid, liquid to vapor, evaporator and condenser applications throughout the petro-chemical, pharmaceutical and beverage processing industries. In some commercial plate-frame style heat exchangers, the process fluid flows between alternate plate pairs, and the secondary fluid flows in the intervening plate pairs. Heat transfer is enhanced via chevron or other turbulence-inducing stamped patterns. Plate-frame heat exchangers have a high capital cost. For OTEC systems, wherein the heat exchangers are in contact with sea water, materials such as titanium or high alloy steel are normally required. As a result, the cost associated with such heat exchangers would be increased further.

[0013] Brazed aluminum plate frame heat exchangers are widely used in gas processing and cryogenic applications such as nitrogen and natural gas liquefaction and for LNG re-gassification. In cryogenic and gas processing heat exchangers, brazed aluminum fins are used on both the warm and cold fluid sides of the heat exchanger. Such heat exchangers are not well-suited for OTEC applications, however, since seawater is corrosive to brazed fin joints. Further, these heat exchangers are typically characterized by small passages that are prone to clogging due to biofouling.

[0014] In an attempt to overcome their corrosion problem in OTEC applications, brazed aluminum fin heat exchangers have been developed wherein aluminum extrusions are used in place of brazed fins on their seawater sides. The brazed fins are retained on the process fluid (e.g., ammonia) side of the heat exchanger, however. Unfortunately, these modified brazed fin/extruded aluminum fin heat exchangers require large braze furnaces for their fabrication. As a result, they are also quite expensive to produce.

SUMMARY OF THE INVENTION

[0015] The present invention provides a heat exchanger that overcomes some of the limitations and drawbacks of the prior art. Embodiments of the present invention enable thermal coupling between a primary fluid, such as a working fluid, and a secondary fluid, such as seawater. Embodiments of the present invention are particularly well-suited for OTEC applications.

[0016] An embodiment of the present invention comprises a plate-frame heat exchanger that includes graphite-foam-based plates, each of which comprises a plurality of conduits for conveying the primary fluid through the heat exchanger. The conduits are formed in the graphite foam itself. The plates are arranged in a frame such that spaced between the plates define channels for conveying the secondary fluid through the heat exchanger.

[0017] Each plate comprises a "sandwich" structure of a graphite-foam core that interposes a pair of barriers. The barriers are substantially impervious to both the primary and secondary fluids. As a result, the barriers inhibit cross-contamination of the two fluids.

[0018] In some embodiments, the barriers are made of a thermally enhanced polymer that is disposed on each of two opposing sides of the graphite-foam core. The barriers are formed on these surfaces in an injection molding process.

[0019] In some embodiments, the barriers are made of metal sheets that are attached to the two surfaces of the graphite-foam core using either an adhesive or by welding, soldering, or brazing the sheets to a thin metal film disposed on the two surfaces.

[0020] In some embodiments, the conduits formed in the graphite-foam core comprise open pores and capillaries that serve to enhance heat transfer through the graphite foam.

[0021] In contrast to prior-art heat exchangers, embodiments of the present invention provide:

- **[0022]** i. an improved ratio of heat transfer surface density to heat exchanger volume; or
- **[0023]** ii. reduced heat exchanger weight; or
- **[0024]** iii. improved thermal transport rates or heat transfer coefficients between the primary fluid and secondary fluid; or
- **[0025]** iv. improved surface area to volume ratio for evaporative and condenser surfaces; or
- **[0026]** v. smaller heat exchanger footprint for a given heat transfer capability; or
- **[0027]** vi. reduced pressure drop for primary fluid through the heat exchanger; or
- **[0028]** vii. any combination of i, ii, iii, iv, v, and vi.

[0029] An embodiment of the present invention comprises a heat exchanger for thermally coupling a first fluid and a second fluid, wherein the heat exchanger comprises: (1) a first frame, wherein the first frame comprises a first core, wherein the first core comprises graphite foam comprising first conduits for conveying the first fluid, and a first barrier for fluidically isolating the first fluid and the second fluid; and (2) a second frame, wherein the second frame comprises a second core, wherein the second core comprises graphite foam comprising second conduits for conveying the first fluid, and a second barrier for fluidically isolating the first fluid and the second fluid; wherein the first frame and the second frame collectively define a channel for conveying the second fluid.

BRIEF DESCRIPTION OF THE DRAWINGS

[0030] FIG. **1** depicts a schematic diagram of an OTEC power generation system in accordance with an illustrative embodiment of the present invention.

[0031] FIG. **2** depicts a schematic drawing of a cross-sectional view of a shell and tube heat exchanger in accordance with the prior art.

[0032] FIG. **3** depicts a schematic drawing of a plate-frame heat exchanger in accordance with the illustrative embodiment of the present invention.

[0033] FIG. **4** depicts a schematic drawing of a heat exchanger core in accordance with the illustrative embodiment of the present invention.

[0034] FIG. **5** depicts operations of a method suitable for forming a heat exchanger in accordance with the illustrative embodiment of the present invention.

[0035] FIG. **6** depicts a schematic drawing of a plate in accordance with the illustrative embodiment of the present invention.

[0036] FIG. **7** depicts sub-operations suitable for forming a plate **402** in accordance with the illustrative embodiment of the present invention.

[0037] FIG. **8** depicts a schematic diagram of a manifold in accordance with the illustrative embodiment of the present invention.

[0038] FIG. **9** depicts a schematic drawing of a plate in accordance with a first alternative embodiment of the present invention.

DETAILED DESCRIPTION

[0039] FIG. **1** depicts a schematic diagram of an OTEC power generation system in accordance with an illustrative embodiment of the present invention. OTEC system **100** comprises turbogenerator **104**, closed-loop conduit **106**, heat exchanger **110-1**, heat exchanger **110-2**, pumps **114**, **116**, and **124**, and conduits **120**, **122**, **128**, and **130**.

[0040] Turbo-generator **104** is a conventional turbine-driven generator. Turbogenerator **104** is mounted on floating platform **102**, which is a conventional floating energy-plant platform. Platform **102** is anchored to the ocean floor by mooring line **132** and anchor **134**, which is embedded in the ocean floor. In some instances, platform **102** is not anchored to the ocean floor but is allowed to drift. Such a system is sometimes referred to as a "grazing plant."

[0041] In typical operation, pump **114** pumps a primary fluid (i.e., working fluid **108**), in liquid form, through closed-loop conduit **106** to heat exchanger **110-1**. Ammonia is often used as working fluid **108** in OTEC systems; however, it will be clear to one skilled in the art that any fluid that evaporates at the temperature of the water in surface region **118** and condenses at the temperature of the water in deep water region **126** is suitable for use as working fluid **108** (subject to material compatibility requirements).

[0042] Heat exchanger **110-1** and **110-2** are configured for operation as an evaporator and condenser, respectively. One skilled in the art will recognize that the operation of a heat exchanger as evaporator or condenser is dependent upon the manner in which it is configured within system **100**. Heat exchanger **110** is described in detail below and with respect to FIG. **3**.

[0043] In order to enable its operation as an evaporator, pump **116** draws warm secondary fluid (i.e., seawater from surface region **118**) into heat exchanger **110-1** via conduit **120**. In a typical OTEC deployment, the water in surface region **118** is at a substantially constant temperature of approximately **25** degrees centigrade (subject to weather and sunlight conditions). At heat exchanger **110-1** heat from the warm water is absorbed by working fluid **108**, which induces working fluid **108** to vaporize. After passing through heat exchanger **110-1**, the now slightly cooler water is ejected back into the body of water via conduit **122**. The output of conduit **122** is typically located deeper than the depth of surface region **118** to avoid reducing the average water temperature in the surface region.

[0044] The expanding working fluid **108** vapor is forced through turbogenerator **104**, thereby driving the turbogenerator to generate electrical energy. The generated electrical energy is provided on output cable **112**. Once it has passed through turbogenerator **104**, the vaporized working fluid enters heat exchanger **110-2**.

[0045] At heat exchanger **110-2**, pump **124** draws cold secondary fluid (i.e., seawater from deep water region **126**) into heat exchanger **110-2** via conduit **128**. Typically deep water region **126** is approximately 1000 meters below the surface of the body of water, at which depth water is at a substantially constant temperature of a few degrees centigrade. The cold water travels through heat exchanger **110-2** where it absorbs heat from the vaporized working fluid. As a result, working fluid **108** condenses back into liquid form.

After passing through heat exchanger **110-2**, the now slightly warmer water is ejected into the body of water via conduit **130**. The output of conduit **130** is typically located at a shallower depth than that of deep-water region **126** to avoid increasing the average water temperature in the deep-water region.

[0046] Pump **114** pumps the condensed working fluid **108** back into heat exchanger **110-1** where it is again vaporized; thereby continuing the Rankine cycle that drives turbogenerator **104**.

[0047] FIG. **2** depicts a schematic drawing of a cross-sectional view of a shell and tube heat exchanger in accordance with the prior art. Heat exchanger **200** comprises folded conduit **202**, shell **204**, inlet **208**, and outlet **210**.

[0048] Conduit **202** is a metal-based fluidic conduit for conveying a primary fluid, such as ammonia, from inlet **208** to outlet **210**. Conduit **202** is typically folded into a serpentine shape to substantially maximize the amount of its surface area that is in contact with shell **204**.

[0049] Shell **204** is a form of thermally conductive graphite foam. Shell **204** includes recess **206** for locating conduit **204**. Shell **204** further includes pass-throughs that facilitate fluidic connection to inlet **208** and outlet **210**. Shell **204** typically comprises two halves that fit together in a clam shell configuration to completely surround and sandwich conduit **202**. Shell **204** also seals conduit **202** from direct contact with secondary fluid during operation of the heat exchanger.

[0050] In operation as an evaporator, relatively cooler primary fluid flows into inlet **208** in liquid form. Heat exchanger **200** is placed into a configuration wherein relatively warmer secondary fluid flows along the outside surfaces of shell **204**. Heat from the secondary fluid is conducted through the graphite foam to the top and bottom surfaces of conduit **202**. The conducted heat causes the primary fluid within conduit **202** to vaporize. Vaporized primary fluid exits heat exchanger **200** at outlet **210**.

[0051] In operation as a condenser, relatively warmer primary fluid flows into inlet **208** in vapor form. Heat exchanger **200** is placed into a configuration wherein relatively cooler secondary fluid flows along the outside surfaces of shell **204**. Heat from the primary fluid is conducted through the graphite foam from the top and bottom surfaces of conduit **202**. This heat is conveyed into the secondary fluid, which acts as a heat sink. The loss of heat causes the primary fluid within conduit **202** to condense into a liquid. Primary fluid exits heat exchanger **200** at outlet **210** in liquid form.

[0052] One skilled in the art will recognize that heat exchanger **200** has several limitations, particularly with respect to OTEC applications. For example, the efficiency of heat exchange between conduit **202** and the graphite foam of shell **204** is a function of the contact area between these elements. Since only the top and bottom surfaces of conduit **202** are in direct contact with graphite foam, the heat transfer coefficient heat exchanger **200** is low.

[0053] Further, for operation in an OTEC application, the relatively small difference between the temperatures of the primary and secondary fluids would require that heat exchanger **200** be inordinately large in order to affect sufficient heat exchange.

[0054] Still further, conduit **202** is typically a heavy metallic tube. As a result, the weight of conduit **202** is a significant contributor to the overall weight of heat exchanger **200**.

[0055] FIG. **3** depicts a schematic drawing of a plate-frame heat exchanger in accordance with the illustrative embodiment of the present invention. Heat exchanger **110** comprises heat exchanger core **302** and manifolds **304-1** and **304-2**.

[0056] Heat exchanger core **302** (hereinafter referred to as "core **302**") comprises a plurality of plates that are joined to a frame to form a complete plate-frame heat exchanger core. Core **302** comprises conduits through which working fluid **108** can flow. Core **302** also includes channels through which seawater can flow. As they are conveyed through core **302**, heat is transferred between the two fluids. Core **302** is described in more detail below and with respect to FIGS. **4-7**.

[0057] Manifolds **304-1** and **304-2** (referred to, collectively, as manifolds **304**) provide working fluid **108** and seawater to the channels of core **302**. Each of manifolds **304** comprises distributor **306** and ports **308**. Manifolds **304-1** and **304-2** are described in detail below and with respect to FIG. **8**.

[0058] FIG. **4** depicts a schematic drawing of a heat exchanger core in accordance with the illustrative embodiment of the present invention. Core **302** comprises plates **402-1** and **402-2**, and frame **404**.

[0059] FIG. **5** depicts operations of a method suitable for forming a heat exchanger in accordance with the illustrative embodiment of the present invention. Method **500** begins with operation **501**, wherein plates **402-1** and **402-2** are provided. Although the illustrative embodiment comprises two plates **402**, it will be clear to one skilled in the art, after reading this specification, how to make and use alternative embodiments of the present invention that comprise any practical number of plates **402**.

[0060] FIG. **6** depicts a schematic drawing of a plate in accordance with the illustrative embodiment of the present invention. Plate **402** comprises core **602**, and barriers **604**.

[0061] FIG. **7** depicts sub-operations suitable for forming a plate **402** in accordance with the illustrative embodiment of the present invention. Operation **501** begins with sub-operation **701**, wherein core **602** is placed in the mold of an injection molding system.

[0062] Core **602** is a graphite-foam extrusion that comprises a plurality of conduits **608** for conveying working fluid through plate **402**. Conduits **608** are depicted as having a circular cross-section; however, one skilled in the art will recognize that channels **608** can have any suitable cross-sectional shape (e.g., triangular, square, rectangular, asymmetric, etc.). Conduits **608** comprise graphite wall surfaces that comprise conduits **610**. Conduits **610** are open pores and/or capillaries that extend into the thickness of the graphite foam. Conduits **610** enable evaporation and condensation to occur over a much larger surface area than comparable conventional heat exchangers. Heat exchangers in accordance with the present invention, therefore, can be characterized by an improved ratio of heat transfer surface density to heat exchanger volume, as compared to prior-art heat exchangers. As a result, for a given heat transfer duty, heat exchangers in accordance with the present invention can be smaller than prior art shell and tube or plate-frame heat exchangers. In some embodiments, conduits **610** are not present or are too small to significantly enhance heat transfer through core **602**.

[0063] Typically, the graphite-foam composition used for core **602** has a specific gravity within the range of 0.6-0.7, and high tensile strength. As a result, core **602** is both lightweight and strong enough to withstand the fluid pressures and flow dynamics that develop within heat exchanger **110**. Heat exchangers in accordance with the present invention, therefore, can be much lighter than comparable conventional metal-based heat exchangers.

[0064] Further, graphite foam has a bulk thermal conductivity of approximately 180 W/M Deg C. range. This thermal conductivity is as high as pure bulk aluminum, for example, and much higher than the effective conductivity of most aluminum fin constructions.

[0065] At sub-operation **702**, a thermally enhanced polymer is injected into the mold to coat each of surfaces **606**. The thermally enhanced polymer material is selected such that it is substantially impervious to both working fluid **108** and seawater once the polymer is cured. For the purposes of this Specification, including the appended claims, a thermally enhanced polymer is defined as a polymer composition that comprises a thermally conductive filler material, such as boron nitride, diamond composites, metals, aluminum nitride, and the like. It will be clear to one skilled in the art, after reading this specification, how to specify, make, and use a thermally enhanced polymer suitable for forming barriers **604**. In some embodiments, a non-thermally enhanced polymer is used to coat each of surfaces **606**; however, such embodiments are typically characterized by a lower thermal transfer rate between working fluid **108** and the seawater in the heat exchanger. In some embodiments, the surface of the graphite foam comprises graphite-foam fibers that protrude into the thickness of barriers **604**. In such embodiments, the thermal transfer rate between the working fluid and secondary fluid is enhanced. It should be noted, however, that the integrity of the barrier, vis-à-vis the mitigation of fluid cross-contamination, is retained.

[0066] At sub-operation **703**, the thermally enhanced polymer is cured to form barriers **604**. As a result, barriers **604** are layers that are substantially impervious to both working fluid **108** and seawater. Barriers **604** are disposed on opposing surfaces **606** of core **602**. Barriers **604**, therefore, inhibit cross-contamination of the two fluids during operation of heat exchanger **110**. In embodiments wherein barriers **604** comprise a non-thermally enhanced polymer, the thickness of the layers is typically reduced to reduce their thermal resistance.

[0067] Since graphite foam is typically quite porous, the polymer flows into the pores and other surface structure of surfaces **606**. As a result, the polymer forms a strong mechanical bond between core **602** and barriers **604**. In addition, this increases the surface area of the interface between the graphite foam and the polymer, which results in a highly thermally conductive interface between core **602** and barriers **604**.

[0068] Upon completion of the injection molding process, plate **402** emerges from the mold as a single unit.

[0069] At operation **502**, plates **402-1** and **402-2** are mounted in seats **408** of frame **404**, which comprises sides **406**, bottom **412**, and top **414**.

[0070] Sides **406** are rigid aluminum alloy members that comprise seats **410**. Seats **410** are recessed regions of sides **406** for accepting and locating plates **402-1** and **402-2**.

[0071] Each of bottom **412** and top **414** is a rigid aluminum-alloy plate that mates with sides **406** to complete frame **404**.

[0072] Sides **406** and bottom **412** and top **414** are joined with substantially galvanic corrosion-free joints **416** to mitigate the effects of corrosion due to exposure to seawater.

[0073] In some embodiments, joints **416** are formed using friction-stir welding. Friction-stir welding employs a rotating probe, wherein a force is applied to the probe perpendicular to the weld surface to join similar metals or alloys together. The immense friction between the probe and materials causes material in the immediate vicinity of the probe to heat up to temperatures below its melting point. This softens the adjoining sections, but because the material remains in a solid state, its original material properties are retained. Movement of the probe along the weld line forces the softened material from the two pieces towards the trailing edge causing the adjacent regions to fuse, hence forming a weld.

[0074] As opposed to other common joining techniques, including other methods that produce galvanic corrosion-free joints, friction-stir welding has several performance advantages. In particular, the resultant weld is comprised of the same material as the joined sections. As a result, galvanic corrosion due to contact between dissimilar metals at the joint is reduced or eliminated. Furthermore, the resultant weld retains the material properties of the material of the joined sections. Friction-stir welding is described in more detail in U.S. patent application Ser. No. 12/484,542, filed Jun. 5, 2009 (Attorney Docket: 711-231US), which is included by reference herein.

[0075] Seats **410** are arranged so that bottom **412** and plate **402-1** collectively define channel **408-1**, plates **402-1** and **402-1** collectively define channel **408-2**, and plate **402-2** and top **414** collectively define channel **408-3** (Channels **408-1** through **408-3** are collectively referred to as channels **408**). Channels **408** are suitable for conveying seawater through heat exchanger **110**.

[0076] At operation **503**, seals **418** are formed along each intersection of a plate **402** and its respective seat **410**. Seals **418** are lines of polymer adhesive applied to seal the spaces between plates **402** and seats **410** so as to inhibit the flow of either working fluid **108** or seawater through them. Seals also serve to inhibit motion of plates **402** relative to frame **404**.

[0077] At operation **504**, manifolds **304-1** and **304-2** are joined with core **302** using a substantially galvanic corrosion-free joining technology, such as friction-stir welding.

[0078] FIG. **8** depicts a schematic diagram of a manifold in accordance with the illustrative embodiment of the present invention. Manifold **304** is representative of each of manifolds **304-1** and **304-2** and comprises distributor **306** and ports **308**. Manifold **304** consists of the same material as frame **404** to facilitate friction-stir welding. Manifold **304** comprises two substantially identical sides in order to mitigate deleterious effects, such as pressure drops or turbulence, which typically arise from transitioning fluid flow between a plurality of small conduits and a large conduit.

[0079] During operation as an inlet manifold, distributor **306** receives working fluid from ports **308** and distributes it into conduits **608** of core **302**. During operation as an outlet manifold, conduits **804** receive working fluid from conduits **608** of core **302** and provide it to ports **308**.

[0080] Distributor **306** comprises region **802** which physically expands the flow of primary fluid in order to introduce it into conduits **804** with substantially uniform flow velocity. The number of conduits **804** is based on the number of plates **402** in core **302**. Conduits **804** are interposed by access ports **806**. Access ports **806** enable access for seawater to channels **408-1** through **408-3** of core **302**. In some alternative embodiments, manifold **304** comprises a second plurality of conduits for fluidically coupling seawater and channels **408-1** through **408-3**. Although the illustrative embodiment of the present invention comprises a heat exchanger through which primary and secondary fluids flow in a substantially parallel manner, it will be clear to one skilled in the art, after reading this specification, how to specify, make, and use alternative embodiments of the present invention in which the primary and secondary fluids flow in a non-parallel manner, such as a cross-flow arrangement.

[0081] It should be noted that conduits **804** are tapered from wide end **708** to narrow end **710**. This tapering facilitates the flow of primary fluid through conduits **608** with substantially uniform flow velocity.

[0082] Although the illustrative embodiment comprises manifolds **304** that are made of the same material as frame **404**, it will be clear to one skilled in the art, after reading this specification, how to specify, make, and use alternative embodiments that comprises manifolds consisting of a different corrosion-resistant material (e.g., a fiberglass composite), which can be joined to frame **404** with a substantially galvanic corrosion-free joint.

[0083] FIG. **9** depicts a schematic drawing of a plate in accordance with a first alternative embodiment of the present invention. Plate **900** comprises core **602**, plates **902**, and adhesive **904**.

[0084] Plates **902** are thin, thermally conductive sheets affixed to surfaces **606** of core **602** by means of adhesive **904**. Core **602** and plates **902** collectively define a "sandwich" structure, wherein plates **902** inhibit cross-contamination between working fluid **108** and seawater during heat exchanger operation. In some embodiments, plates **902** are solid, mesh, or perforated sheets that augment the mechanical strength of core **602** to enable plate **900** to withstand greater pressures and forces inside heat exchanger **300**. In embodiments wherein plates **902** are not solid, however, an additional barrier layer, such as barrier **604**, is provided to inhibit fluidic cross-contamination. In some embodiments, plates **902** are made of aluminum, aluminum alloy, or another metal that is suitable for joining plate **900** to frame **404** by means of a galvanic corrosion-free joining technology, such as friction-stir welding. In such embodiments, therefore, joints **418** are substantially galvanic corrosion-free joints.

[0085] In some embodiments, plates **902** are affixed to core **602** by brazing or welding them to thin metal layers deposited on each of surfaces **606**. In such embodiments, adhesive **904** is not required.

[0086] It is to be understood that the disclosure teaches just one example of the illustrative embodiment and that many variations of the invention can easily be devised by those skilled in the art after reading this disclosure and that the scope of the present invention is to be determined by the following claims.

What is claimed is:

1. A heat exchanger for thermally coupling a first fluid and a second fluid, wherein the heat exchanger comprises:
- a first frame, wherein the first frame comprises;
  - a first core, wherein the first core comprises graphite foam comprising first conduits for conveying the first fluid; and
  - a first barrier for fluidically isolating the first fluid and the second fluid; and
- a second frame, wherein the second frame comprises;
  - a second core, wherein the second core comprises graphite foam comprising second conduits for conveying the first fluid; and
  - a second barrier for fluidically isolating the first fluid and the second fluid;
- wherein the first frame and the second frame collectively define a channel for conveying the second fluid.

2. The heat exchanger of claim **1** wherein the second barrier comprises a plate, and wherein the plate is mechanically rigid, and wherein the plate is substantially impervious for each of the first fluid and the second fluid.

3. The heat exchanger of claim **1** wherein the first barrier comprises a metal.

4. The heat exchanger of claim **3** wherein the metal comprises aluminum.

5. The heat exchanger of claim **1** further comprising:
- a frame, wherein the frame consists of a first metal;
- wherein the second barrier consists of the first metal; and
- wherein the second barrier consists of the first metal;
- wherein the frame, first barrier, and second barrier are joined with substantially galvanic corrosion-free joints.

6. The heat exchanger of claim **5** wherein the galvanic corrosion-free joints are friction-stir welding joints.

7. The heat exchanger of claim **1** wherein the first barrier comprises a polymer that is substantially impervious to each of the first fluid and the second fluid.

8. The heat exchanger of claim **7** wherein the polymer is a thermally enhanced polymer.

9. The heat exchanger of claim **1** wherein the first core consists substantially of graphite foam.

10. The heat exchanger of claim **1** wherein the first core consists of graphite foam.

11. The heat exchanger of claim **1** wherein each of the first conduits further comprises second conduits, and wherein the second conduits and the first conduits are fluidically coupled.

12. A heat exchanger for thermally coupling a first fluid and a second fluid, wherein the heat exchanger comprises:
- (1) a plurality of plates, wherein each of the first plates comprises;
  - (a) a core, wherein the core comprises a plurality of conduits for conveying the first fluid, and further wherein the core comprises graphite foam;
  - (b) a first barrier, wherein the first barrier is substantially impervious to the first fluid and the second fluid; and
  - (c) a second barrier, wherein the second barrier is substantially impervious to the first fluid and the second fluid;
  - wherein the first barrier is physically coupled with a first surface of the core;
  - wherein the second barrier is physically coupled with a second surface of the core that is opposite the first surface of the core; and
  - wherein the first barrier and second barrier are substantially thermally conductive; and
- (2) a frame for locating each of the plurality of plates, wherein the frame locates the plurality of plates such that the frame and the plurality of plates collectively define a plurality of channels for conveying the second fluid.

13. The heat exchanger of claim **12** wherein each of the frame, the first barrier, and the second barrier comprises a first metal, and wherein the frame and each of the first barriers and second barriers are joined with friction-stir welding joints.

14. The heat exchanger of claim **13** wherein each of the first barrier and second barrier comprises a polymer.

15. The heat exchanger of claim **14** wherein the polymer is a thermally enhanced polymer.

16. A method for forming a heat exchanger for thermally coupling a first fluid and a second fluid, wherein the method comprises:

providing a plurality of plates, wherein each of the plurality of plates comprises a graphite-foam core and a barrier that is substantially impervious to the first fluid and the second fluid, wherein each of the graphite-foam cores comprises a plurality of conduits for conveying the first fluid;

providing a frame for locating the plurality of plates; and

mounting the plurality of plates in the frame;

wherein the frame and the plurality of plates collectively define a plurality of channels for conveying the second fluid.

17. The method of claim **16** further comprising fluidically coupling a manifold and the plurality of conduits.

18. The method of claim **16** further comprising joining the plurality of plates and the frame, wherein the plurality of plates and the frame are joined with friction-stir welding joints.

19. The method of claim **16** wherein at least one of the plurality of barriers is formed by operations comprising:

locating a first core in a mold of an injection molding system, wherein the first core is the core of one of the plurality of plates;

injecting a polymer into the mold; and

curing the polymer.

20. The method of claim **19** further comprising providing the polymer as a thermally enhanced polymer.

21. The method of claim **16** wherein at least one of the plurality of barriers is formed by operations comprising:

bonding a first plate to a first surface of a first core, wherein the first core is the core of one of the plurality of plates; and

bonding a second plate to a second surface of the first core;

wherein each of the first plate and the second plate is substantially impervious for the first fluid and the second fluid.

22. The method of claim **21** wherein the first plate is bonded to the first surface by means of an adhesive.

23. The method of claim **21** wherein the first plate is bonded to the first surface by operations comprising:

disposing a first layer on the first surface, wherein the first layer comprises a first metal; and

joining the first plate and the first layer.

24. The method of claim **23** wherein the first plate and first layer are joined with a brazed joint.

25. The method of claim **23** wherein the first plate and first layer are joined with a welding joint.

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