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(54) COMPOSITE HEAT PIPE STRUCTURE

(76) Inventors: **Timothy Hassett**, Santa Rosa, CA (US); **Mark Hodowanec**, Leesburg, VA (US)

Correspondence Address:
POLSTER, LIEDER, WOODRUFF & LUCCHESI
12412 POWERSCOURT DRIVE SUITE 200
ST. LOUIS, MO 63131-3615 (US)

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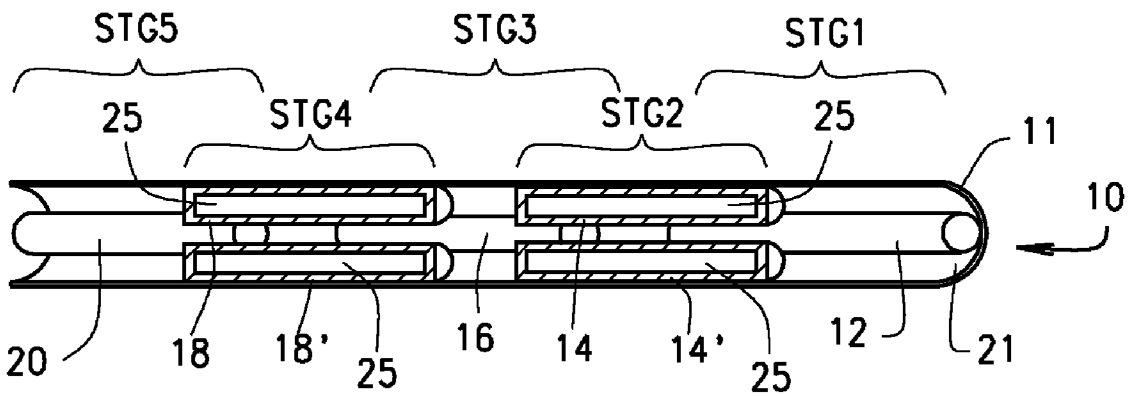
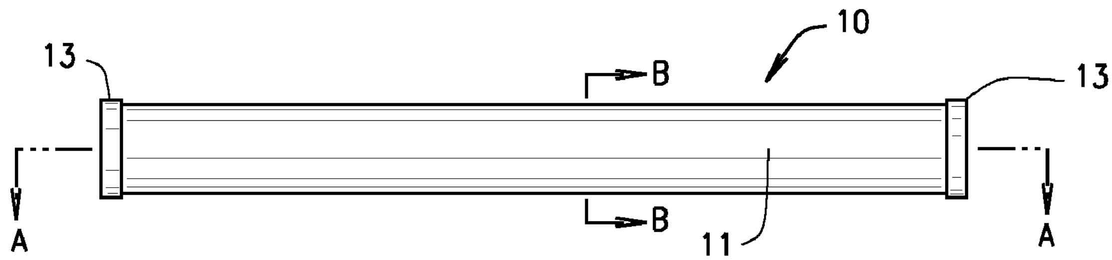
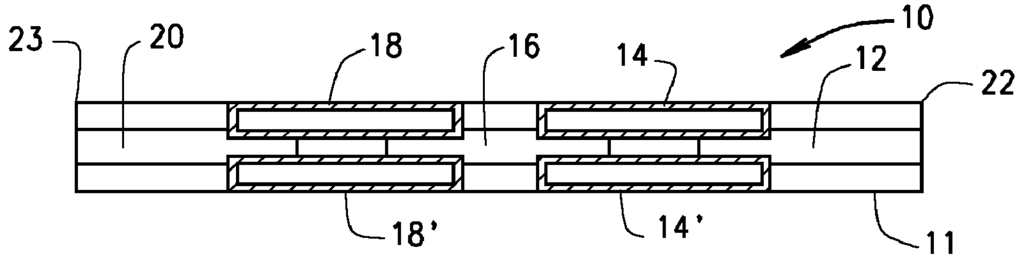
(57) **ABSTRACT**

A composite heat pipe structure is provided. In various embodiments, the composite heat pipe structure includes an outer body and a plurality of internal heat pipes sequentially disposed in a longitudinally adjacent relationship within an interior cavity of the outer body. The internal heat pipes are sequentially thermally coupled to one another along a portion of each respective internal heat pipes so that heat absorbed at a first end of the outer body is transferred to a second end of the outer body, via the internal heat pipes, with a high rate of thermal efficiency.

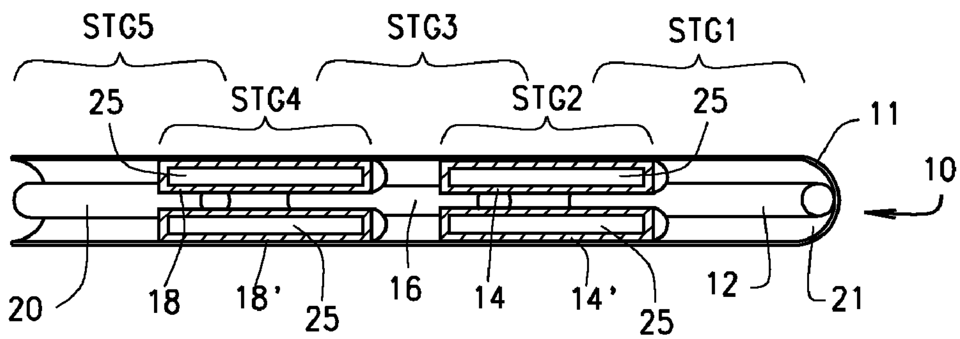




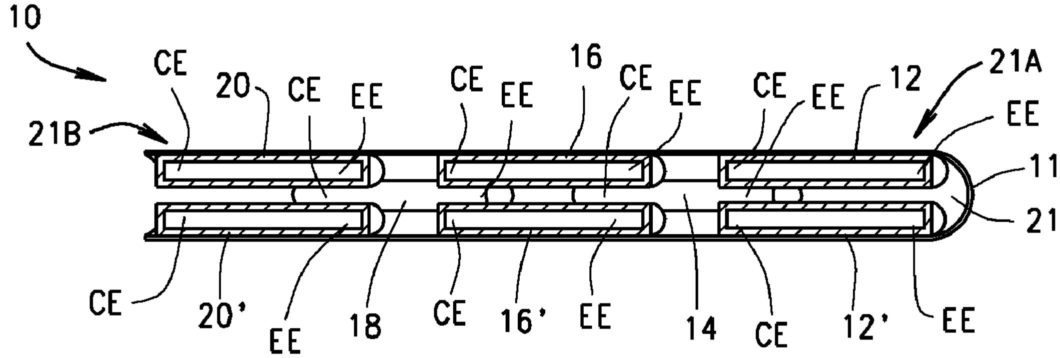
F I G. 1



F I G. 2



F I G. 3



F I G. 3A

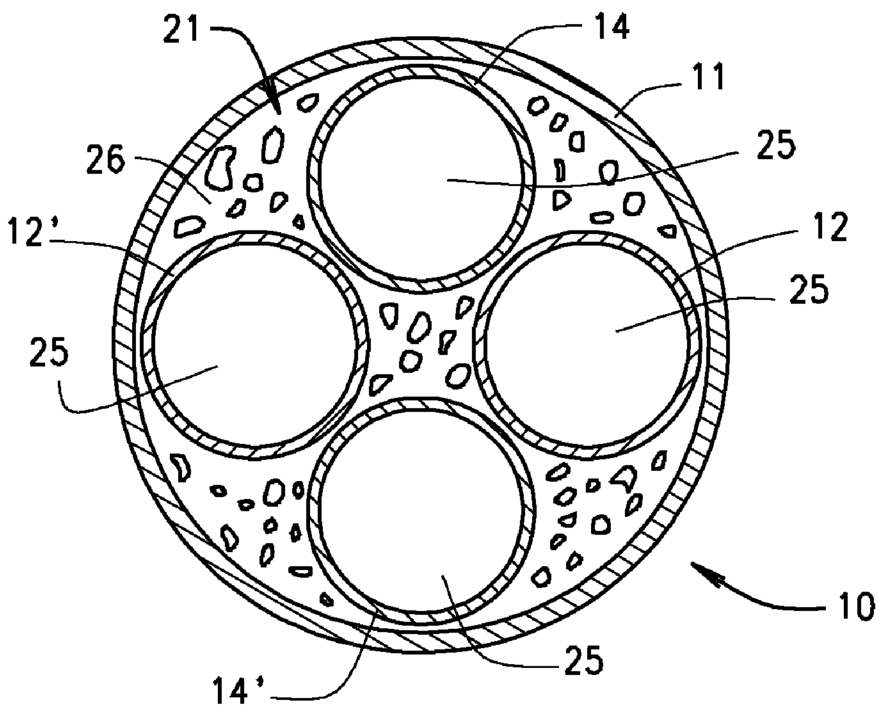


FIG. 4

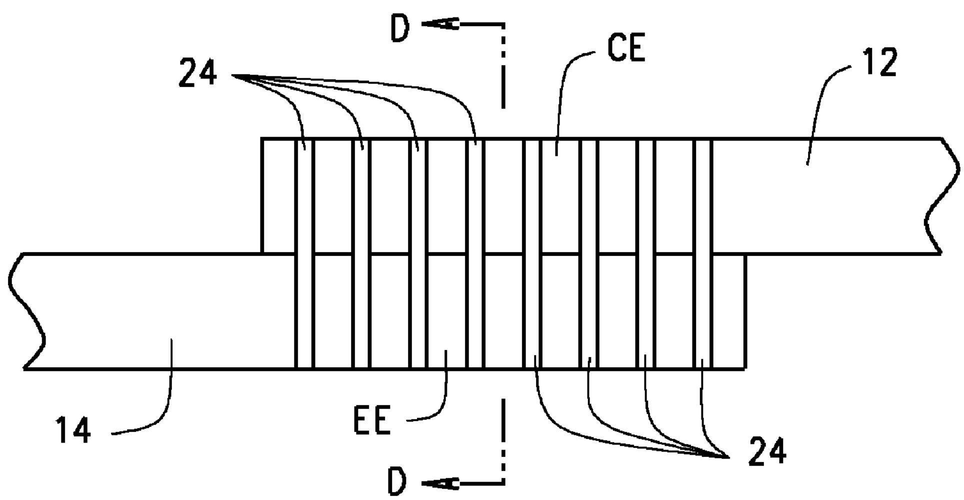


FIG. 5

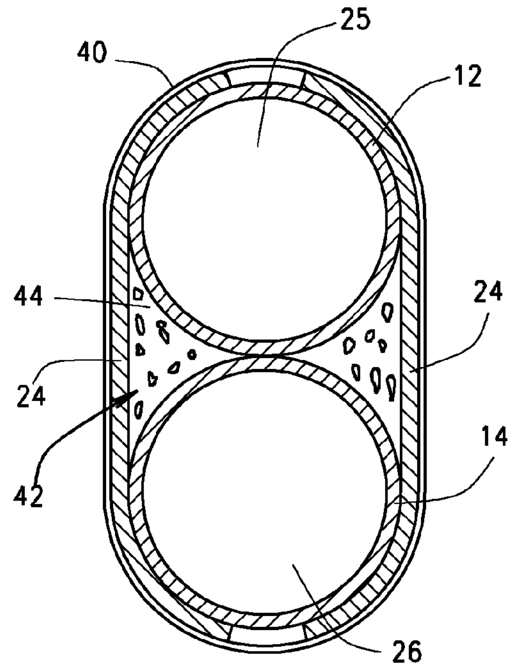


FIG. 5A

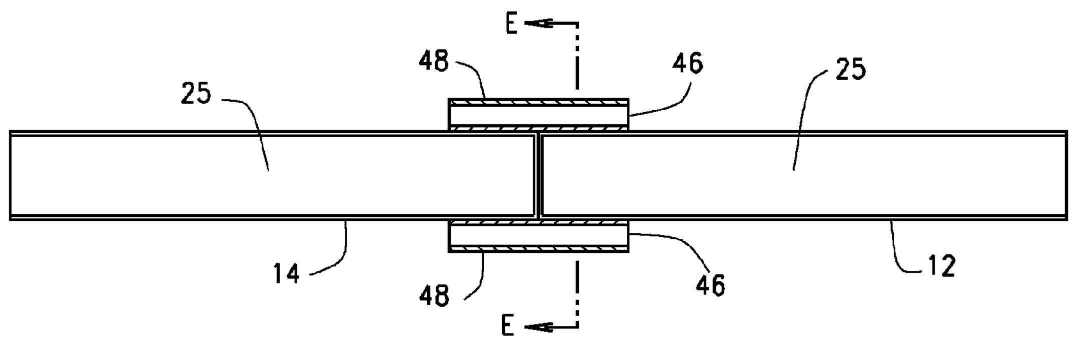


FIG. 6

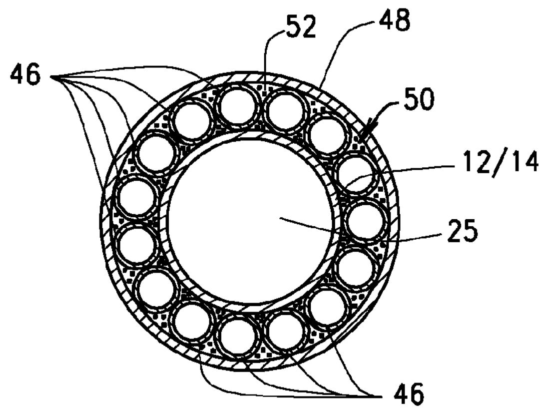


FIG. 6A

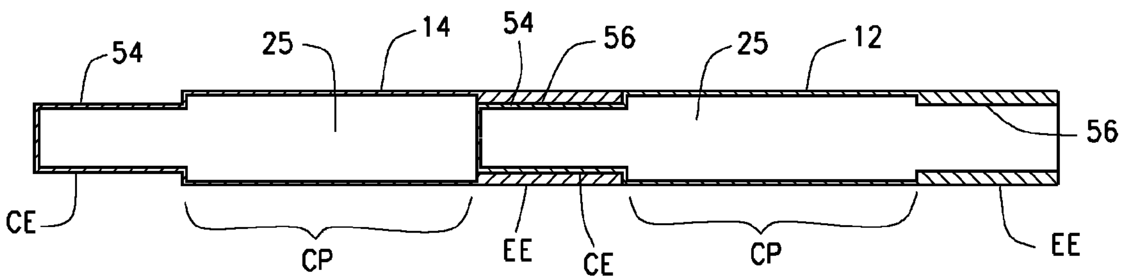
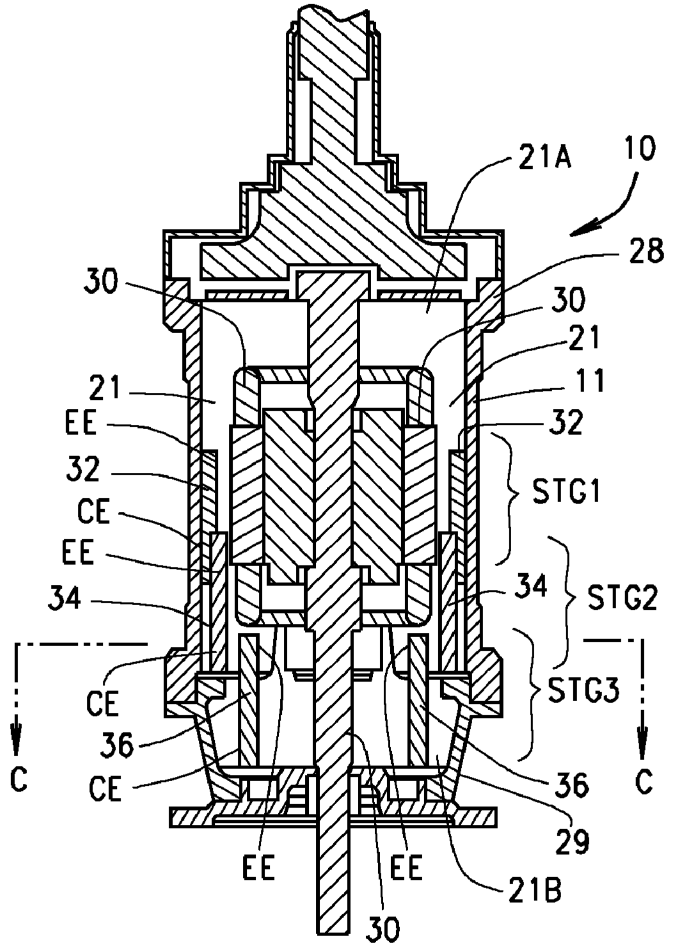


FIG. 7


21A
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28
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21
11
EE
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STG1
CE
EE
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STG2
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STG3
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C
C
36
36
CE
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EE
EE
21B
30

FIG. 8

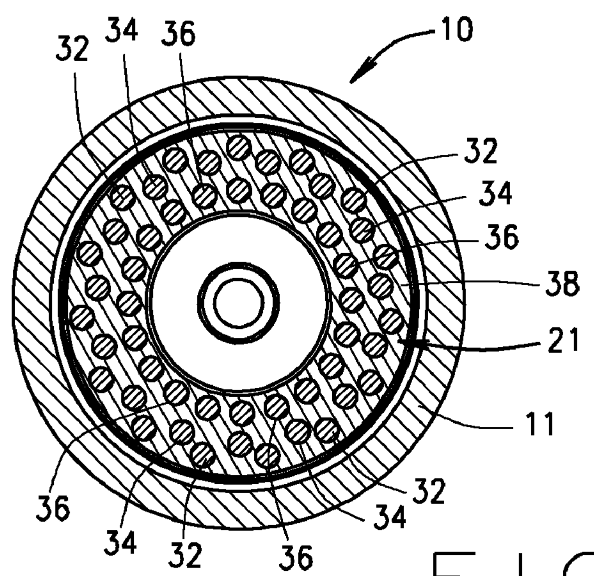
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FIG. 8A

COMPOSITE HEAT PIPE STRUCTURE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 61/020,606, filed on Jan. 11, 2008, the disclosure of which is incorporated herein by reference in its entirety.

[0002] Additionally, the present application is related in general subject matter to U.S. patent application Ser. No. 11/765,140, filed Jun. 19, 2007, which is hereby incorporated by reference in its entirety.

FIELD

[0003] The present teachings relate to heat pipes. More specifically, the present teachings relate to a composite heat pipe structure constructed of a plurality of thermally interconnected internal heat pipes disposed within an interior cavity of the composite heat pipe structure. The composite heat pipe structure generally extends over a particular distance for which heat is to be transferred.

BACKGROUND

[0004] The statements in this section merely provide background information related to the present disclosure and may not constitute prior art.

[0005] Heat pipes are a heat transfer mechanism that can transport large quantities of heat with a very small difference in temperature between hot and cold interfaces. A typical heat pipe consists of a sealed hollow tube made of a thermally conductive material, e.g., a thermally conductive metal such as copper or aluminum. The heat pipe contains a relatively small quantity of a "working fluid" or coolant (such as water, ethanol or mercury) with the remainder of the heat pipe being filled with a vapor phase of the working fluid, all other gases being substantially excluded. Heat is transferred from an evaporator end of a heat pipe to an opposing condenser end of the heat pipe by a rapid transition of heat vaporized working fluid from the evaporator end to the condenser end.

[0006] More particularly, heating the evaporator end of the heat pipe will cause the working fluid inside the heat pipe at the evaporator end to turn to vapor, thereby increasing the vapor pressure inside the heat pipe. Latent heat of evaporation absorbed by the vaporization of the working fluid reduces the temperature at the evaporator end of the heat pipe. Moreover, the vapor pressure at the evaporator end of the heat pipe is higher than the equilibrium vapor pressure at the condenser end of the heat pipe. This pressure difference drives a rapid mass transfer of the heated vaporized working fluid from the evaporator end to the condenser end of the heat pipe where the vapor condenses, thereby releasing its latent heat and heating the condenser end of the heat pipe. The condensed working fluid then flows back to the evaporator end of the heat pipe.

[0007] However, the length of heat pipes can be limited by difficulties encountered in moving the condensed working fluid from the condenser end of the heat pipe back to the evaporator end. Therefore, in some instances, heat pipes can contain a wick that returns the working fluid to the evaporator end by capillary action. Such wicks typically consist of metal powder sintered onto the inside walls of the heat pipe, but can, in principle, be any material capable of soaking up the coolant. Wicks aid in returning the condensed working fluid to the evaporator end, however, limitations in heat pipe length can still exist as a result of difficulties in returning the condensed fluid to the evaporator end of the heat pipe.

[0008] For example, gravitational forces, or absence thereof, can impede or assist movement of the condensed working fluid from the condenser end to the evaporator end of the heat pipe. Such gravitational limitations are generally a function of orientation of the heat pipe. In the case of heat pipes that are vertically-oriented with the evaporator end down, the fluid movement is assisted by the force of gravity. For this reason, heat pipes can be the longest when vertically oriented with the evaporator end of the heat pipe below the condenser end. The length of a heat pipe will be most limited when the heat pipe is vertically oriented with the evaporator end of the heat pipe above the condenser end. In this orientation, gravity attracts the condensed fluid to the condenser end of the heat pipe rather than the evaporator end. When horizontal, the maximum heat pipe length will be somewhere between the maximum heat pipe lengths in the two vertical orientations.

SUMMARY

[0009] The present disclosure provides a composite heat pipe structure that is structured and operable to transfer heat from a first end of the composite heat pipe structure to a second end of the composite heat pipe structure with a high rate of thermal efficiency, i.e., with very little thermal resistance.

[0010] In various embodiments, the composite heat pipe structure includes an outer body and a plurality of internal heat pipes sequentially disposed in a longitudinally adjacent relationship within an interior cavity of the outer body. The internal heat pipes are sequentially thermally coupled to one another along a portion of each respective internal heat pipes so that heat absorbed at a first end of the outer body is transferred to a second end of the outer body, via the internal heat pipes, with a high rate of thermal efficiency.

[0011] In various other embodiments, the composite heat pipe structure includes an outer body and a plurality of internal heat pipes longitudinally disposed within an interior cavity of the outer body such that a condenser end of each internal heat pipe is thermally coupled with an evaporator end of at least one longitudinally adjacent internal heat pipe. Therefore, heat absorbed at a first end of the outer body is transferred to a second end of the outer body, via the internal heat pipes, with a high rate of thermal efficiency.

[0012] In still other embodiments, the composite heat pipe structure includes an outer body and a plurality of internal heat pipe stages longitudinally disposed within and along a length of an interior cavity of the outer body. Each heat pipe stage includes at least one internal heat pipe, wherein each internal heat pipe has an interior reservoir filled with a working fluid structured to rapidly and efficiently transfer heat from an evaporator end of the internal heat pipe to a condenser end of the respective internal heat pipe. Additionally, each internal heat pipe is longitudinally disposed within the interior cavity of the outer body such that the condenser end of each internal heat pipe of each stage is thermally coupled with the evaporator end of an internal heat pipe of the longitudinally adjacent heat pipe stage. Therefore, heat absorbed at a first end of the outer body is transferred, via the internal heat pipe stages, to a second end of the outer body with a high rate of thermal efficiency.

[0013] Further areas of applicability of the present teachings will become apparent from the description provided herein. It should be understood that the description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the present teachings.

DRAWINGS

[0014] The drawings described herein are for illustration purposes only and are not intended to limit the scope of the present teachings in any way.

[0015] FIG. **1** is a side view of a composite heat pipe structure, in accordance with various embodiments of the present disclosure.

[0016] FIG. **2** is a side cross-sectional view, along line A-A, of the composite heat pipe shown in FIG. **1**, in accordance with various embodiments of the present disclosure.

[0017] FIG. **3** is a sectional view, along line A-A, of the composite heat pipe structure shown in FIG. **1**, in accordance with various embodiments of the present disclosure.

[0018] FIG. **3**A is a sectional view, along line A-A, of the composite heat pipe structure shown in FIG. **1**, rotated 90° from the view shown in FIG. **3**, in accordance with various embodiments of the present disclosure.

[0019] FIG. **4** is an end cross-sectional view, along line B-B, of the composite heat pipe structure shown in FIG. **1**, in accordance with various embodiments of the present disclosure.

[0020] FIG. **5** is a partial view of two internal heat pipes of the composite heat pipe structure shown in FIG. **1**, thermally coupled by mini lateral heat pipes, in accordance with various embodiments of the present disclosure.

[0021] FIG. **5**A is cross-sectional view, along line D-D, of the two internal heat pipes thermally coupled by mini lateral heat pipes, shown in FIG. **5**, in accordance with various embodiments of the present disclosure.

[0022] FIG. **6** is a cross-sectional side view of two internal heat pipes of the composite heat pipe structure shown in FIG. **1**, thermally coupled by mini axial heat pipes, in accordance with various embodiments of the present disclosure.

[0023] FIG. **6**A is cross-sectional view, along line E-E of the two internal heat pipes thermally coupled by mini lateral heat pipes, shown in FIG. **5**, in accordance with various embodiments of the present disclosure.

[0024] FIG. **7** is a cross-sectional side view of two internal heat pipes of the composite heat pipe structure shown in FIG. **1**, thermally interconnected at distal ends, in accordance with various embodiments of the present disclosure.

[0025] FIG. **8** is side cross-sectional view of a composite heat pipe structure, such as that shown in FIG. **1**, wherein the composite heat pipe structure comprises a component of a motor, in accordance with various embodiments of the present disclosure.

[0026] FIG. **8**A is a cross-sectional view, along line C-C, of the composite heat pipe structure shown in FIG. **8**, in accordance with various embodiments of the present disclosure.

[0027] Corresponding reference numerals indicate corresponding parts throughout the several views of drawings.

DETAILED DESCRIPTION

[0028] The following description is merely exemplary in nature and is in no way intended to limit the present teachings, application, or uses.

[0029] Generally, in various embodiments, the present disclosure provides a composite heat pipe structure that is structured to minimize the effect of gravity on the transfer of a condensed working fluid from a heat rejection, or condenser, end to a heat absorption, or evaporator, end of conventional heat pipes. Minimizing the effect of gravity minimizes the length restriction, especially in applications where the heat rejection/condenser end of a conventional heat pipe is below the heat absorption/evaporator end. In various embodiments, the composite heat pipe structure can be constructed by integrating a plurality of internal heat pipes within an interior cavity of an outer body of heat pipe structure. The internal heat pipes are shorter and have a smaller diameter than the outer body, and each has a respective evaporator end and condenser end. In various implementations, the internal heat pipes can be sequentially positioned in a longitudinally adjacent relationship within the outer body such that the evaporator end of one or more of the internal heat pipes will transfer heat to the condenser end of one or more other internal heat pipes. This sequential positioning can be repeated multiple times to construct a composite heat pipe structure of generally any desired length. To enhance the thermal connection between the internal heat pipes, the outer body can be constructed of a high thermally conductive material.

[0030] The composite heat pipe structure can generally be any structure having an outer body suitable for disposition of the internal heat pipes within an internal cavity thereof. More specifically, the composite heat pipe structure can be any structure, machine or device from which heat needs to be removed and includes an outer body suitable for disposition of the internal heat pipes within an internal cavity thereof, such as a motor, turbine, gear box, etc. For example, in various embodiments, the composite heat pipe structure can have an outer body in form of a cylindrical pipe. Alternatively, in various embodiments, the composite heat pipe structure can be a machine structure, device or component having a body in the form of something other than a pipe. For example, in various embodiments, the heat pipe structure can be a motor, e.g., a liquid/oil cooled motor, whereby the liquid is cooled by the internal heat pipes disposed within the motor. As long as the composite heat pipe structure outer body is suitable to house the internal heat pipes such that heat can be transferred from the condenser end of one or more internal heat pipes to the evaporator end of one or more other internal heat pipes, as described below, the resulting composite heat pipe structure is within the scope of the present disclosure. Although the composite heat pipe structure outer body can have any suitable form, for clarity and simplicity, the composite heat pipe structure will be exemplarily illustrated and described herein as having the form of a pipe. However, it should be understood that the scope of the present disclosure should not be so limited.

[0031] Referring now to FIGS. **1**, **2**, **3** and **3**A, the present disclosure provides a composite heat pipe structure **10** having an outer body **11**. In the various embodiments wherein the composite heat pipe structure **10** comprises a pipe, the composite heat pipe structure **10** can additionally include opposing end caps **13**. For clarity and simplicity, the end caps **13** are not shown in FIGS. **2**, **3** and **3**A. In various embodiments, the composite heat pipe structure **10** includes a plurality of internal heat pipes, e.g., internal heat pipes **12**, **12'**, **14**, **14'**, **16**, **16'**, **18**, **18'**, **20** and **20'**, integrated within an interior cavity **21** of the outer body **11**. Although the composite heat pipe structure **10** is shown to include ten internal heat pipes **12-20'**, it should be understood that, in various embodiments, the composite heat pipe structure **10** can include more than or less than ten internal heat pipes and remain within the scope of the present disclosure. However, for clarity and simplicity, the composite heat pipe structure **10** will be described herein as including ten internal heat pipes **12-20'**.

[0032] Each of the internal heat pipes **12-20'** includes an interior reservoir **25** filled with a working fluid, such as water, ethanol or mercury, that will evaporate, i.e., turn to a gaseous vapor state, when heated to a specific evaporation temperature particular to the respective working fluid. Additionally, as shown in FIG. **3**A, each of the internal heat pipes **12-20'** respectively includes an evaporation end EE and an opposing condenser end CE. Furthermore, each of the internal heat pipes **12-20'** has a diameter that is smaller than the diameter of the outer body **11**, and more particularly, has a longitudinal length that is shorter than that of the outer body **11**. It should be understood that, although each of the internal heat pipes **12-20'** are illustrated as having generally the same diameter and length as all the other internal heat pipes **12-20'**, the diameter and/or length of various ones, or various pairs, of various stages of the internal heat pipes **12-20'** can be different than the diameter and/or length of one or more of the other internal heat pipes **12-20'**.

[0033] Generally, the composite heat pipe structure **10** includes a plurality of, i.e., two or more, internal heat pipe stages STG, e.g., STG**1**, STG**2**, STG**3**, STG**4** and STG**5**, shown in FIG. **3**. Each stage STG can include one, two, three or more internal heat pipes, e.g., internal heat pipes **12-20'**. Importantly, the internal heat pipe(s) of each stage STG, are disposed within the cavity **21** in a head-to-foot relationship with the heat pipe(s) of the longitudinally adjacent stage STG. Accordingly, the condenser end CE and/or evaporator end EE of each internal heat pipe of each stage STG is longitudinally adjacent the condenser end CE or evaporator end EE of at least one other internal heat pipe of at least one longitudinally adjacent stage. More particularly, the condenser end CE and/or the evaporator end EE of each internal heat pipe of each stage STG is in thermally conductive contact with, i.e., thermally coupled to, the condenser end CE or evaporator end EE of at least one respective internal heat pipe of at least one longitudinally adjacent stage STG. Thus, the internal heat pipes **12-20'** are sequentially thermally coupled to each other in longitudinally adjacent relationship within the cavity **21** such that heat absorbed at a first end **22** of the outer body **11** is transferred to a second end **23** of the outer body, via the internal heat pipes **12-20'**.

[0034] For example, the internal heat pipes **12-20'** can be disposed within the cavity **21**, such that the condenser end CE of each of the internal heat pipes **12-18'** is adjacent the evaporator end EE of at least one of the respective longitudinally adjacent internal heat pipes **14-20'**. Moreover, in various embodiments, the condenser end CE of each of the internal heat pipes **12-18'** overlaps, i.e., extends past, and is laterally adjacent the evaporator end EE of at least one of the respective longitudinally adjacent internal heat pipes **14-20'**.

[0035] Referring now to FIGS. **3**, **3**A and **4**, in various embodiments, each stage STG of the composite heat pipe structure **10** includes a pair of internal heat pipes. For example, a first stage STG**1** includes internal heat pipes **12** and **12'**, a second stage STG**2** includes internal heat pipes **14** and **14'**, a third stage STG**3** includes internal heat pipes **16** and **16'**, a fourth stage STG**4** includes internal heat pipes **18** and **18'**, and a fifth stage STG**5** includes internal heat pipes **20** and **20'**. The stages STG**1**-STG**5** are positioned within the cavity **21** in a head-to-foot formation.

[0036] As illustrated, the condenser ends CE of the internal heat pipes **12** and **12'** of the first stage STG**1** are in thermally conductive contact with the evaporator ends EE of the internal heat pipes **14** and **14'** of the second stage STG**2**. Additionally, the condenser ends CE of the internal heat pipes **14** and **14'** of the second stage STG**2**, are in thermally conductive contact with the evaporator ends EE of the internal heat pipes **16** and **16'** of the third stage STG**3**. Furthermore, the condenser ends CE of the internal heat pipes **16** and **16'** of the third stage STG**3** are in thermally conductive contact with the evaporator ends EE of the internal heat pipes **18** and **18'** of the fourth stage STG**4**. Finally, the condenser ends CE of the internal heat pipes **18** and **18'** of the fourth stage STG**4**, are in thermally conductive contact with the evaporator ends EE of the internal heat pipes **20** and **20'** of the fifth stage STG**5**.

[0037] In such embodiments, the pair of internal heat pipes **12** and **12'** of the first stage STG**1** have their evaporator ends EE adjacent a first distal end **22** of the composite heat pipe structure **10**, as shown in FIG. **2**. Conversely, the internal heat pipes **20** and **20'** of the fifth stage STG**5** have their condenser ends CE adjacent a second distal end **23** of the composite heat pipe structure **10**, as shown in FIG. **2**.

[0038] In operation, heat at a first portion **21**A of the cavity **21**, i.e., heat at a first end of the composite heat pipe structure **10**, will be absorbed, or conducted, by the evaporator ends EE of the first stage STG**1** internal heat pipes **12** and **12'**. The absorbed heat will cause the working fluid inside the internal heat pipes **12** and **12'** at the evaporator ends EE to turn to vapor, thereby increasing the vapor pressure inside the internal heat pipes **12** and **12'**. Subsequently, the vapor pressure at the evaporator ends EE of the internal heat pipes **12** and **12'** will be higher than the equilibrium vapor pressure at the condenser ends CE of the internal heat pipes **12** and **12'**. The pressure difference drives a rapid mass transfer of the heated vaporized working fluid from the evaporator ends EE of the internal heat pipes **12** and **12'** to the condenser ends CE of the internal heat pipes **12** and **12'** where the vapor condenses and releases its latent heat, thereby heating the condenser ends CE of the internal heat pipes **12** and **12'**. Thus, the heat absorbed, or conducted, at the evaporator ends EE of the internal heat pipes **12** and **12'** is efficiently transferred, i.e., transferred with minimal thermal resistance, to the condenser ends CE of the internal heat pipes **12** and **12'**.

[0039] Subsequently, via the thermally conductive contact between the condenser ends CE of the first stage STG**1** internal heat pipes **12** and **12'** and the evaporator ends EE of the adjacent second stage STG**2** internal heat pipes **14** and **14'**, the heat from the condenser ends CE of the internal heat pipes **12** and **12'** is efficiently transferred to the evaporator ends EE of the adjacent internal heat pipes **14** and **14'**. The heat from the evaporator ends EE of the internal heat pipes **14** and **14'** is then efficiently transferred to the condenser ends CE of the internal heat pipes **14** and **14'**, as described above with regard to internal heat pipes **12** and **12'**. In the same manner, the heat transferred to the condenser ends CE of the second stage STG**2** internal heat pipes **14** and **14'** is transferred to the evaporator ends EE of third stage STG**3** internal heat pipes **16** and **16'** and then efficiently transferred to the condenser ends CE of the internal heat pipes **16** and **16'**. Continuing in the same manner, the heat transferred to the condenser ends CE of the third stage STG**3** internal heat pipes **16** and **16'** is transferred to the evaporator ends EE of the fourth stage STG**4** internal heat pipes **18** and **18'** then efficiently transferred to the condenser ends CE of the internal heat pipes **18** and **18'**.

Finally, the heat transferred to the condenser ends CE of the fourth stage STG**4** internal heat pipes **18** and **18'** is transferred to the evaporator end EE of fifth stage STG**5** internal heat pipes **20** and **20'** and then efficiently transferred to the condenser ends CE of the internal heat pipes **20** and **20'**, whereby the heat can be dissipated at a second portion **21**B of the cavity **21**, i.e., a second end of the composite heat pipe structure **10**.

[0040] Accordingly, the heat absorbed, or conducted, at the evaporator ends EE of the first stage STG**1** internal heat pipes **12** and **12'** is transferred to the condenser ends CE of the fifth stage STG**5** internal heat pipes with a high level of thermal efficiency. More specifically, heat from the first end of the composite heat pipe structure **10** is transferred to the second end of the composite heat pipe structure **10** a high level of thermal efficiency. As used herein, the term thermal efficiency refers to the ability to transfer large amounts of heat with very low thermal resistance which results in transfer of large amounts of heat with very small differences in temperature.

[0041] Although the composite heat pipe structure **10** is exemplarily illustrated and described herein as including five stages, i.e., stages STG**1**-STG**5**, it should be understood that it is envisioned that the composite heat pipe structure **10** can include more than, or less than five stages. For example, the composite heat pipe structure **10** can include two, three, four, five, six or more stages and remain within the scope of the present disclosure. Additionally, although each of the stages, e.g., stages STG**1**-STG**5**, have been exemplarily illustrated and described herein as including a pair of, i.e., two, internal heat pipes, it should be understood that each stage can include more than or less than a pair of internal heat pipes and remain within the scope of the present disclosure. For example, in various embodiments, each stage of the composite heat pipe structure **10** can include a single internal heat pipe, while in other embodiments each stage of the composite heat pipe structure **10** can include three, four, five or more internal heat pipes. Accordingly, the performance of the composite heat pipe structure **10** can be enhanced by increasing the number of internal heat pipes disposed within the cavity **21**, as described above. The number of internal heat pipes can be increased by utilizing internal heat pipes that are shorter in length and/or smaller in diameter.

[0042] Referring particularly to FIG. **4**, in various embodiments, the composite heat pipe structure **10** further includes a heat conductive medium **26** disposed within the cavity **21** and surrounding the internal heat pipes **12-20'**. The heat conductive medium **26** is disposed within the cavity **21** such that it is in thermally conductive contact with each of the internal heat pipes **12-20'**. Therefore, the heat conductive medium **26** will efficiently transfer heat from the condenser ends CE of the internal heat pipes **12-18'** to the respective evaporator ends EE of the internal heat pipes **14-20'**. The heat conductive medium **26** can be any suitable substance, e.g., a solid, a gas, a liquid, paste, a foam, etc., having high thermally conductive properties that will efficiently transfer heat between the adjacent internal heat pipes **12-20'**, as described above. For example, in various embodiments, the heat conductive medium **26** can be a highly conductive metal such as copper or silver; a highly conductive thermal grease and/or paste, e.g., compounds specifically designed to transfer heat that can include solid metal particles such as copper and/or silver; and highly conductive liquids such as water, glycols and various types of oil.

[0043] In such embodiments, the combination of the thermally conductive outer body **11**, the highly efficient heat transfer characteristics of the internal heat pipes **12-20'**, and the highly thermally conductive medium **26** will transmit heat in parallel paths to maximize the thermal conductivity of the composite heat pipe structure.

[0044] Referring now to FIGS. **5** and **5**A, in various embodiments, the composite heat pipe structure **10** can include a plurality of mini lateral heat pipes **24** disposed within the cavity **21** and thermally connecting the condenser ends CE of the internal heat pipes **12-20'** to the respective evaporator ends EE of the internal heat pipes **14-20'**. For clarity and simplicity, FIGS. **5** and **5**A exemplarily illustrates the mini lateral heat pipes **24** thermally connecting the condenser end CE of internal heat pipe **12** with the evaporator end EE of adjacent internal heat pipe **14**, however, it should be understood that the condenser end CE of each internal heat pipe can be thermally coupled to the evaporator end EE of the respective adjacent internal heat pipe, via the mini lateral heat pipes **24**.

[0045] The mini lateral heat pipes **24** are structured substantially the same as the internal heat pipes **12-20'**, described above, only having small dimensions and having a curvature such that they at least partially wrap around the outer surface of the respective internal heat pipes. Additionally, in various embodiments, the mini lateral heat pipes **24** can be banded about, and secured to, the respective internal heat pipe condenser ends CE and evaporator ends EE via a housing **40**. Alternatively, the mini lateral heat pipes **24** can be secured to, or coupled to, the internal heat pipes via any suitable method, means or device, e.g., via welding, soldering, or other fastening devices.

[0046] In various embodiments, a cavity **42**, formed between the housing **40** and the respective internal heat pipes can be filled with a heat conductive medium **44** to enhance the transfer of heat from the respective internal heat pipe condenser end CE to the respective internal heat pipe evaporator end EE, as described above. The heat conductive medium **44** can be any suitable substance, e.g., a solid, a gas, a liquid, paste, a foam, etc., having high thermally conductive properties that will efficiently transfer heat between the adjacent internal heat pipes. For example, in various embodiments, the heat conductive medium **44** can be a highly conductive metal such as copper or silver; a highly conductive thermal grease and/or paste, e.g., compounds specifically designed to transfer heat that can include solid metal particles such as copper and/or silver; and highly conductive liquids such as water, glycols and various types of oil.

[0047] Accordingly, in such embodiments, the mini lateral heat pipes **24** efficiently transfer heat between the adjacent condenser ends CE and evaporator end EE of the adjacent internal heat pipes, e.g., internal heat pipes **12** and **14**, as described above.

[0048] Referring now to FIGS. **6** and **6**A, the internal heat pipes, e.g., internal heat pipes **12** and **14**, of adjacent stages, e.g., the first and second stages STG**1** and STG**2**, can be disposed within the cavity **21** in a coaxial orientation. In such embodiments, the composite heat pipe structure **10** can include a plurality of mini axial, or longitudinal, heat pipes **46** disposed within the cavity **21** to thermally connect the condenser ends CE of the internal heat pipes **12-20'** to the respective evaporator ends EE of the internal heat pipes **14-20'**. For clarity and simplicity, FIGS. **6** and **6**A exemplarily illustrates the mini axial heat pipes **46** thermally connecting the condenser end CE of internal heat pipe **12** with the evaporator end EE of adjacent internal heat pipe **14**, however, it should be understood that the condenser end CE of each internal heat pipe can be thermally coupled to the evaporator end EE of the respective adjacent internal heat pipe, via the mini axial heat pipes **46**.

[0049] The mini axial heat pipes **46** are structured substantially the same as the internal heat pipes **12-20'**, described above, only having small dimensions, i.e., smaller diameters and lengths. Additionally, in various embodiments, the mini axial heat pipes **46** can be banded about, and secured to, the respective internal heat pipe condenser ends CE and evaporator ends EE via a housing **48**. Alternatively, the mini axial heat pipes **46** can be secured to, or coupled to, the internal heat pipes via any suitable method, means or device, e.g., via welding, soldering, or other fastening devices.

[0050] In various embodiments, a cavity **50**, formed between the housing **48** and the respective internal heat pipes can be filled with a heat conductive medium **52** to enhance the transfer of heat from the respective internal heat pipe condenser end CE to the respective internal heat pipe evaporator end EE, as described above. The heat conductive medium **52** can be any suitable substance, e.g., a solid, a gas, a liquid, paste, a foam, etc., having high thermally conductive properties that will efficiently transfer heat between the adjacent internal heat pipes. For example, in various embodiments, the heat conductive medium **52** can be a highly conductive metal such as copper or silver; a highly conductive thermal grease and/or paste, e.g., compounds specifically designed to transfer heat that can include solid metal particles such as copper and/or silver; and highly conductive liquids such as water, glycols and various types of oil.

[0051] Accordingly, in such embodiments, the mini axial heat pipes **46** efficiently transfer heat between the adjacent condenser ends CE and evaporator end EE of the adjacent internal heat pipes, e.g., internal heat pipes **12** and **14**, as described above.

[0052] Referring now to FIG. **7**, in various embodiments, the internal heat pipes, e.g., internal heat pipes **12** and **14**, of adjacent stages, e.g., the first and second stages STG**1** and STG**2**, can be disposed within the cavity **21** in a coaxial orientation and be physically and thermally interconnected with the respective condenser ends CE and evaporator ends EE. For example, in various embodiments, each internal heat pipe is structured such that the condenser end CE has an outside diameter that is smaller than the outside diameter of a central portion CP of the respective internal heat pipe, thereby providing a male node **54** at the condenser end CE of each internal heat pipe. Furthermore, in such embodiments, each internal heat pipe is structured such that the evaporator end EE has a inside diameter that is smaller than the outside diameter of the central portion CP, thereby providing a female node receptacle **56** at the evaporator end EE of each internal heat pipe.

[0053] Moreover, in such embodiments, each internal heat pipe is structured such that the inside diameter of each female node receptacle **58** is substantially the same as the outside diameter of each male node **54**. Therefore, the internal heat pipes can be securely physically and thermally interconnected within the cavity **21** by inserting the male node **54** of each of the internal heat pipes into the female node receptacle **56** of the respective adjacent internal heat pipes.

[0054] For clarity and simplicity, FIG. **7** exemplarily illustrates the physical and thermal interconnection of the condenser end CE of internal heat pipe **12** with the evaporator end EE of adjacent internal heat pipe **14**, however, it should be understood that the condenser end CE of each of the internal heat pipe **12-18'** can be physically and thermally coupled to the evaporator end EE of the respective adjacent internal heat pipes **14-20'**, via the male nodes **54** and the female node receptacles **56**, as described above.

[0055] The male nodes **54** and female node receptacles **56** can be securely physically and thermally interconnected utilizing any suitable connection method, means or device. For example, the male nodes **54** and female node receptacles **56** can be securely physically and thermally interconnected utilizing a substantially tight friction fit, utilizing mating threads formed within the male nodes **54** and female node receptacles **56**, by welding or soldering the male nodes **54** within the female node receptacles **56**, etc.

[0056] In various implementations of such embodiments, each internal heat pipe can include an interior wall (not shown) at the evaporator end of the central portion CP. Accordingly, the interior reservoir **25** of each internal heat pipe is formed between the interior wall and the interior side of the distal end of the respective male node **54**. Thus, a closed circuit for the working fluid is provided within the cavity **25** formed between the interior wall and the interior side of the distal end of the respective male node **54**. Alternatively, the evaporator end of the central portion CP of each internal heat pipe can be open, i.e., absent the interior wall, such that each respective interior reservoir **25** is formed only when the male node **54** of the adjacent internal heat pipe is securely physically and thermally interconnected with the female node receptacle **56** of the respective internal heat pipe, as described above. Thus, a closed circuit for the working fluid is provided within the cavity **25** formed when the male node **54** of the adjacent internal heat pipe is securely physically and thermally interconnected with the female node receptacle **56** of the respective internal heat pipe.

[0057] Alternatively, in various embodiments, the composite heat pipe structure can comprise a plurality of short sections, absent the internal heat pipes, that are physically and thermally interconnected, via male nodes and female node receptacles, such as those described above with regard to the internal heat pipes illustrated in FIG. **7**.

[0058] Referring now to FIGS. **8** and **8**A, as described above, the composite heat pipe structure **10** can be any structure, machine or device from which heat needs to be removed and includes an outer body suitable for disposition of the internal heat pipes within an internal cavity thereof, such as a motor, turbine, gear box, etc. For example, as exemplarily illustrated in FIGS. **8** and **8**A, in various embodiments the composite heat pipe structure **10** can comprise a portion of a motor.

[0059] In such embodiments, the outer body **11** comprises a frame **28** and end cap **29** of the motor **10** and the cavity **21** comprises the space between the outer body **11**, i.e., frame **28** and end cap **29**, and a stator assembly **30** of the composite heat pipe structure/motor **10**. FIGS. **8** and **8**A exemplarily illustrate the composite heat pipe structure **10** of such embodiments to include three stages, i.e., the first STG**1**, the second STG**2** and the third STG**3**. Each stage STG**1**, STG**2** and STG**3** includes a plurality of internal heat pipes **32**, **34** and **36**, respectively, that are structured substantially the same as the internal heat pipes **12-20'**, described above.

[0060] The internal heat pipes **32**, **34** and **36** are disposed around, and in thermally conductive contact with, the stator assembly **30** within the cavity/space **21** such that the condenser end CE of each internal heat pipe **32** is in thermally conductive contact with the evaporator end EE of a respective one or more of the internal heat pipes **34**. Similarly, the condenser end CE of each internal heat pipe **34** is in thermally conductive contact with the evaporator end EE of a respective one or more of the internal heat pipes **36**. Accordingly, heat from a first portion **21**A of the cavity/space **21** will be efficiently transferred to a second portion **21** B of the cavity/space **21**, via the internal heat pipes **32**, **34** and **36**, as described above with regard to internal heat pipes **12**-**20'**.

[0061] As illustrated in FIGS. **8** and **8**A, in various embodiments, the internal heat pipes **32**, **34** and **36** can be disposed within a back iron ring (BIR) **38** that is disposed within the cavity/space **21**. The BIR **38** is structured to house the internal heat pipes **32**, **34** and **36** to provide support and stability of the internal heat pipes **32**, **34** and **36** within the cavity/space **21**. In various implementations, the BIR **38** can further provide a heat conductive medium, such as the heat conductive medium **26** described above, to enhance the efficient transfer of heat between the internal heat pipes **32**, **34** and **36**.

[0062] Using simulations, an example of the thermal efficiency of the composite heat pipe structure **10**, as described herein, will now be provided. The example includes an instance wherein the composite heat pipe structure is 0.625" in diameter and 24" in length. Similar to the composite heat pipe structure **10** illustrated in FIGS. **2**, **3**, and **3**A, the example composite heat pipe structure includes five stages of internal heat pipes, for a total of 10 internal heat pipes. Two inches of overlap is implemented between each stage of internal heat pipes to provide thermally conductive contact between the internal heat pipes of one stage and the internal heat pipes of the adjacent stage. A thermally conductive medium that fills the entire internal cavity of the composite heat pipe structure is implemented, which transfers the heat between the adjacent stages of internal heat pipes.

[0063] The table below compares simulated performance of traditional heat pipes to the example composite heat pipe structure described above:

Orientation	¼" by 6" single heat pipe	¼" by 24" single heat pipe	⅝" by 24" single heat pipe	⅝" by 24" composite heat pipe
Horizontal	68 W	17 W	33 W	136 W
Vertical (evaporator down)	98 W	47 W	110 W	196 W
Vertical (evaporator up)	38 W	0 W	0 W	76 W

[0064] As illustrated in the table above the composite heat pipe structure of the present disclosure provides high thermal efficiency in the transfer of heat from the first end to the second end of the composite heat pipe structure.

[0065] Based on the present disclosure, one of ordinary skill in the art can readily appreciate that multiple stages of internal heat pipes can be implemented to create a composite heat pipe structure that overcomes the length limitations of known single pipe heat pipes.

[0066] The description herein is merely exemplary in nature and, thus, variations that do not depart from the gist of that which is described are intended to be within the scope of the teachings. Such variations are not to be regarded as a departure from the spirit and scope of the teachings.

What is claimed is:

1. A composite heat pipe structure comprising:

an outer body;

a plurality of internal heat pipes sequentially disposed in a longitudinally adjacent relationship within an interior cavity of the outer body such that internal heat pipes are sequentially thermally coupled to one another along a portion of each respective internal heat pipe so that heat absorbed at a first end of the outer body is transferred to a second end of the outer body, via the internal heat pipes, with a high rate of thermal efficiency.

2. The structure of claim **1**, wherein the outer body comprises cylindrical pipe.

3. The structure of claim **1**, wherein the outer body comprises a frame and end cap of a motor and the interior cavity comprises a space between the frame and end cap, and a stator assembly of the motor.

4. The structure of claim **1**, wherein the outer body comprises a portion of a turbine housing and the interior cavity comprises a space within the turbine housing.

5. The structure of claim **1**, wherein the outer body comprises a portion of a gearbox housing and the interior cavity comprises a space within the gearbox housing.

6. The structure of claim **1**, wherein the structure further comprises a heat conductive medium disposed within the interior cavity and surrounding the internal heat pipes, whereby the heat conductive medium improves the efficiency of a transfer of heat between the thermally coupled longitudinally adjacent heat pipes.

7. The structure of claim **1**, wherein the structure further comprises a plurality of mini lateral heat pipes disposed within the interior cavity and thermally connecting the longitudinally adjacent heat pipes, whereby the mini lateral heat pipes improve the efficiency of a transfer of heat between the thermally coupled longitudinally adjacent heat pipes.

8. The structure of claim **1**, wherein the structure further comprises a plurality of mini axial heat pipes disposed within the interior cavity and thermally connecting the longitudinally adjacent heat pipes, whereby the mini axial heat pipes improve the efficiency of a transfer of heat between the thermally coupled longitudinally adjacent heat pipes

9. The structure of claim **1**, wherein each internal heat pipe comprises a male node formed at a first end and a female node receptor formed at an opposing second end such that the internal heat pipes are sequentially thermally coupled to one another by securely physically coupling the male node of each internal heat pipe into the female node receptacle of the respective longitudinally adjacent internal heat pipe.

10. The structure of claim **1**, wherein each internal heat pipe comprises an interior reservoir filled with a working fluid structured to rapidly and efficiently transfer heat absorbed at an evaporator end of each internal heat pipe to a condenser end of the respective internal heat pipe.

11. A composite heat pipe structure comprising:

an outer body;

a plurality of internal heat pipes longitudinally disposed within an interior cavity of the outer body such that a condenser end of each internal heat pipe is thermally coupled with an evaporator end of at least one longitudinally adjacent internal heat pipe so that heat absorbed at a first end of the outer body is transferred to a second end of the outer body, via the internal heat pipes, with a high rate of thermal efficiency.

12. The structure of claim **11**, wherein the outer body comprises cylindrical pipe.

13. The structure of claim **11**, wherein the outer body comprises a frame and end cap of a motor and the interior cavity comprises a space between the frame and end cap, and a stator assembly of the motor.

14. The structure of claim **11**, wherein the outer body comprises a portion of a turbine housing and the interior cavity comprises a space within the turbine housing.

15. The structure of claim **11**, wherein the outer body comprises a portion of a gearbox housing and the interior cavity comprises a space within the gearbox housing.

16. The structure of claim **11**, wherein the structure further comprises a heat conductive medium disposed within the interior cavity and surrounding the internal heat pipes, whereby the heat conductive medium improves the efficiency of a transfer of heat between the thermally coupled condenser ends of the internal heat pipes to the evaporator ends of the respective longitudinally adjacent heat pipes.

17. The structure of claim **11**, wherein the structure further comprises a plurality of mini lateral heat pipes disposed within the interior cavity and thermally connecting the condenser ends of the internal heat pipes to the evaporator ends of the respective longitudinally adjacent heat pipes, whereby the mini lateral heat pipes improve the efficiency of a transfer of heat between the thermally coupled condenser ends and evaporator ends.

18. The structure of claim **11**, wherein the structure further comprises a plurality of mini axial heat pipes disposed within the interior cavity and thermally connecting the longitudinally adjacent heat pipes, whereby the mini axial heat pipes improve the efficiency of a transfer of heat between the thermally coupled longitudinally adjacent heat pipes

19. The structure of claim **11**, wherein each internal heat pipe comprises a male node formed at the condenser end and a female node receptor formed at evaporator end such that the internal heat pipes are sequentially thermally coupled to one another by securely physically coupling the male node of each internal heat pipe into the female node receptacle of the respective longitudinally adjacent internal heat pipe.

20. The structure of claim **11**, wherein each internal heat pipe comprises an interior reservoir filled with a working fluid structured to rapidly and efficiently transfer heat absorbed at the evaporator end of each internal heat pipe to the condenser end of the respective internal heat pipe.

21. A composite heat pipe structure comprising:

an outer body;

a plurality of internal heat pipe stages longitudinally disposed within and along a length of an interior cavity of the outer body, each heat pipe stage including:

at least one internal heat pipe, each internal heat pipe having an interior reservoir filled with a working fluid structured to rapidly and efficiently transfer heat from an evaporator end of the internal heat pipe to a condenser end of the respective internal heat pipe, and each internal heat pipe being longitudinally disposed within the interior cavity of the outer body such that the condenser end of the at least one internal heat pipe of each stage is thermally coupled with the evaporator end of a respective one of the at least one internal heat pipe of the longitudinally adjacent heat pipe stage so that heat absorbed at a first end of the outer body is transferred, via the internal heat pipe stages, to a second end of the outer body with a high rate of thermal efficiency.

22. The structure of claim **21**, wherein the outer body comprises cylindrical pipe.

23. The structure of claim **21**, wherein the outer body comprises a frame and end cap of a motor and the internal cavity comprises a space between the frame and end cap, and a stator assembly of the motor.

24. The structure of claim **21**, wherein the outer body comprises a portion of a turbine housing and the interior cavity comprises a space within the turbine housing.

25. The structure of claim **21**, wherein the outer body comprises a portion of a gearbox housing and the interior cavity comprises a space within the gearbox housing.

26. The structure of claim **21**, wherein the structure further comprises a heat conductive medium disposed within the cavity and surrounding the heat pipe stages, whereby the heat conductive medium improves the efficiency of a transfer of heat between the thermally coupled condenser ends and evaporator ends of the at least one internal heat pipe of each longitudinally adjacent heat pipe stage.

27. The structure of claim **21**, wherein the structure further comprises a plurality of mini lateral heat pipes disposed within the cavity and thermally connecting the condenser ends and evaporator ends of the at least one internal heat pipe of each longitudinally adjacent heat pipe stage, whereby the mini lateral heat pipes improve the efficiency of a transfer of heat between the thermally coupled condenser ends and evaporator ends.

28. The structure of claim **21**, wherein the structure further comprises a plurality of mini axial heat pipes disposed within the interior cavity and thermally connecting the longitudinally adjacent heat pipes, whereby the mini axial heat pipes improve the efficiency of a transfer of heat between the thermally coupled longitudinally adjacent heat pipes

29. The structure of claim **21**, wherein each internal heat pipe comprises a male node formed at the condenser end and a female node receptor formed at evaporator end such that the internal heat pipes are sequentially thermally coupled to one another by securely physically coupling the male node of each internal heat pipe into the female node receptacle of the respective longitudinally adjacent internal heat pipe.

30. The structure of claim **21**, wherein each heat pipe stage comprises a single internal heat pipe.

31. The structure of claim **21**, wherein each heat pipe stage comprises two or more internal heat pipes.

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