A heat pipe includes a casing and a sintered powder wick arranged at an inner surface of the casing. The sintered powder wick is in the form of a multi-layer structure of at least three layers and each layer has an average powder size different from that of the other layers, wherein the layer with large-sized powders is capable of reducing the flow resistance to the condensed liquid to flow back while the layer with small-sized powders is still capable of providing a relatively large capillary force for the wick.
HEAT PIPE WITH SINTERED POWDER WICK

TECHNICAL FIELD

[0001] The present invention relates generally to heat pipes as heat transfer/dissipating device, and more particularly to a heat pipe with a sintered powder wick.

BACKGROUND

[0002] Heat pipes have excellent heat transfer performance due to their low thermal resistance, and therefore are an effective means for heat transfer or dissipation from heat sources. Currently, heat pipes are widely used for removing heat from heat-generating components such as central processing units (CPUs) of computers. A heat pipe is usually a vacuum casing containing therein a working fluid, which is employed to carry, under phase transitions between liquid state and vapor state, thermal energy from one section of the heat pipe (typically referring to as “evaporating section”) to another section thereof (typically referring to as “condensing section”). Preferably, a wick structure is provided inside the heat pipe, lining the inner walls of the casing, for wicking the working fluid back to the evaporating section after it is condensed at the condensing section. Specifically, as the evaporating section of the heat pipe is maintained in thermal contact with a heat-generating component, the working fluid contained at the evaporating section absorbs heat generated by the heat-generating component and then turns to vapor. Due to the difference of vapor pressure between the two sections of the heat pipe, the generated vapor moves towards and carries the heat simultaneously to, the condensing section where the vapor is condensed into liquid after releasing the heat into ambient environment by, for example, fins thermally contacting the condensing section. Due to the difference of capillary pressure developed by the wick structure between the two sections, the condensed liquid is then wicked back by the wick structure to the evaporating section where it is again available for evaporation.

[0003] The wick structure currently available for heat pipes includes fine grooves integrally formed at the inner walls of the casing, screen mesh or bundles of fiber inserted into the casing and held against the inner walls thereof, or sintered powder combined to the inner walls by sintering process. Among these wicks, the sintered powder wick is preferred to the other wicks with respect to heat transfer ability and ability against gravity of the earth.

[0004] The primary function of a wick is to draw condensed liquid back to the evaporating section of a heat pipe under the capillary pressure developed by the wick. Therefore, the capillary pressure is an important parameter affecting the performance of the wick. Since it is well recognized that the capillary pressure of a wick increases due to a decrease in pore size of the wick, the sintered powder wick generally has a capillary pressure larger than that of the other wicks due to its very dense structure of small particles. In order to obtain a relatively large capillary pressure for a sintered powder wick, small-sized powder is often used so as to reduce the pore size formed between the particles of the powder. However, it is not always the best way to choose a sintered powder wick based on the size of powder, because the flow resistance to the condensed liquid also increases due to a decrease in pore size of the wick. The increased flow resistance reduces the speed of the condensed liquid in returning back to the evaporating section and therefore limits the heat transfer performance of the heat pipe. As a result, a heat pipe with a wick that has too large or too small a pore size often suffers dry-out problem at the evaporating section as the condensed liquid cannot be timely sent back to the evaporating section of the heat pipe.

[0005] Therefore, there is a need for a heat pipe with a sintered powder wick which can provide simultaneously a relatively large capillary force and a relatively low flow resistance so as to effectively and timely bring the condensed liquid back from its condensing section to its evaporating section and thereby to avoid the undesirable dry-out problem at the evaporating section.

SUMMARY

[0006] A heat pipe in accordance with a preferred embodiment of the present invention includes a casing and a sintered powder wick arranged at an inner surface of the casing. The sintered powder wick is in the form of a multi-layer structure of at least three layers and each layer has an average powder size different from that of each of the other layers.

[0007] The present invention in another aspect, relates to a method for manufacturing a sintered heat pipe. The preferred method includes steps of: (1) providing a hollow casing and at least three groups of powder with each group having an average powder size different from that of each of the other groups; (2) filling said at least three groups of powder sequentially into said casing at a location adjacent to an inner surface of the casing with the later filled group of powder being stacked on the earlier filled group of powder; and (3) conducting sintering process to the casing and the filled powder, whereby a sintered powder wick with a multi-layer structure is formed inside the casing.

[0008] Other advantages and novel features of the present invention will become more apparent from the following detailed description of preferred embodiment when taken in conjunction with the accompanying drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 is a longitudinal cross-sectional view of a heat pipe in accordance with a first embodiment of the present invention;

[0010] FIG. 2 is a longitudinal cross-sectional view of a heat pipe in accordance with a second embodiment of the present invention;

[0011] FIG. 3 is a longitudinal cross-sectional view of a heat pipe in accordance with a third embodiment of the present invention;

[0012] FIGS. 4-5 are longitudinal cross-sectional views showing the steps of a preferred method in manufacturing the heat pipe of FIG. 1; and

[0013] FIGS. 6-8 are longitudinal cross-sectional views showing the steps of a preferred method in manufacturing the heat pipe of FIG. 2.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0014] FIG. 1 illustrates a heat pipe 10 in accordance with a first embodiment of the present invention. The heat pipe 10
includes a casing 12 and a capillary wick 14 arranged at an inner surface of the casing 12. The casing 12 includes an evaporating section 121 and a condensing section 123 at respective opposite ends thereof, and a central section 122 located between the evaporating section 121 and the condensing section 123. The casing 12 is typically made of high thermally conductive materials such as copper or copper alloys. The wick 14 is saturated with a working fluid (not shown), which acts as a heat carrier for carry thermal energy from the evaporating section 121 toward the condensing section 123 when undergoing a phase transition from liquid state to vaporous state. In more detail, heat that needs to be dissipated is transferred firstly to the evaporating section 121 of the heat pipe 10 to cause the working fluid saturated in the wick 14 to evaporate. Then, the heat is carried by the working fluid in the form of vapor to the condensing section 123 where the heat is released to ambient environment and the vapor is condensed into liquid. The condensed liquid then is brought back, via the wick 14, to the evaporating section 121 where it is again available for evaporation.

[0015] The capillary wick 14 is a sintered powder wick which is formed by sintering small-sized powder, such as metal powder including copper and aluminum, or ceramic powder under high temperature. Along a longitudinal direction of the casing 12, the wick 14 has a multi-layer structure, which includes in sequence a first layer 141, a second layer 142 and a third layer 143. In this embodiment, the first, second and third layers 141, 142, 143 correspond to the evaporating, central and condensing sections 121, 122, 123 of the casing 12, respectively. Each layer of the wick 14 has an average powder size different from that of each of the other layers. The first layer 141 has the smallest average powder size, whereas the third layer 143 has the largest average powder size. That is, the three layers 141, 142, 143 are stacked together in such a manner that the average powder sizes thereof gradually increase along the longitudinal direction from the evaporating section 121 toward the condensing section 123.

[0016] Since the particle size of the powder also determines the pore size formed between the particles of the powder, the average pore sizes of these layers 141, 142, 143 also increase along the longitudinal direction from the evaporating section 121 toward the condensing section 123. According to the general rule that the capillary pressure of a wick and its flow resistance to the condensed liquid increase due to a decrease in pore size of the wick, the multi-layer construction of the wick 14 is thus capable of providing a capillary pressure gradually increasing from the condensing section 123 toward the evaporating section 121, and a flow resistance gradually decreasing from the evaporating section 121 toward the condensing section 123. Specifically, the third layer 143 and the second layer 142 have a large average pore size and therefore provide a relatively low resistance to the condensed liquid to flow back, thereby effectively reducing the barriers the condensed liquid encounters in returning back from the condensing section 123 toward the evaporating section 121. The first layer 141, however, is constructed to have a small average pore size in order to still maintain a relatively high capillary force for the wick 14. Therefore, the wick 14 is capable of providing simultaneously a relatively low flow resistance to the condensed liquid when it flows at the condensing and central sections 123, 122 and a relatively high capillary force for drawing the condensed liquid back from the condensing and central sections 123, 122 toward the evaporating section 121. As a result, the condensed liquid is timely brought back to the evaporating section 121 in an accelerated manner, thereby effectively avoiding dry-out problem happening at the evaporating section 121.

[0017] FIG. 2 illustrates a heat pipe 20 according to a second embodiment of the present invention. The heat pipe 20 includes a casing 22 and a capillary wick 24 arranged at an inner surface of the casing 22. The wick 24 is in the form of a multi-layer structure which includes an outer layer 241, an intermediate layer 242 and an inner layer 243. These layers 241, 242, 243 are stacked together along a radial direction of the casing 22 with the outer layer 241 being connected to the inner surface of the casing 22. Each layer of the wick 24 has an average powder size different from that of the other layers, and these layers 241, 242, 243 are stacked in such a manner that the average powder sizes thereof gradually increase along the radial direction from the inner surface of the casing 22 towards a central axis X-X of the casing 22. Since powder size defines pore size between particles of the powder, the average pore sizes of these layers 241, 242, 243 also gradually increase from the inner surface of the casing 22 towards the central axis X-X of the casing 22. According to the above-mentioned general rule that the capillary pressure of a wick and its flow resistance to the condensed liquid increase due to a decrease in pore size of the wick, the inner layer 243 and the intermediate layer 242 have a large average pore size and therefore are capable of providing a relatively low resistance to the condensed liquid to flow back. The outer layer 241, however, has a small average pore size and therefore is still capable of maintaining a relatively high capillary force for the wick 24. Thus, the multi-layer construction of the wick 24 is capable of providing between these layers 241, 242, 243 along the radial direction of the casing 22 a gradient of capillary pressure gradually increasing from the central axis X-X of the casing 22 toward the inner surface of the casing 22, and a gradient of flow resistance gradually decreasing from the inner surface of the casing 22 toward a central axis X-X of the casing 22. Furthermore, the small-sized outer layer 241 of the wick 24 is also capable of maintaining an increased contact surface area with the inner surface of the casing 22, as well as a large contact surface with the working fluid saturated in the wick 24, to thereby facilitate heat transfer between the heat pipe 20 and a heat source outside the heat pipe 20 that needs to be cooled.

[0018] FIG. 3 illustrates a heat pipe 30 according to a third embodiment of the present invention. Similar to the second embodiment, the heat pipe 30 also has a multi-layer powder-based capillary wick 34 arranged at an inner surface of the heat pipe 30. The wick 34 includes an outer layer 341, an intermediate layer 342 and an inner layer 343 which are stacked along a radial direction of the heat pipe 30 with the outer layer 341 being connected to the inner surface of the heat pipe 30. These layers 341, 342, 343 have different powder sizes to each other. In contrary to the second embodiment, these layers 341, 342, 343 are arranged in an order that the powder sizes thereof gradually decrease from the inner surface of the heat pipe 30 towards a central axis Y-Y of the heat pipe 30. Therefore, the large-sized outer layer 341 has a relatively large pore size and accordingly develops a relatively low resistance to the condensed liquid to return back. However, this construction of the wick 34 is
suitable for heat pipes with relatively short lengths, in comparison with the wick 24.

[0019] The heat pipe 10 as disclosed in the first embodiment can be made by using the method as illustrated in FIGS. 4-5. In order to form the multi-layer capillary wick 14, three groups of powder are prepared in advance with each group having an average powder size different from that of the other groups. Firstly, a mandrel 40 is inserted into the casing 12 with a space 50 formed between the casing 12 and the mandrel 40. The three groups of powder are sequentially filled into the space 50 with the later filled group of powder being stacked on the earlier filled group of powder along the longitudinal direction of the casing 12. The three groups of powder are filled into the casing 12 in such an order that the powder size of the later filled group of powder is larger than that of the earlier filled group of powder so as to prevent the particles of the later filled group of powder from falling into the spaces defined between the particles of the earlier filled group of powder. After all of these groups of powder are filled into the casing 12, the casing 12 with the three groups of powder is subject to heat with a high temperature, for example, about 950 degrees Celsius when the powder is copper powder, to thereby sinter the three groups of powder together whereby the heat pipe 10 with the multi-layer sintered powder wick 14 arranged along the inner surface of the casing 12 is obtained.

[0020] The heat pipe 20 as disclosed in the second embodiment can be made by using the method as illustrated in FIGS. 6-8. Three groups of powder with different powder sizes from each other are filled sequentially into the casing 22 at a location adjacent to the inner surface of the casing 22 with the later filled group of powder being stacked on the earlier filled group of powder along the radial direction of the casing 22. The three groups of powder are filled into the casing 22 in the order that the powder size of the later filled group of powder is larger than that of the earlier filled group of powder. When filling each group of powder, a mandrel is used to control the thickness thereof. For example, as illustrated in FIG. 6, a first mandrel 40a is inserted into the casing 22 to control the thickness of the first group of powder, which is to be formed as the outer layer 241 of the wick 24. Likewise, second and third mandrels 40b, 40c with smaller diameters than that of the first mandrel 40a are respectively and successively used to control the thicknesses of the second and third groups of powder, which are to be constructed as the intermediate and inner layers 242, 243 of the wick 22, respectively. In order to keep the powder in place and prevent, after the corresponding mandrel 40a, 40b or 40c is drawn out, the powder from dropping into the hollow space that is originally occupied by the corresponding mandrel 40a, 40b or 40c, each group of powder is pre-sintered at a suitable temperature, for example, about 630 degrees Celsius in the context of copper powder, before the corresponding mandrel 40a, 40b or 40c is used to control the thickness thereof is drawn out of the casing 22. Finally, all of these groups of powder filled into the casing 22 together with the casing 22 are sintered under a high temperature, for example, about 950 degrees Celsius to thereby obtain the heat pipe 20 with the multi-layer sintered powder wick 24 arranged in the casing 22. It is apparent that, if the filling order of the three groups of powder into the casing 22 is reversed, this method is also suitable for manufacturing the heat pipe 30 of the third embodiment. In this situation, in order to prevent the later filled small-sized powder from falling into the spaces defined between particles of the former filled large-sized powder, partitioning means such as a layer of polymeric bonding agent can be applied between every two adjacent groups of powder. However, the bonding agent can be decomposed by subsequently applying heat thereto.

[0021] It is to be understood, however, that even though numerous characteristics and advantages of the present invention have been set forth in the foregoing description, together with details of the structure and function of the invention, the disclosure is illustrative only, and changes may be made in detail, especially in matters of shape, size, and arrangement of parts within the principles of the invention to the full extent indicated by the broad general meaning of the terms in which the appended claims are expressed.

What is claimed is:
1. A heat pipe comprising:
   a casing; and
   a sintered powder wick arranged at an inner surface of the casing;
   wherein the sintered powder wick is in the form of a multi-layer structure of at least three layers and each layer has an average powder size different from that of each of the other layers.
2. The heat pipe of claim 1, wherein said at least three layers are stacked in such a manner that the average powder sizes thereof increase along a predetermined direction.
3. The heat pipe of claim 2, wherein said direction is a radial direction of the casing.
4. The heat pipe of claim 2, wherein said direction is a longitudinal direction of the casing.
5. The heat pipe of claim 1, wherein the sintered powder wick is one of a sintered metal powder wick and a sintered ceramic powder wick.
6. A method for manufacturing a heat pipe comprising steps of:
   providing a hollow casing and at least three groups of powder with each group having an average powder size different from that of each of the other groups;
   filling said at least three groups of powder sequentially into said casing at a location adjacent to an inner surface of the casing with the later filled group of powder being stacked on the earlier filled group of powder; and
   conducting sintering process to the casing and the filled powder, whereby a sintered powder wick with a multi-layer structure is formed inside the casing.
7. The method of claim 6, wherein said at least three groups of powder are filled into said casing in such an order that the average powder size of the later filled group of powder is larger than that of the earlier filled group of powder.
8. The method of claim 6, wherein a mandrel is used to be inserted into said casing with a space formed between the casing and the mandrel, and said at least three groups of powder are filled into said space to be stacked along a longitudinal direction of the casing.
9. The method of claim 6, wherein said at least three groups of powder are stacked along a radial direction of the
casing, and when filling each group of powder, a mandrel is used to control a thickness thereof.

10. The method of claim 9 further comprising a step of pre-sintering each group of powder before a corresponding mandrel used to control a thickness thereof is drawn out of the casing.

11. A heat pipe comprising:

a metal casing having an outer surface and an inner surface;

a wick formed on the inner surface of the metal casing; and

working fluid received in the metal casing and capable of becoming into vapor upon receiving heat at a first place of the heat pipe and liquid upon releasing the heat at a second place of the heat pipe, the liquid being drawn by the wick from the second place of the heat pipe to the first place of the heat pipe; wherein the wick forms capillary pressure in drawing the liquid, the capillary pressure being in gradient along one of radial and longitudinal directions of the heat pipe.

12. The heat pipe of claim 11, wherein the wick is formed by sintering powders having different powder sizes.

13. The heat pipe of claim 12, wherein the powders have three different sizes, with the powders having the largest size being located near the second place of the heat pipe and the powders having the smallest size being located near the first place of the heat pipe.

14. The heat pipe of claim 12, wherein the powders have three different sizes, with the powders having the largest size being located close to the casing and the powders having the smallest size being located close to a center of the heat pipe.

15. The heat pipe of claim 12, wherein the powders have three different sizes, with the powders having the largest size being located close to a center of the heat pipe and the powders having the smallest size being located close to the casing.

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