A heat pipe comprises a hollow wick impregnated with a liquid heat medium and an outer tubular cylinder within which the wick is installed and hermetically sealed. The wick is made up of a ribbon-shaped material of relatively narrow width wound in the form of a helix and is fabricated by winding the wick material preferably in alternately opposite helical directions on a mandrel, which is thereafter extracted to leave a hollow tubular wick.

7 Claims, 3 Drawing Figures
PRIOR ART

FIG. 1

FIG. 2

FIG. 3
HEAT PIPE AND MANUFACTURING METHOD THEREOF

BACKGROUND OF THE INVENTION

The present invention relates generally to heat pipes and more particularly to a heat pipe having a wick construction such as to effectively transfer a liquid heat medium by capillary action from a condensing section to a heating section, and also to a method of manufacturing the same.

In general, a heat pipe comprises a hollow sealed vessel, a wick material disposed on the inner wall surface of this vessel, and an evaporative liquid heat medium impregnated in the wick material. The function of the wick is to transfer by capillary action the liquid heat medium which has been condensed in the condensing section of the heat pipe to the heating section (evaporation part).

Examples of wick materials used hitherto are netting of extremely fine mesh made of wire materials of metals such as SUS and Cu, netting of extremely fine mesh of non-metal materials such as glass fiber and fireproof fabrics, and sintered alloys of fine granular structure.

Of these wick materials, the netting materials have the advantages of simple composition and low cost of production but, on the other hand, have had the following drawbacks.

1. A net-form wick of both great width and great length is difficult to produce, whereby limits are imposed on the length and diameter of heat pipes which can be produced.

2. It is difficult to cause the wick material to adhere intimately to the inner wall surface of the outer cylinder constituting the sealed vessel of the heat pipe, whereby there is possibility of obstruction of heat transfer and increase in the thermal resistivity therebetween.

3. In the case where the outer cylinder is made of a flexible material, and a flexible heat pipe is produced, the wick does not easily and smoothly bend, whereby the heat pipe becomes bent. Furthermore, the wick easily separates from the outer cylinder.

4. In the case where the wick is installed in a multi-layer arrangement, the layers of the wick easily separate in local portions.

5. The treatment of the end parts of the wick is difficult, whereby the yield of the material is poor.

SUMMARY OF THE INVENTION

Accordingly, it is a general object of the present invention to provide a novel and useful heat pipe and a method of producing the same in which the above described difficulties are overcome.

Another object of the invention is to provide a heat pipe having a new wick construction and a method of producing the same. A feature of this wick construction is that a wick net ribbon having a suitable width is wound in a helical form. By adopting this wick construction, it is possible to produce a long heat pipe, even when a wick net ribbon of relatively small width is used.

A further object of the invention is to provide a heat pipe having a wick construction wherein the directions of the mesh strands are inclined relative to the axial direction of the heat pipe and to provide of method of producing the same. When this wick construction is incorporated in a heat pipe having an outer cylinder made of a flexible material, the wick can deflect without bending sharply and without separating from the outer cylinder to which it intimately adheres when the heat pipe is bent. Furthermore, when an external stress is applied locally to a part of this heat pipe, it does not give rise to a local depression or flattening of the pipe since the wire material of the wick netting resists this stress.

A still further object of the invention is to provide a heat pipe having a multilayer wick construction wherein wick netting ribbons constituting the multiple layers are alternately wound in opposite helical winding directions. This structural feature affords high resistance to separation between the wick layers and effective transfer due to capillary action of the liquid heat medium.

Further objects and features of the invention will be apparent from the following detailed description when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

In the accompanying drawings:

FIG. 1 is a schematic perspective view, with a part cut out, for a description of the operation of the heat pipe of known type;

FIG. 2 is a perspective view for the description of an intermediate step of winding a wick netting ribbon in the process of forming a wick for the heat pipe of the invention; and

FIG. 3 is a perspective view, with a part cut away, of an exemplary embodiment of a heat pipe according to the invention.

DETAILED DESCRIPTION

As conductive to a full understanding of the present invention, the principle of a heat pipe of known type to which the wick construction constituting an essential part of the invention is applicable will first be described in conjunction with FIG. 1.

The outer cylinder 11 of this heat pipe has the shape of a hollow cylinder or tube with closed ends, the interior space thereof being hermetically sealed from the outside. A wick 12 is disposed to extend along the inner wall surface of the outer cylinder 11 and is impregnated with a liquid heat medium such as water, acetone, ammonia or methanol, etc.

When one end part (heating part) A of the outer cylinder of the heat pipe 10 is heated, the liquid within the wick 12 at that end part is heated and vaporizes, absorbing heat of vaporization. The resulting vapor of the heat medium enters a vapor passageway 13 through the center of the heat pipe.

When the liquid thus vaporizes, the pressure in the region rises, whereby this vapor travels in the arrow direction through the passageway 13 in a state of holding the heat of vaporization, that is, a latent heat. This vapor thus reaching the right end part (as viewed in FIG. 1) of the passageway 13, that is, a cooling part B, condenses at the outer surface of the wick 12, discharging its heat of vaporization. Furthermore, the condensation of the vapor gives rise to a lowering of the vapor pressure at this part, whereby the above mentioned movement of the vapor in the arrow direction occurs continuously.

Thus, heat applied to the outer cylinder 11 in the heating part A at one end of heat pipe 10 is transferred to the cooling part B at the other end of the heat pipe 10 and is there discharged, whereby heat transfer is accomplished.
The liquid heat medium which has condensed in the wick 12 at the cooling part B is conveyed by capillary action through the wick 12 to the heating part A. Thereafter, in the same manner, the above described operation is repeated continuously, and the heat medium thereby undergoes repeated circulation.

In the above described operation, the intimate contact of the wick 12 to the inner wall surface of the outer cylinder 11 has a great influence on the performance of the above mentioned heating and cooling parts and on the contact thermal resistivity within the heat pipe, and becomes an important factor determining the performance of the heat pipe. Furthermore, in the case where the heat pipe is to be used in a deflected or curved state, it is necessary to prevent the wick from buckling and separating from the inner wall surface of the outer cylinder 11.

The present invention contemplates the provision of a high performance heat pipe in which the above mentioned problems are solved by the incorporation therewith of a wick of a construction as described below.

In the fabrication of the wick in the heat pipe of the invention, a wick material 20 having meshes and having the shape of a ribbon of relatively narrow width and long length as indicated in FIG. 2 is prepared. For this material, a suitable material heretofore used as a wick material is used in the form of many strands disposed in the width and length directions to form netting meshes.

This ribbon wick material 20 is wound helically around a mandrel 21 of an outer diameter substantially equal to the diameter of the vapor passageway 13 of the heat pipe 10 in which the wick is to be formed. During this winding, the starting end of the wick material is cut beforehand or after winding so that the final end edge 20 of the wick will be perpendicular to the axis of the mandrel 21. In addition, the end edge is hemstitched or bound with a binding fiber or wire to prevent unraveling thereof.

Then, the wick material 10 is wound preferably helically in one direction around the mandrel 21 in a manner such that adjacent lateral edge parts of the wick material do not overlap but are in mutually intimate contact without gaps therebetween. At the same time, the adjacent edge parts of the wick material 20 thus wound are stitched together with the same binding fiber or wire as mentioned above, as shown at 22.

When the wick material 20 progressively wound in this manner reaches a specified wound length from the winding start point, the terminal part of the material is cut at right angles to the heat pipe axis, similarly as in the case of the winding starting part, and stitching is carried out. Thus, a cylindrical wick 23 of one layer is formed.

In order to fabricate the wick 12 with multiple layers in the heat pipe 10, the wick material 20 is wound over the first wick layer 23 in a helical wending direction opposite that of the first wick layer thereby to form a second wick layer. In this manner, this helical wending in alternately opposite directions is repeatedly carried out until the desired number of layers is obtained.

Finally, the two ends of the wick thus obtained are stitch-bound or otherwise finished by a procedure such as welding, brazing, or bonding with an adhesive. Thereafter, the mandrel 21 is extracted. Thus, a wick 30 of the desired length, diameter, and number of layers can be fabricated (see FIG. 3).

While, in the fabrication of a wick of multiple layers in the above described manner, it is possible to stitch together the adjacent edge parts of the tape material 20 in only the innermost and outermost layers and to omit this stitching in the intermediate layers, it is preferable that this stitching 22 be carried out in all layers.

It has also been found that the angle of inclination of the wick material 20 relative to the axis of the mandrel 21 (i.e., the angle between the axial direction of the mandrel 21 and the direction of the lateral edges of the wick material 20) in the above described process of helically wending the wick material 20 is preferably 45°. When this angle is used, the resulting wick has maximum flexibility. For this purpose, the width W of the wick material 20 is selected to satisfy the equation \( W = \pi D/2 \), where \( D \) is the outer diameter of the wick 30.

Next, the wick 30 formed in the above described manner is inserted into an outer cylinder 31 as indicated in FIG. 3. Then, by means of an expansion tool or jig (not shown), the wick 30 is expanded outward from its hollow interior thereby to force the outer surface of the wick 30 into intimate contact with the inner wall surface of the outer cylinder 31.

One example of this expansion tool is simply a sphere of an appropriate diameter which is forced through the hollow interior of the wick 30 within the outer cylinder 31 from one end of the wick to the other (not shown).

In this process, if a force is applied to the wick 30 to compress it in the axial direction in conjunction with the use of the expansion tool, the wick 30 will have a natural tendency to expand outward since it is made up of helically wound wick material, whereby the intimate contact between the wick and the outer cylinder 31 will be further improved. In this case, since the strands of the netting meshes of the wick material forming the wick 30 extend at an inclination (preferably 45°) relative to the axial direction of the wick 30, the wick has the ready tendency to expand as a result of axial compressive force imparted thereto, whereby it contacts firmly and intimately against the inner wall surface of the outer cylinder 31.

Furthermore, in the case where the wick 30 is made up of a few layers, e.g. one or two layers, it is possible to cause it to expand into intimate contact with the inner surface of the outer cylinder 31 with the use of an expansion tool, by pulling the wick 30 beforehand slightly in the axial direction to cause a reduction in the diameter thereof, inserting the wick in this condition into the outer cylinder 31, and then applying an axial compression in reverse to the wick.

After the wick 30 has been thus inserted into and caused to adhere intimately to the outer cylinder 31, an end cover 32 is secured to each end of the outer end of the outer cylinder 31 thereby to render the outer cylinder into a hermetically sealed vessel. Thereafter, the interior of the outer cylinder 31 is evacuated by an evacuating device, such as a vacuum pump, and the wick 30 is impregnated with a liquid heat medium. The end covers 32 may be provided separately with wick material secured to their inner surfaces. Thus, a heat pipe 33 according to the invention is completed (FIG. 3).

Since this wick is formed by wending a wick material of ribbon form into a helical structure as described above, the wick tends to expand when an axially compressive force is applied thereto as described above, whereby the diameter of the wick is caused to expand and the wick contacts intimately the inner wall surface of the outer cylinder. For this reason, it is possible to reduce the contact thermal resistance in the interior of
the heat pipe to a very low value. Furthermore, the aforementioned capillary action is also improved.

Furthermore, since the strands forming the netting meshes of the wick are inclined relative to the wick axis, the netting mesh angle varies as a result of deflection or bending of the heat pipe 33 and pliably follows the bending. Accordingly, there is no possibility of buckling of the wick, whereby there is no separation of the wick from the inner surface of the outer cylinder.

In the case of a wick made up of several layers, since the wick material in alternate layers is wound helically in opposite directions, the layers strongly resist separation thereof and exhibit high strength with respect to bending without losing their pliability. In such a case of a multiple layer wick construction, since the actual cross sectional area of the wick including the spaces between the layers becomes large, that much more liquid can be absorbed and transferred, and a heat pipe of a large heat transfer capacity can be obtained.

As another effect of the inclined orientation of the strands of the wick relative to the heat pipe axis, all strands resist any local force imparted to a part of the heat pipe thereby to resist local flattening of the heat pipe.

Moreover, since the wick is made up of wound wick material of relatively narrow width, a wick of any desired length can be readily formed, and even a wick of great length can be easily produced. In addition, the quantity of wick material which must unavoidably be scrapped as waste in this production is small, and the wick can be produced at low cost.

Further, this invention is not limited to the described embodiments but various variations and modifications may be made without departing from the scope and spirit of the invention.

What is claimed is:

1. A heat pipe comprising a hollow wick impregnated with a liquid heat medium and an outer tubular cylinder accommodating said wick in a hermetically sealed condition, said wick including a ribbon-shaped material wound in the form of a helix, mutually adjacent lateral edges of said wick material being disposed in intimate contact with each other, without overlapping or separating, and bound with each other by hem stitching.

2. The heat pipe as defined in claim 1, wherein said wick material is formed as a netting with intersecting strands respectively extending in the longitudinal and transverse directions of said material, said strands being wound in both directions of said wick in the form of the helix, oriented with an inclination relative to the axial direction of the heat pipe.

3. The heat pipe as defined in claim 2, wherein the inclination of said strands is substantially substantially degess.

4. A method of manufacturing a heat pipe, comprising the steps of forming a ribbon-shaped hollow wick in the form of a helix in such a manner that mutually adjacent lateral edges of the wick material are disposed in intimate contact with each other, without overlapping or separating, binding the lateral edges of the wick material with each other, hermetically sealing the wick within a tubular outer cylinder, and impregnating the wick with a liquid heat medium.

5. The method as defined in claim 4, wherein said forming step includes the steps of winding the ribbon-shaped wick helically around a mandrel of a diameter close to the prescribed inner diameter of the hollow wick, and extracting the mandrel from the wound wick material.

6. The method as defined in claim 4, further comprising the step of applying a force to the wick in the outer cylinder in an axial direction thereof, thereby to cause the diameter of the wick to expand, and to cause the outer surface of the wick to contact intimately the inner wall surface of the cylinder.

7. The method as defined in claim 4, further comprising the step of expanding the wick in the outer cylinder so as to contact intimately the inner wall surface of the cylinder, by forcibly passing a sphere through the hollow interior of the wick, the sphere having a diameter slightly larger than the inner diameter of the hollow wick.