United States Patent [19]

Kosson et al.

[11] **3,901,311**

[45] **Aug. 26, 1975**

[54] **SELF-FILLING HOLLOW CORE ARTERIAL HEAT PIPE**

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[73] Assignee: **Grumman Aerospace Corporation**, Bethpage, N.Y.

[22] Filed: **Jan. 12, 1973**

[21] Appl. No.: **323,150**

[52] **U.S. Cl.** **165/105**; 138/40; 122/366

[51] **Int. Cl.** **F28d 15/00**

[58] **Field of Search** 165/105; 261/92, 94, 99; 62/511, 494; 138/40, 44; 122/366

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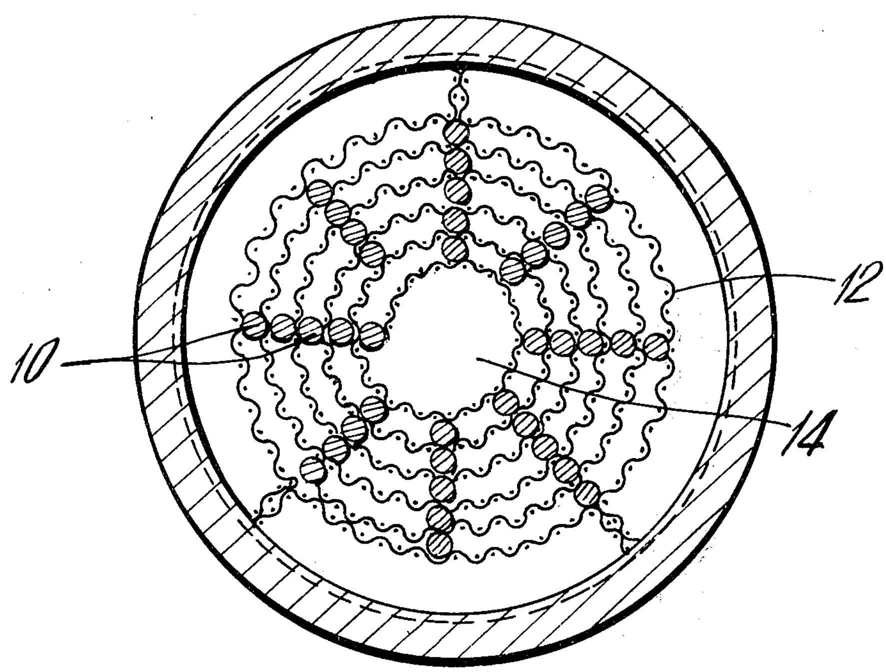
Primary Examiner—Albert W. Davis, Jr.
Attorney, Agent, or Firm—Morgan, Finnigan, Pine, Foley & Lee

[57] **ABSTRACT**

An arterial heat pipe is disclosed which is self-filling and has a high capacity. It comprises a porous structure that is disposed around a hollow core.

27 Claims, 15 Drawing Figures



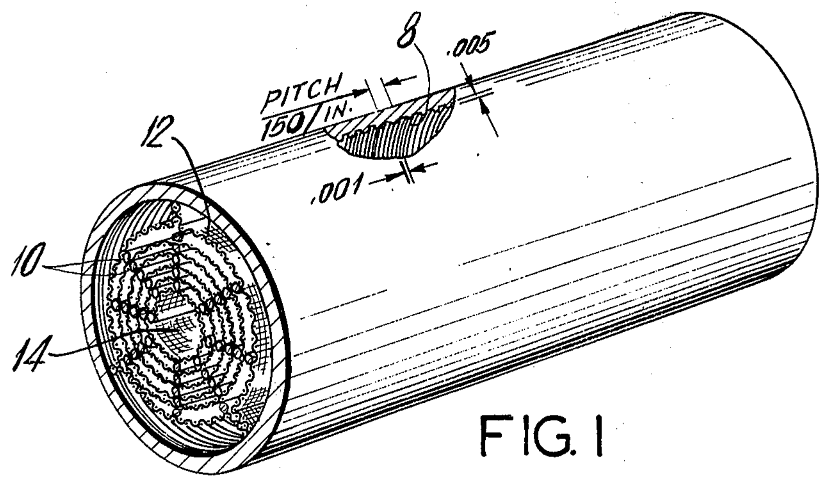


FIG. 1

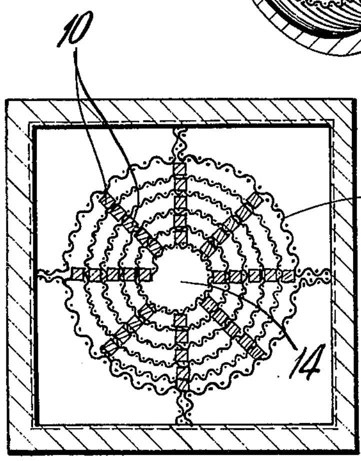


FIG. 3

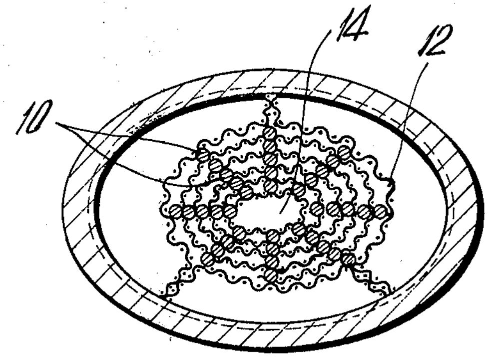


FIG. 4

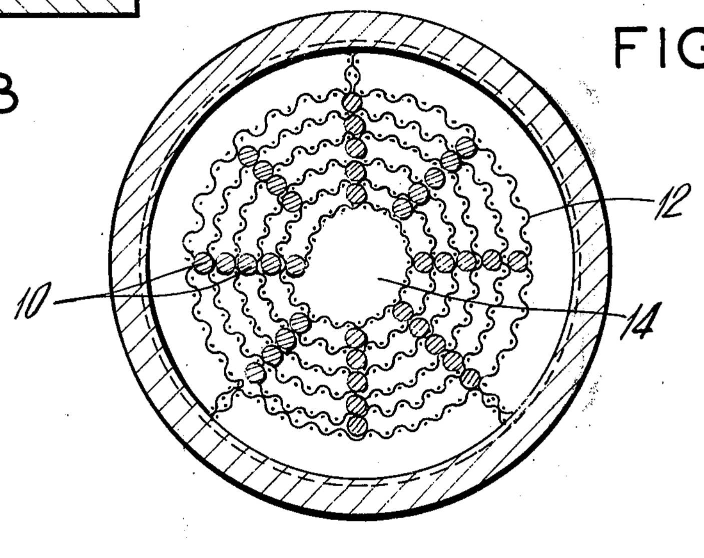


FIG. 2

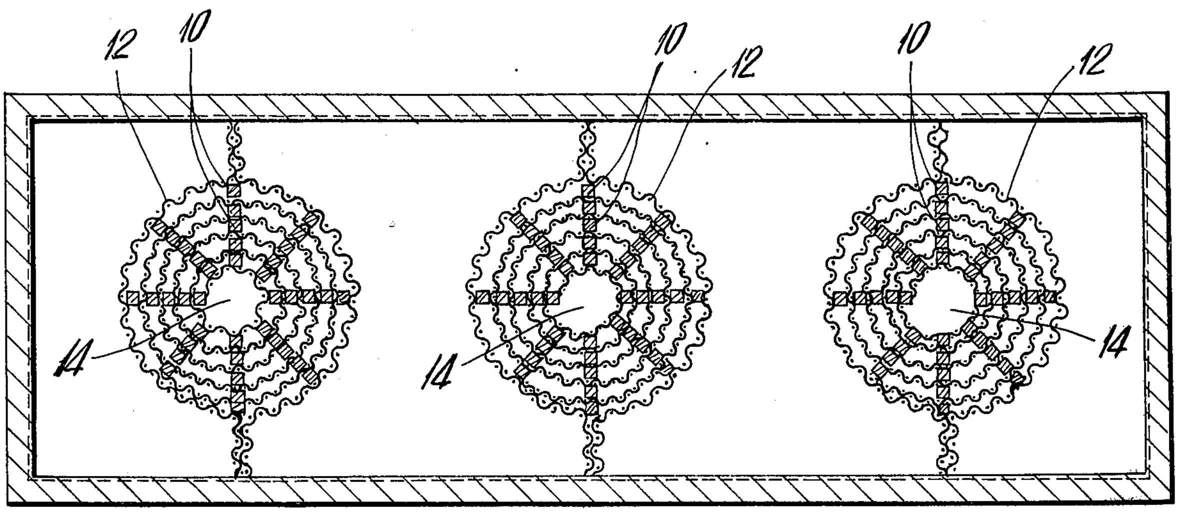


FIG. 5

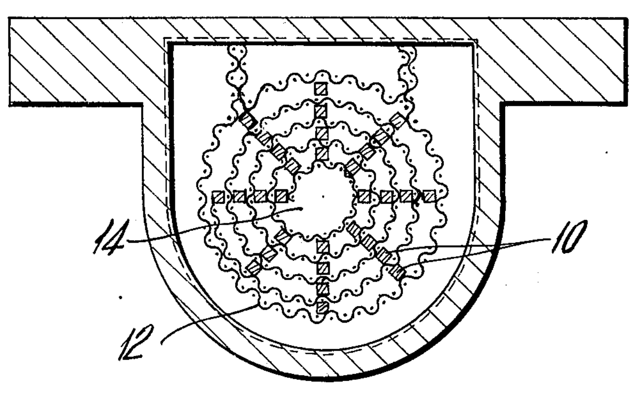


FIG. 6

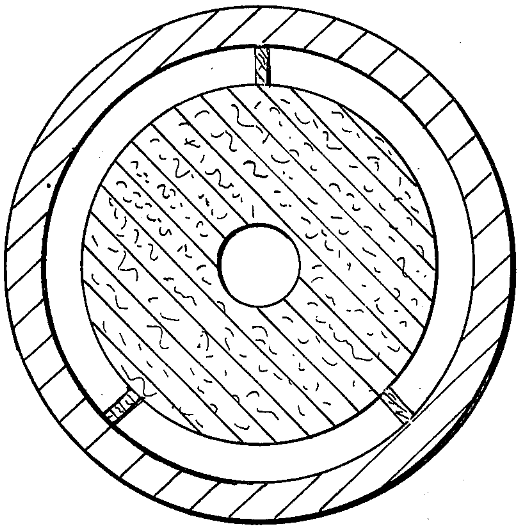


FIG. 7

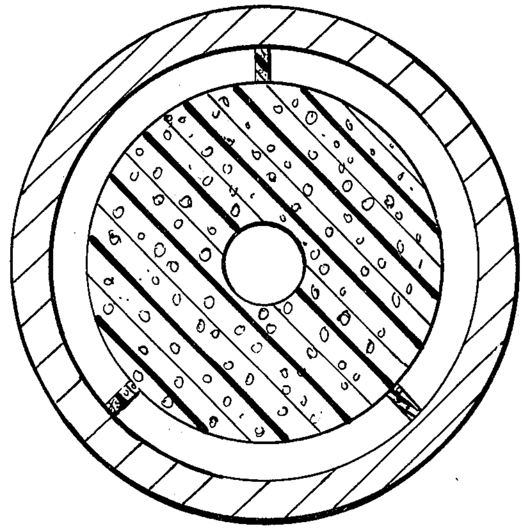


FIG. 8

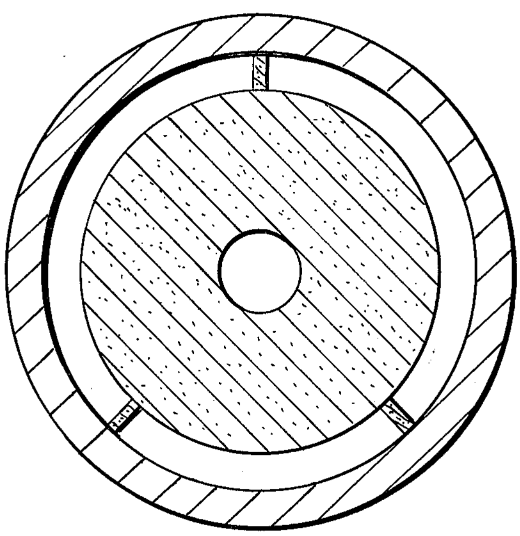


FIG. 9

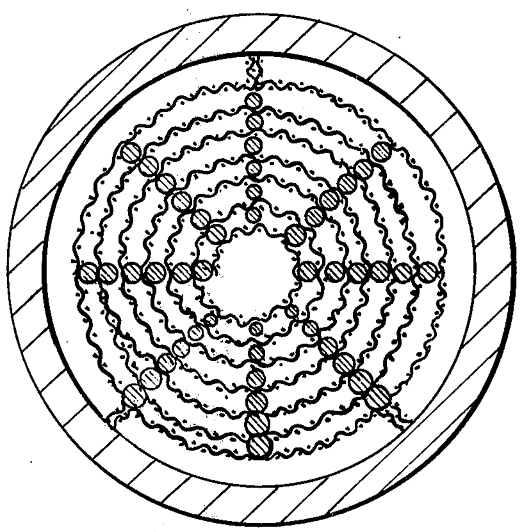


FIG. 10

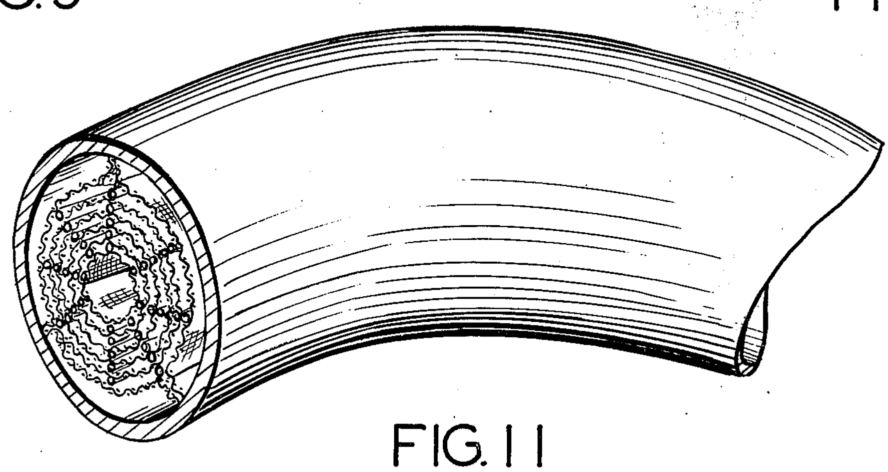


FIG. 11

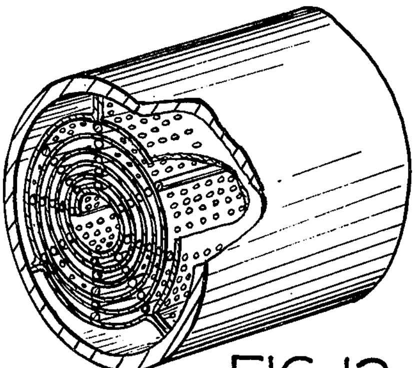


FIG. 12

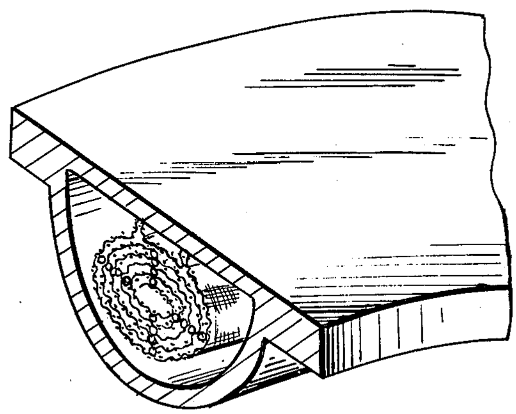


FIG. 15

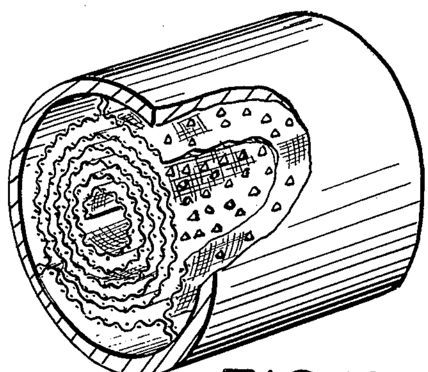


FIG. 13

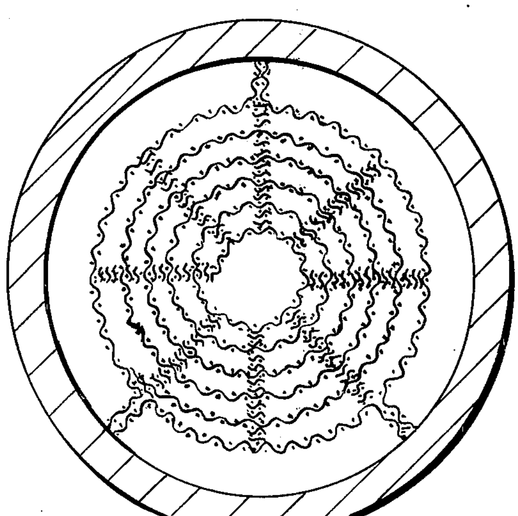


FIG. 14

SELF-FILLING HOLLOW CORE ARTERIAL HEAT PIPE

BACKGROUND OF THE INVENTION

Heat pipes have been described in the prior art which have arteries which could be filled by immersing the artery in the vaporizable liquid which was used in the heat pipe. After filling, these prior art heat pipes were easily drained of the vaporizable liquid which would collect at the lower part of the heat pipe. This draining phenomenon was apparently caused by a pressure differential between vapor and liquid at a given point on the artery surface where said pressure differential exceeds the value which can be sustained by surface tension. If the heat pipe is tilted or transient pressure variations are induced by vibration, the liquid pressure will drop. This may occur due to manufacturing defects in the artery surface. Also, heat pipes have been limited in the heat transfer capabilities by the design of the artery configuration.

It is therefore a primary object of this invention to provide a new and novel heat pipe which is self-filling and has a high capacity for heat exchange which is provided by a porous artery that is disposed around a hollow core. The structure of this heat pipe includes an outer casing and a supported axially disposed artery which is preferably formed by a plurality of screen layers which are formed around a supporting means which results in an axially disposed free space within the artery.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is an elevation of a section of a heat pipe of this invention which shows in partial cutaway, the wall capillary which is a grooved surface on the internal wall of the casing.

FIG. 2 is a cross-sectional view of a heat pipe according to the present invention.

FIG. 3 is a cross-section of a heat pipe of this invention which is generally square in cross-section.

FIG. 4 is a cross-section of a heat pipe of this invention which is ovoid in cross-section.

FIG. 5 is a cross-section of a heat pipe of the invention which has flat sides and more than one artery.

FIG. 6 is a cross-section of a heat pipe of the invention which has one flat side.

FIG. 7 is a cross-section of a heat pipe of the invention wherein the artery is made of felt.

FIG. 8 is a cross-section of a heat pipe of the invention wherein the artery is made of open cell foam.

FIG. 9 is a cross-section of a heat pipe of the invention wherein the artery is made of sintered metal.

FIG. 10 is a cross-section of an artery of the invention wherein the spacer means are elongated rods having different cross-sectional areas.

FIG. 11 is an elevation of a heat pipe of the invention where the casing extends through an arcuate path.

FIG. 12 is a partial cutaway of a heat pipe of the invention where the screen layers are formed of a perforated metal sheet.

FIG. 13 is a partial cutaway of a heat pipe of the invention wherein the spacing means between the screen layers are a plurality of elevated points.

FIG. 14 is a cross-section of a heat pipe of the invention wherein the spacing means in the artery comprise a plurality of screening strips that are spaced between the screen layers.

FIG. 15 is an elevation of a heat pipe wherein the casing has one flat side and extends through an arcuate path.

DETAILED DESCRIPTION OF THE INVENTION

The heat pipe of this invention comprises a closed outer casing having a wall capillary and a vaporizable liquid carried therein and having an axially disposed artery formed by a porous structure that is disposed around a means which forms an axially disposed hollow core.

The porous structure may be made of felt, open-celled foamed materials, sintered metal structures which are formed, for example, by powder metallurgy or by the sintering of multi-layered knitted or woven multi-layered screen structures or most preferably by a plurality of screen layers, said screen layers being separated by spacing means to provide a spacing of said screen layers which will permit capillary filling of said artery and longitudinal flow of vaporizable liquid. The artery may be formed by wrapping screens and spacers on a mandrel. Once the predetermined size is reached, the mandrel is removed.

The artery of said heat pipe may be formed by winding a screen in a spiral around a hollow perforate mandrel to build up a multi-layered structure. The mandrel may be made of screening or any other perforate material which will provide structural support for the artery with substantially unrestricted liquid flow from the screen layers to the inner part of said hollow mandrel. As the multi-layered plurality of screen layers are formed around the hollow core, spacer means may be placed at predetermined intervals to form an artery structure which will fill by capillary action.

Whether the artery is made of a supported screen layered structure or of other materials, the porosity will be controlled so as to permit capillary filling of the artery and longitudinal flow of vaporizable liquid in the portion of the artery surrounding the axially disposed hollow core. The operable degree of porosity may be readily ascertained by adjustment of the density of the selected material to suit the physical characteristics of the selected vaporizable liquid.

Two or more legs (i.e., up to about **16**) may be employed for this purpose. The legs or webs may have openings therein. These openings may be from about **1/20** to about ⅔ of the total area of the leg. Only a small number of these are required if it is desired to equalize vapor pressure cirumferentially in the heat pipe. This vapor pressure corresponds to the saturation pressure of the vaporizable liquid at the temperature of the evaporator (hot) end of the heat pipe. The hollow core, when it is not filled with liquid, will contain vapor at a pressure which corresponds to the saturation pressure of the vaporizable liquid at a temperature only slightly above the temperature of the condenser (cold) end of the heat pipe. The vapor pressure in the hollow core will be lower than the vapor pressure on the outside of the artery, hence liquid will flow into the artery, condensing the vapor in the hollow core, until the artery core is completely filled with liquid. The filling process has been termed "Clapeyron" or "pressure" priming and has been used to fill artery cores having diameters too large to fill by surface tension (capillary) forces alone. The hollow core constitutes a liquid flow passage with low viscous losses compared with the surrounding annulus. In this type of heat pipe it is believed that upwards of **90** percent of total fluid flow is obtained in said hollow core which accounts for the high heat transfer capability.

The annulus surrounding the hollow core is essential to the pressure priming process. It provides enough liquid flow to establish and maintain the temperature differences within the pipe needed to initiate the pressure priming process.

The heat pipe may have a casing which is substantially linear or one which extends through an arcuate path to form a generally curved type of structure. These curved type structures may be either generally toroidal, e.g., semi-circular or U-shaped. Either of these types of heat pipes may be circular, square, rectangular or ovid in cross-section.

Other embodiments of the heat pipe may be shaped with cross-sections having one or more flat sides or a plurality of arteries may be arranged side-by-side with appropriate dividing walls to form a multiple heat pipe type of assembly. Such heat pipes may be used for special purposes, for instance, as the means for cooling a

Similarly when a screen-type artery is employed, the selection of the dimensions of the spacer means must be matched to the particular vaporizable liquid in order to make a self-filling artery. The spacer means may be round, square, oval or rectangular elongated rods. It is also contemplated that elevated points at spaced intervals on the surface of the screen may be used as spacing means. These elevated points may be in the form of dimples formed by deformation of the screen material itself or that are applied by bolting, welding, soldering or adhesively bonding an appropriate metal, plastic or other suitable type of material to the surface of the screen. An alternate spacing means may comprise strips of screening that are fastened to the screen layers or held by friction within the layered structure.

As specific materials there may be used open-celled foamed, sintered, powdered, woven or knitted metal or felt material or polymeric structures such as selected polyurethane foams in addition to the screen spacer rod structures. Metals may be ferrous or non-ferrous or alloys thereof. The selected material should be inert with respect to the selected vaporizable liquid and should be readily wettable thereby. Those skilled in the art will appreciate that capillarity is a result of the attractive force between unlike molecules which is shown by the wetting of a solid surface by a liquid and is dependent on the nature of the liquid and the solid as well as the particular configuration of the solid material.

A typical artery according to this invention may have a hollow internal space with 1–20 percent of the total cross-sectional area of the heat pipe. The spacers which separate the layers will be sized to achieve a layer separation in the range of about 0.005 inch to about 0.020 inch. When liquid ammonia is used as the vaporizable liquid, circular rods having a diameter of from about 0.009 inch to about 0.020 inch, preferably about 0.016 inch have been found to be operable.

Rods or spacing means may be provided in graded sizes with slightly larger spaces being provided toward the outer area of the artery.

Other usable vaporizable liquids include water, acetone; methyl alcohol and low molecular weight halogenated hydrocarbons such as dichloromonofluoromethane, dichlorodifluoromethane, monochlorodifluoromethane, carbontetrafluoride and the like.

It is contemplated that the heat pipes of this invention will by usable from low to moderately high temperatures as for example, from cryogenic levels to about 300°F.

The screen layers may be made of stainless steel, aluminum, fiberglass or any metal alloy or any material which is compatible with the selected vaporizable liquid.

The screen layers may also be made of spaced annular rings of different sizes. The screen itself may be of a woven, knitted or perforated type of construction. Mesh sizes (U.S. standard mesh) in the order of about 50 to about 350 mesh, preferably about 100 mesh may be used depending on the particular vaporizable liquid. A variety of homogeneous porous materials such as compressed steel wool may also be used in place of the multiple layers of screen.

In a preferred embodiment the hollow core artery will be supported by a plurality of radially disposed legs or webs which will space the artery at approximately equal distances from the internal surface of the heat pipe. These legs may be made of screening and will preferably extend along the entire length of the artery. large surface area which is exposed to high temperatures.

The wall capillary may be a brazed screen or liner which is affixed to the internal wall or it may be a spiral groove which is cut or etched into the wall of the heat pipe. The grooves may also be a series of unconnected grooves which extend around the internal wall of the heat pipe.

The width of these grooves should be small enough to fill under surface tension forces. This is to insure that longitudinal flow will be maintained along the internal walls of the heat pipe and localized "hot spots" due to drying out of the wall will be avoided.

The grooves may be spaced so that these are about 60 to about 300 per inch, preferably about 250 per inch and are cut about 0.0015 inch – 0.0075 inch wide, preferably about 0.0050 inch wide and about 0.010 inch in depth. It is preferred to cut these grooves so that they are trapezoidal in cross-section.

The grooves should be sized so that their geometrical capillary characteristics match those of the leg or web screening components used to fabricate the supporting parts of the artery and that said parts communicate with substantially all of the wall capillary. An aluminum screen of 120 U.S. standard mesh has been found useful for a screen wall capillary when brazed to the internal wall of the heat pipe.

DESCRIPTION OF THE PREFERRED EMBODIMENT

An eight ft., one inch I.D. aluminum tube was provided with 150 circumferential wall grooves 8 per inch, with a depth of 0.005 inch, an opening of 0.002 inch and a root of 0.001 inch. A solid mandrel 0.200 inch in diameter was wrapped with 100 mesh woven stainless steel screening, each wrap being separated by 0.013 inch spacer wires 10 which are spaced so as to separate the screen layers 12. Thereafter, an annular mesh screen sock or sleeve may be placed around the artery to maintain geometric continuity and the mandrel is withdrawn leaving the hollow core 14. The sleeve, if used, may be made by soft soldering or welding a seam on an annularly formed screen which is sized to cover the outside of the artery. Thereafter, the ends of the artery are covered with 100 mesh caps (not shown). The artery legs 16 or webs which also act as supports, are formed by spot welding three sections of wire screening so that a circular tube retaining assembly is formed with three double screen sections extending outwardly at **120°** intervals on the surface of said circular tube. The double screen outwardly extending projections are trimmed so that they are long enough to touch the internal walls of the heat pipe but not long enough to prevent proper installation in the heat pipe by frictional engagement with the threaded internal wall.

Thereafter, the artery is placed in the circular tube retainer assembly and this is then fitted into the heat pipe casing. The pipe is then capped, with one cap having a small diameter fill tube attached. The heat pipe is then charged with ammonia through the fill tube, which is then sealed by welding.

In another embodiment, an aluminum screen was brazed to the wall of the tube to form the wall capillary which engaged with an artery supported by eight legs.

Although the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that changes may be made in the form and details therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A heat pipe having a closed casing, a wall capillary and a vaporizable liquid carried thereby and including an axially disposed artery formed by a porous structure disposed around a hollow core, said porous structure having a controlled porosity which permits capillary filling of said porous structure and pressure priming of the hollow core, with said artery and said hollow core providing longitudinal flow of vaporizable liquid, said axially disposed artery being supported in said heat pipe by a plurality of legs.

2. The heat pipe of claim **1** wherein said porous structure is formed from felt.

3. The heat pipe of claim **1** wherein said porous structure is formed from an open-celled foam material

4. The heat pipe of claim **1** wherein said porous structure is formed from a sintered metal structure.

5. A heat pipe having a closed casing, a wall capillary and a vaporizable liquid carried thereby and including a supported axially disposed artery formed by a plurality of screen layers that are disposed around a hollow core and are separated by spacing means to provide a spacing of said screen layers which will permit capillary filling of said screen layers and pressure priming of the hollow core, with both providing longitudinal flow of vaporizable liquid, said supported axially disposed artery being supported in said heat pipe by a plurality of legs.

6. The heat pipe of claim **5** wherein the plurality of screen layers are formed by a spirally wound screen.

7. The heat pipe of claim **2** wherein the spacing means comprise a plurality of elongated rods.

8. The heat pipe of claim **7** wherein the elongated rods have different cross-sectional area.

9. The heat pipe of claim **7** wherein the elongated rods have the same cross-sectional area.

10. The heat pipe of claim **5** wherein the wall capillary system has a configuration which matches the screening components of the supported axially disposed artery.

11. The heat pipe of claim **5** wherein the casing of said heat pipe has a substantially linear configuration.

12. The heat pipe of claim **11** wherein said heat pipe is substantially circular in cross-section.

13. The heat pipe of claim **11** wherein said heat pipe has a cross-section with at least one flat side.

14. The heat pipe of claim **5** wherein said screen layers are formed of woven metal wire mesh.

15. The heat pipe of claim **5** wherein the screen layers are formed of from about 50 to about 350 mesh stainless steel woven wire screening.

16. The heat pipe of claim **5** wherein the wall capillary is a series of unconnected, grooves which extend around the internal wall of the heat pipe.

17. The heat pipe of claim **5** wherein the axially disposed artery is supported by at least two legs that are constructed of screen mesh.

18. The heat pipe of claim **5** wherein the plurality of screen layers are concentrically disposed annular rings.

19. The heat pipe of claim **5** wherein the axially disposed artery is supported in the heat pipe by a plurality of screen mesh legs.

20. The heat pipe of claim **5** wherein the plurality of screen layers are formed of a knitted wire structure.

21. The heat pipe of claim **5** wherein the wall capillary is a spiral groove which is cut into the wall of the closed casing.

22. The heat pipe of claim **5** wherein said heat pipe has a casing which extends through an arcuate path.

23. The heat pipe of claim **17** wherein said heat pipe is substantially circular in cross-section.

24. The heat pipe of claim **17** wherein said heat pipe has a cross-section with at least one flat side.

25. The heat pipe of claim **5** wherein said screen layers are formed of a perforated metal sheet.

26. The heat pipe of claim **5** wherein the spacing means comprise a plurality of elevated points on the surface of said screen layers.

27. The heat pipe of claim **5** wherein said spacing means comprise a plurality of screening strips which are spaced between the screen layers.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,901,311 Dated August 26, 1975

Inventor(s) Robert Kosson et al.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 3, line 14, "ovid" should read -- ovoid --.

Claim 7, claim reference numeral "2" should read -- 5 --.

Claim 23, claim reference numeral "17" should read -- 22 --.

Claim 24, claim reference numeral "17" should read -- 22 --.

Signed and Sealed this

twenty-seventh **Day of** *April 1976*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks