# United States Patent [19]

**Waters**

[11] **3,822,743**

[45] **July 9, 1974**


[54] **HEAT PIPE WITH PLEATED CENTRAL WICK AND EXCESS FLUID RESERVOIR**


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[22] Filed: **Nov. 20, 1972**

[21] Appl. No.: **307,790**

**Related U.S. Application Data**

[62] Division of Ser. No. 182,038, Sept. 20, 1971, Pat. No. 3,720,988.

[52] **U.S. Cl.** ..... **165/105,** 29/191

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

[58] **Field of Search** ..... 136/86; 29/157.3 R; 165/105



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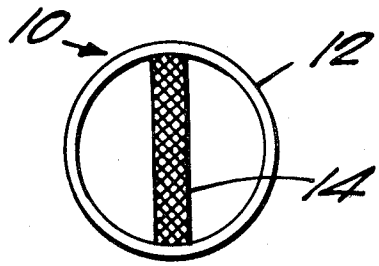
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*Attorney, Agent, or Firm*—D. N. Jere; Walter J. Jason; Donald L. Royer



[57] **ABSTRACT**

A heat pipe wick structure including a homogeneous central wick is fabricated by forming a plurality of laterally disposed longitudinal pleats in a sheet of wire screen, and compressing the formed pleats laterally together and inserting the same longitudinally into the tubular container of a heat pipe. The pleats can be formed in a laterally central portion of the sheet with a flat screen portion on each side thereof, and the side portions are turned back over opposite sides of the formed central wick to serve as wall screens in the tubular container. Reservoir screens having a generally U-shaped cross section normally engaged by the formed pleats can be additionally installed on both sides of the central wick in the tubular container.


**5 Claims, 4 Drawing Figures**



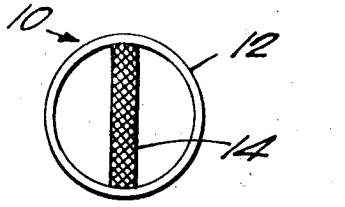
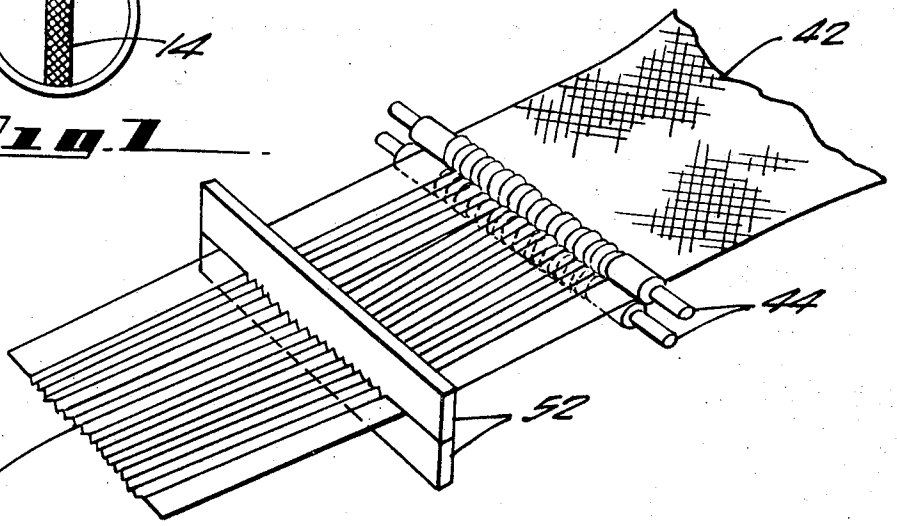



Fig. 1



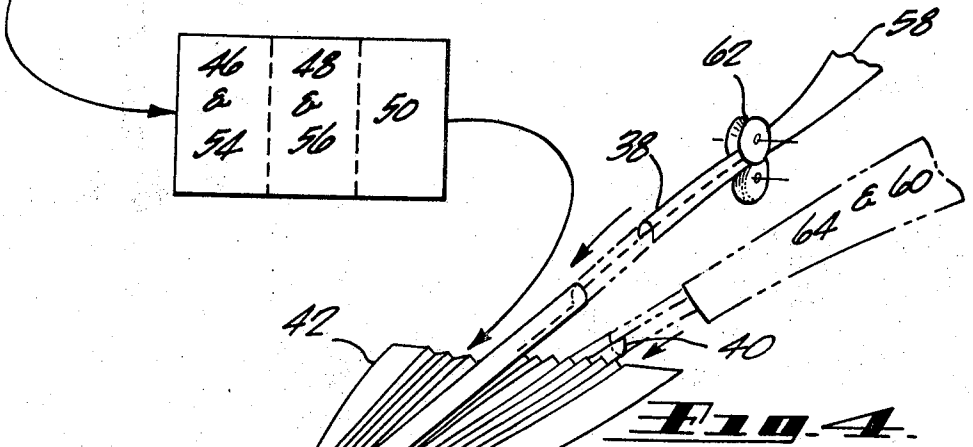




Fig. 4

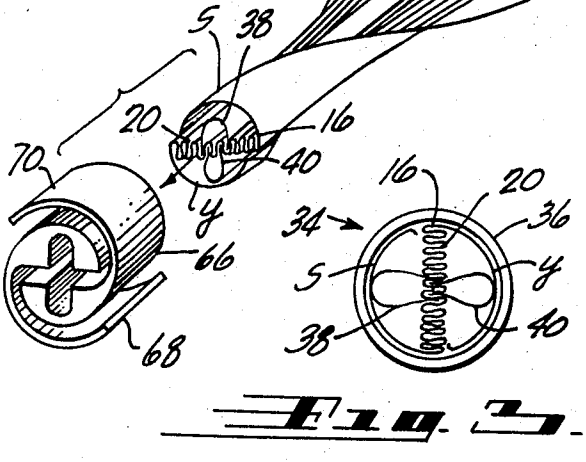



Fig. 3

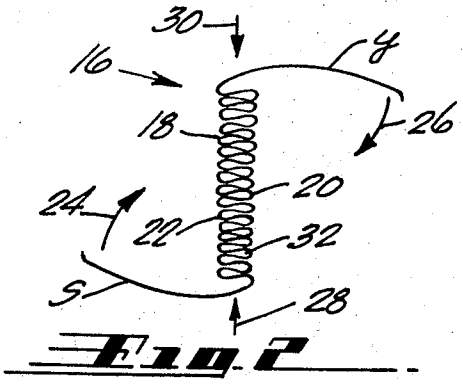



Fig. 2

# HEAT PIPE WITH PLEATED CENTRAL WICK AND EXCESS FLUID RESERVOIR

This is a division of application Ser. No. 182,038 filed Sept. 20, 1971, now U.S. Pat. No. 3,720,988.

## BACKGROUND OF THE INVENTION

My present invention pertains generally to the field of heat pipes and, more particularly, to a novel heat pipe wick and method of making the same.

A great deal of trouble has been encountered in making and installing a porous central wick in a heat pipe. The earlier porous central wicks were fabricated from foamed metals in a generally rectangular cross sectional configuration and longitudinally installed in the tubular container of a heat pipe. For relatively long heat pipes, however, the producers of porous (foamed) metals have not been able to make long and uniform wick structures which can be feasibly installed in a heat pipe. The foamed metals are quite fragile and, moreover, their effective porosity or permeability to liquid flow is frequently not as good as desired or required. Of course, it is impossible to install a foamed metal wick in an angularly formed or bent heat pipe, or to form or bend the tubular container having a foamed metal wick installed therein without seriously damaging the wick. A better and more durable porous central wick was obviously desirable and clearly needed for heat pipes.

## SUMMARY OF THE INVENTION

Briefly, and in general terms, my invention is preferably accomplished by providing a heat pipe wick structure including a homogeneous central wick which is fabricated by forming a plurality of laterally disposed longitudinal pleats in a sheet of wire screen or similar material of predetermined length and width, and compressing the formed pleats laterally together and inserting the same longitudinally into an open end of the tubular container of a heat pipe. The central wick is secured diametrically in position by the elastic expansion of the formed pleats in the tubular container and consequent engagement therewith. The pleats are arranged in a stack providing a plurality of longitudinal passageways with small diameter pores or openings. Compression of the stack reduces the pore diameter of the passageways.

The plurality of pleats can be formed in a laterally central portion of a sheet of wire screen with a flat screen portion on each side of the central portion. The side portions can be turned back over opposite sides of the formed central wick and, after installation of the central wick and turned side portions in the tubular container of a heat pipe, the turned side portions are positioned therein as wall screens for conveying and spreading liquid to the tubular container wall and any circumferential or longitudinal grooves thereof.

Reservoir screens to take up excess liquid and prevent possible blockage of a cooler (condenser) portion of the heat pipe can also be installed therein. The reservoir screens are preferably formed from respective sheets of wire screen or similar material of predetermined length and width, and are longitudinally installed on both sides of the formed central wick. Each reservoir screen preferably has a generally U-shaped cross section wherein the open ends are engaged by the compressed pleats of the central wick and are thus held in a fixed position in the heat pipe.



## BRIEF DESCRIPTION OF THE DRAWING

My invention will be more fully understood, and other features and advantages thereof will become apparent, from the following description of an exemplary embodiment and method of making the invention. The description is to be taken in conjunction with the accompanying drawing, in which:

FIG. 1 is an elevational end view of a heat pipe having a sintered, homogeneous central wick;

FIG. 2 is an elevational end view of a wick being schematically formed according to this invention for installation in the tubular container of a heat pipe;

FIG. 3 is an elevational end view of a heat pipe including a wick structure fabricated in accordance with my invention; and

FIG. 4 is a fragmentary perspective view, shown partially in schematic and diagrammatic form, of illustrative apparatus for fabricating the wick structure and installing it in the tubular container of a heat pipe.

## DESCRIPTION OF THE PRESENT EMBODIMENT AND METHOD

In the following description of an exemplary embodiment and method of making my invention, some specific dimensions and types of materials are disclosed. It is to be understood, of course, that such dimensions and types of materials are given as examples only and are not intended to limit the scope of this invention in any manner.

FIG. 1 is an elevational end view of an open (uncapped) heat pipe **10** including an elongated tubular container **12** and a central (diametrical) homogeneous wick **14.** The container **12** has a generally circular cross section, and the wick **14** has a generally rectangular cross section with slightly rounded ends. The container **12** is made of a suitable metallic tube having a relatively thin wall thickness. The wick **14** is fabricated by stacking many layers of fine wire cloth in a stack and then vacuum sintering the stack into an integral assembly which is press-fitted into the container **12.** A dense homogeneous wick of fine pore size capable of pumping against high gravity heads is thus produced. The assembly of wire cloth layers and sintering processes are, however, very time-consuming and another method of making a porous, central wick structure was developed.

FIG. 2 is an elevational end view of a wick **16** being schematically formed according to this invention. The basic construction and features of the wick **16** are illustrated in this figure. The wick **16** is constructed in a long continuous length of fine woven wire screen **18** folded lengthwise back and forth along its width into a vertical stack or core **20** of horizontal pleats or convolutions **22.** The lower and upper end portions S and y of the screen **18** are formed into semicircular cylindrical wall screens as indicated by the arrows **24** and **26,** and the entire structure is inserted into an elongated tubular container preferably of a circular cross sectional chamber. The stack **20** is vertically compressed together as indicated by arrows **28** and **30** as it is inserted and installed in the tubular container. It is noted that the end portions S and *y* can be omitted from the wick **16,** particularly when a fine screw thread (not shown) has been tapped in the internal wall surface of the tubular container to spread the working

fluid (liquid) therein. If only a number of formed pleats is desired, these can be cut out of the stack **20.**

It can be easily seen that the wick **16** is readily self-supporting within a heat pipe extrusion (tubular container) and creates its own spring force, both in the stack **20** and in the end portions S and *y*, to ensure good diametrical and circumferential wall contacts, respectively. The folded screen wick structure clearly has good stability and is not fragile. It can be tailored to achieve whatever pore size desired. When the screen **18** was folded a number of times into the stack **20,** small individual passageways **32** are created which act as longitudinal pores or flow passages to give high axial conductance of the working fluid (liquid). If a smaller pore size is needed for pumping or refilling against a gravity head, then more folds of the screen **18** are provided and the stack **20** pressed more firmly together into the tubular container. Nevertheless, the wick **16** (central stack **20**) has an effective permeability to liquid flow of the order of 100 times that for an equivalent multilayered sintered wick **14** (FIG. **1**). The wick **16** can also be fabricated very inexpensively as compared to the sintered wick **14.** While the stack **20** preferably has a generally rectangular cross section, it can be of a different cross sectional configuration such as an oval one or a non-uniform one wherein the pleats **22** are varied in their horizontal widths vertically along the stack as may be desired or required.

FIG. **3** is an elevational end view of a heat pipe **34** including a tubular container **36** having wick **16** installed therein together with two excess liquid reservoir screens **38** and **40.** The wick **16** and reservoir screens **38** and **40** preferably extend substantially over the full internal length of the tubular container **36** which is hermetically closed (sealed) after it has been properly charged with a predetermined amount of a suitable working fluid. The reservoir screens **38** and **40** are provided to take up excess liquid rather than have it accumulate at the cooler (condenser) end portion of the heat pipe **34** and block up such portion thereof. Thus, the reservoir screens **38** and **40** provide static storage spaces to accommodate any volume increases of the working fluid. These screens **38** and **40** can also help maintain the semicircular end portions S and *y* (wall screens) in firm contact with the internal wall surface of the tubular container **36** so that the wall screens can better bring liquid to the container wall surface and/or any circumferential screw thread (helical) grooves or longitudinal grooves therein. Of course, the reservoir screens **38** and **40** can be radially shorter and need not contact the wall screens at all.

The wick **16** and the reservoir screens **38** and **40** are quite flexible and this allows the heat pipe **34** to be angularly bent or otherwise formed essentially without damage in any respect. Of course, the central portion (stack **20**) of wick **16** retains its high porosity without any damage since it is also flexible but not fragile. Illustratively, for a ½ inch pipe with a 0.42 inch inner diameter, the stack **20** of wick **16** can have a lateral thickness (pleat or convolution width) of 0.1 to 0.12 inch and a pleat spacing gap (curved end portions or passages) of approximately 0.004 inch, for example. The wick **16** and the reservoir screens **38** and **40** can be fabricated of either a 100 mesh × 0.003 inch diameter wire screen or a 200 mesh × 0.002 inch diameter wire screen. The working fluid can be, for example, anhydrous ammonia. Of course, various other working fluids including water can be used as may be desired or required.

FIG. **4** is a fragmentary perspective view, shown partially in simplified and diagrammatic form, of exemplary apparatus for fabricating the wick **16** and screens **38** and **40,** and assembling them together for direct installation in the tubular container **36** (FIG. **3**). It is noted that the elevational end view of wick **16** and screens **38** and **40** as shown in FIG. **3** is of one end of the heat pipe **34** whereas the generally similar end view of such elements as shown in FIG. **4** is of the other end (rotated 90°) of the heat pipe. The wick **16** is made by passing fine woven wire screen material **42** through, for example, four successive sets of forming rolls **44, 46, 48** and **50.** The first three sets of rolls **44, 46** and **48** are preferably followed by respective sets of combs **52, 54** and **56.** The sets of rolls **44, 46** and **48,** and their respective sets of combs **52, 54** and **56** have pleat forming teeth profile angles of 120°, 90° and 60°, for example. The last set of rolls **50** has a pleat forming teeth profile angle of, for example, 30°. Thus, as the screen material **42** is passed from one set of rolls (and combs) to the next, the pleated shape is progressively formed until it becomes ready for insertion into the tubular container **36.** The last set of rolls **50** need not be followed by a set of combs because of the fineness of the pleats formed by that time.

Simultaneously with the formation of the pleated material **42,** reservoir screen materials **58** and **60** are being formed into U-shaped reservoir screens **38** and **40** by respective sets of rolls **62** and **64.** The unpleated end portions or side flanges S and *y* of the screen material **42** can be turned over by a wick turning guide **66** to form such side flanges to the inner diameter of tubular container **36** for wall screens. The guide **66** includes lower and upper sections **68** and **70** which are rigidly secured to fixed structure or are fixedly mounted within a suitable housing (not shown) attached to fixed structure. The guide **66** is preferably tapered conically to flare radially outwards a small amount from front to back in order to facilitate insertion and turning of the pleated screen material **42.** The reservoir screens **38** and **40** are, of course, inserted into the guide **66** at the same time as the screen material **42** which is formed into a wick **16** including central stack **20** and wall screens S and *y*.

It is noted that in the end view configuration shown in FIG. **4,** the upper reservoir screen **38** is laterally spread very slightly wider at its open end (cross sectionally viewed) than is the lower reservoir screen **40** and both screens are, in this instance, illustratively shown radially shorter than as indicated in the other end view of FIG. **3.** These are very minor and inconsequential differences since the main purpose of the reservoir screens **38** and **40** is to provide static storage spaces to take up excess liquid that would otherwise accumulate in the vapor spaces at the condenser end of the (closed) tubular container **36.** The pleats of the central stack **20** merely engage the open ends of the reservoir screens **38** and **40** to secure them structurally.

For greater structural stability, the reservoir screens **38** and **40** are preferably secured at a middle section of the central stack **20** and are long enough radially so that their outer ends contact and engage the wall screens S and *y* as illustrated in FIG. **3.** This is, of course, not absolutely necessary and the screens **38** and

40 can be radially shorter as shown in FIG. 4. Also, the radial open ends of the screens 38 and 40 can be secured to sections other than the middle section of central stack 20, either both to the same section or separately to respectively different sections of the central stack. In fact, if the reservoir screens 38 and 40 were structurally secured by other means than by the (pleats of) central stack 20, the open ends of the screens 38 and 40 can be closed and they can be positioned in any location in the spaces between the central stack and the wall screens S and y.

Referring further to FIG. 3, the radially inner open ends of the reservoir screens 38 and 40 are secured between pleats at each side of a middle section of the central stack 20. The radially open ends of the screens 38 and 40 can be spaced as close together as possible so long as they can be structurally secured firmly by the pleats of the stack 20. The radially open ends of the screens 38 and 40 should not, however, be secured excessively spread apart by a middle section (of the stack 20) which is more than, for example, about one-sixth of the stack's diametrical length.

Liquid normally enters the static storage space of a reservoir screen through its longitudinally (passageway) open end. In FIG. 3, this is perpendicular to the plane of the paper into the passageway area generally enclosed by a reservoir screen. While the longitudinally open end of a reservoir screen normally abuts against the plane of the closing end cap, there are abutting gaps which are large compared to the screen pores to provide preferred (lower resistance) passage of liquid therethrough and entry into the reservoir screen through its longitudinally open end. Of course, where the cooler (condenser) portion of the heat pipe 34 is located in a longitudinally middle part of the tubular container 36, excess liquid from the liquid in the stack 20 enters the reservoir screens 38 and 40 through the radially open ends thereof. In this instance, the reservoir screens 38 and 40 are preferably secured to the middle section of stack 20, where the liquid normally tends to concentrate.

It can be seen from FIG. 3 that the reservoir screens 38 and 40, together with the stack 20, divide the tubular container 36 cross sectionally into six passageways with three on each side of the diametrical stack. The passageways of the screens 38 and 40 must have a greater capillary pumping action than their adjacent passageways (areas exterior thereto) in order to fill with liquid first. Capillary pumping pressure of a passageway is broadly dependent upon its effective capillary pumping radius or, very generally, proportional to the sum of the reciprocals of the cross sectional width and length of the passageway. Thus, the radially open ends of the screens 38 and 40 cannot be spread too far apart at the stack 20 since the screens' effective capillary pumping radii are then excessively increased, such that their pumping pressures would be so reduced that they would not be filled first with surplus liquid, and blockage of the condenser end may occur.

The reservoir screens 38 and 40 preferably extend over the full internal length of the heat pipe 34. The screens 38 and 40 can, however, extend over the entire pipe 34 length except for the evaporator region thereof, or the screens can cover only the condenser region of the heat pipe. The reservoir screens 38 and 40 are preferably provided in the heat pipe 34 where it is to be used in a zero gravity environment, and are preferably omitted where it is to be used in a gravity field which normally serves to return liquid to the evaporator region. The wall screens S and y and/or suitable liquid spreading grooves in the internal wall surface of the tubular container 36 are desirably used in both zero and normal gravity environments to provide proper spreading and resupply of liquid to the walls in the heat pipe 34 under dynamic operating conditions.

In summary, a simple and efficient method has been disclosed for making a wick structure in long lengths and assembling it in a heat pipe without requiring expensive tooling. The wick structure can be fabricated without the need for special furnaces employing relatively difficult sintering processes. A wick structure is produced which can be tailored to meet the desired permeability requirements of any particular application. The wick structure can be made with a high porosity (low effective density) and yet not be fragile. The wick structure is also highly flexible and allows a heat pipe containing it to be angularly bent or otherwise formed to a considerable degree without damage to either part.

While an exemplary embodiment and method of my invention have been described above and shown in the accompanying drawing, it is to be understood that the particular embodiment and method described are merely illustrative of, and not restrictive on, the broad invention and that various changes in design, structure and arrangement may be made in the invention without departing from the spirit and scope of the appended claims.

I claim:

1. A heat pipe comprising:
   - a wick structure including a plurality of laterally disposed longitudinal pleats formed in a first sheet of mesh screen material of predetermined length and width, said pleats being arranged in a stack providing a plurality of longitudinal passageways with small diameter pores, and said pleats being normally expandable elastically whereby compression of said stack reduces the pore diameter of said passageways;
   - a tubular container, said stack of pleats being compressed together and longitudinally installed in said tubular container with the ends of said stack engaging opposing walls in said container; and
   - a predetermined amount of working fluid provided in said tubular container.

2. The invention as defined in claim 1 wherein said plurality of pleats are uniformly formed with rectangular planforms and compressed together in a stack to provide a longitudinal wick structure having a substantially rectangular cross section.

3. The invention as defined in claim 1 further comprising at least one reservoir screen formed from a second sheet of mesh screen material of predetermined length and width, said reservoir screen being normally secured in a fixed position to said stack and longitudinally coupled thereto with an effective capillary pumping radius to take up excess volume increases in said working fluid whereby blockage in said heat pipe can be precluded.

4. The invention as defined in claim 1 wherein said plurality of laterally disposed longitudinal pleats are formed in a laterally central portion of said first sheet with a flat screen portion of predetermined width on each side thereof, said side portions being turned back

over opposite sides of said stack and contacting wall surfaces in said tubular container when installed therein to provide wall screens for said heat pipe.

5. The invention as defined in claim 4 further comprising at least one reservoir screen having a generally U-shaped cross section formed from a second sheet of mesh screen material of predetermined length and width, said formed reservoir screen being normally secured in a fixed position to said stack and longitudinally coupled thereto with the U-shaped cross section open ends of said reservoir screen engaged by said pleats of said stack.

* * * * *

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# UNITED STATES PATENT OFFICE
# CERTIFICATE OF CORRECTION

Patent No. 3,822,743 Dated July 9, 1974

Inventor(s) Elmer D. Waters

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

Front page, left column, Code "[76]" should read --[75]--; and below the Inventor data, insert --[73] Assignee: McDonnell Douglas Corporation, Santa Monica, California--. Front page, right column, in the Attorney, Agent, or Firm data, the name "D. N. Jere" should read --D. N. Jeu--.

Signed and sealed this 10th day of December 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents