United States Patent

van Loo

[15] 3,656,545

[45] Apr. 18, 1972

[54] FIBROUS VAPOR COOLING MEANS

[72] Inventor: **Conenraad van Loo**, San Jose, Calif.

[73] Assignee: **Varian Associates**, Palo Alto, Calif.

[22] Filed: **May 21, 1968**

[21] Appl. No.: **730,704**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 668,082, Sept. 15, 1967, abandoned.

[52] **U.S. Cl.**.....**165/74,** 62/64, 62/316, 165/105, 313/36, 313/44, 313/46

[51] **Int. Cl.**.....**H01j 7/24,** F28f 13/00

[58] **Field of Search**.....165/105, 74, 134, 133; 313/36, 313/44, 46; 174/15; 62/316, 514, 64

[56] **References Cited**

UNITED STATES PATENTS

801,489	10/1905	Uthemann	165/134 X
2,829,870	4/1958	Poppe	313/44 X
2,883,446	4/1959	Nye	174/35
3,066,499	12/1962	Fisher et al.	174/15 X
3,360,035	12/1967	van Loo et al.	165/105
3,405,299	10/1968	Hall et al.	165/105 X
194,510	8/1877	Butler	62/316
296,432	4/1884	Moebius	62/316 X
1,063,312	6/1913	Amsbary	62/316

Primary Examiner—Albert W. Davis, Jr.

Attorney—Stanley Z. Cole

[57] **ABSTRACT**

Improved means for vapor cooling a surface submersed in a liquid cooling agent, said means comprising a fibrous layer held in intimate relation with the surface. The fibrous layer defines a plurality of spacial paths communicating between opposite sides thereof, said paths comprising interspersed vapor conduits and capillaries. In one embodiment the fibrous layer comprises a plurality of stainless steel fibers spun into yarns which are knitted together into a fabric.

13 Claims, 7 Drawing Figures

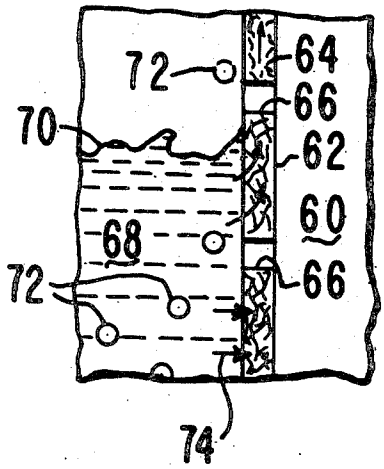


FIG. 1

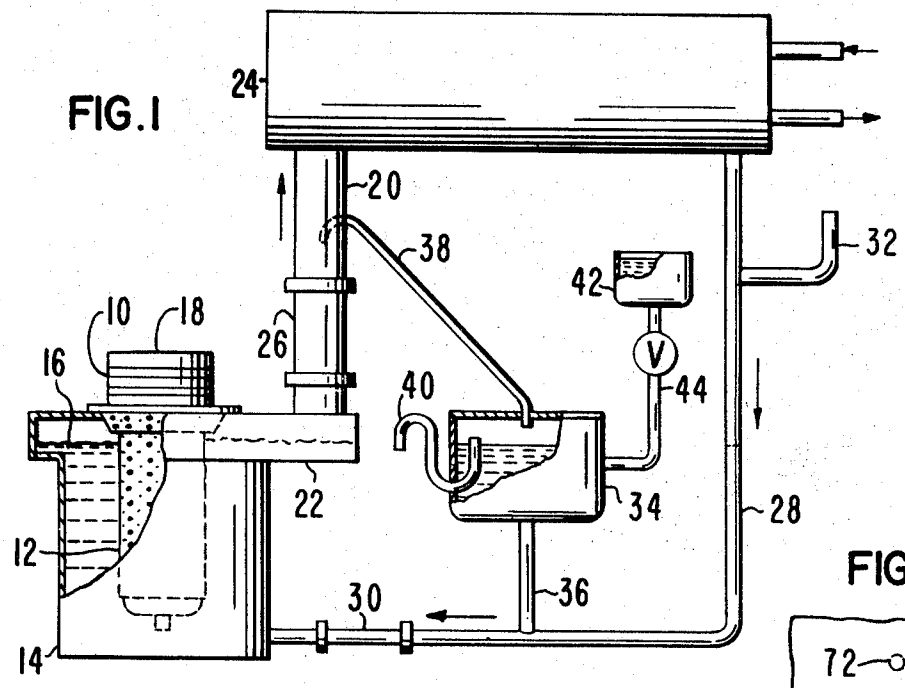
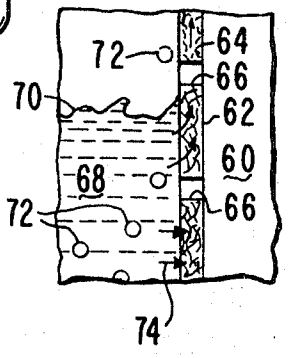


FIG. 3



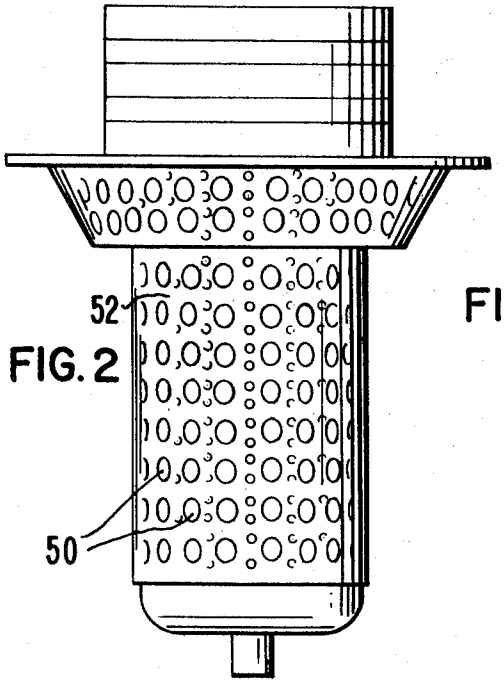


FIG. 2

FIG. 4

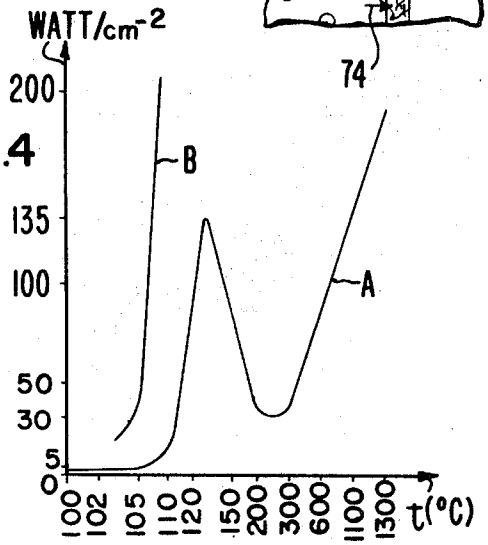


FIG. 2A





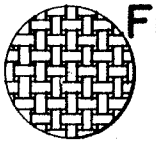


FIG. 2C

FIG. 2B

INVENTOR.
COENRAAD VAN LOO
BY
Robert W. Dilts
ATTORNEYS

FIBROUS VAPOR COOLING MEANS

BACKGROUND OF THE INVENTION

This is a continuation-in-part of my copending application, Ser. No. 668,082, filed Sept. 15, 1967, now abandoned.

This invention relates to improved vapor cooling means.

Vapor phase cooling principles and techniques have been used for some time now in cooling devices such as high power electron tubes and nuclear fuel elements. By this technique the latent heat of vaporization phenomenon is used to advantage by having a liquid dissipate such heat from a surface being cooled upon vaporization of the liquid. This heat dissipation is in addition to that normally conducted from the surface by unvaporized liquid.

Heat is dissipated from the surface of a heated object submersed in a liquid such as water by vaporization of that liquid which is in abutment with surface sections. Once a vapor bubble has been formed it must be removed from the heated surface and replaced with additional liquid. If the vapor bubble were to remain in contact with the surface, additional heat could only be dissipated there by conventional conduction which naturally would be insufficient in systems designed for vapor cooling. Failure to remove the bubble and replace it with unvaporized liquid causes a "hot spot" to form resulting in destruction of the device due to overheating.

Compounding this problem of fluid-dynamics is the fact that the vaporized fluid must be continuously replaced with liquid with but minimal impedance to the flow of the departing vapor. As impeding forces to this flow increase, the rate of flow decreases thereby decreasing the rate of heat dissipation. These forces will also cause larger bubbles to develop prior to departure from the heated surface. During formation of a large bubble it remains in contact with the heated surface where it essentially acts as a heat dam. This increases the chance of hot-spot formation resulting in device overheating or "run away." Moreover, even a vapor film may form on a relatively large surface area causing effective reversion from vapor cooling to conduction cooling for that area. This inevitably results in irreversible overheating.

Ideal vapor cooling nucleation would apparently consist of large numbers of small vapor bubbles forming uniformly along the interface of a heated surface and a liquid having a high latent heat of vaporization. Ideal ebullition would be rapid removal of the vapor bubbles from the surface and immediate replenishment of the vacated space with additional liquid which has but minimally impeded the flow of the departing bubbles. To date these ideals have not been achieved. Lesser degrees of success have served as a limitation of the art.

More recently the broad principal of vapor cooling has been combined with the phenomenon of capillarity in a cooling device known as the heat pipe. In practice it has less general application than vapor cooling devices of today. But where the heat pipe can be used, it can isothermally dissipate vast quantities of heat.

The heat pipe consists of an evacuated tubular envelope having a capillary lining covering its interior surface. It contains a small quantity of liquid which saturates the capillary lining and which has a substantial vapor pressure at the desired operating temperature. The liquid is vaporized at a heat input end of the tube, condenses at a heat output end, and is returned to the heat input end by either gravitational, capillary attraction or both through the capillary lining. This lining may thus be thought of as an ordinary wick although in practice it usually is composed of inorganic materials for added life.

Where it has application the heat pipe offers several particular advantages over present day vapor cooling devices. First, its effective thermal conductivity can be hundreds of times that of the best solid heat conductors. It operates as an isothermal device thereby preventing significant transient heat loss which in turn alleviates internal thermal stress. The existence or orientation of gravitational forces does not have an operational effect. The vaporization-condensation-vaporization cycle occurs in one closed, integral device rather than in multiplicity of system components.

For all of its advantages, and especially that of the vast quantities of heat which theoretically can be transferred in a given time, the heat pipe is not without limitations. It must be vacuum tight and maintained in an evacuated state. Of more importance however is the fact that its total power dissipation is a function of the temperature of the object being cooled. Today, for example, there is no known heat pipe which can dissipate over some 10,000 watts of power unless the surface being cooled is over approximately 1,000° K. (727° C.). This limits the applicability of the heat pipe in several engineering fields. In the electron tube art, for example, a temperature in excess of approximately 400° C. will cause degassing and a general poisoning of the tube's internal atmosphere.

Capillarity principles have also been combined with those of evaporative refrigeration in cooling packaged electronic equipment. U.S. Pat. No. 2,643,282, for example, teaches the housing of electronic components in a container which is packed with wicking material and partially filled with a liquid refrigerant. Liquid is drawn by capillary action in the wick to the surfaces of the electronic components for evaporative cooling. Heat is withdrawn from the container through the use of cooling coils. U.S. Pat. No. 3,066,499 applies this technology to packaged electronic equipment in which only selected components are evaporatively cooled. Massive wicking material is employed in both cases to enable the equipment to be operated and evaporatively cooled in any attitude without need for baffles to hold the liquid reserve supply in any specific position. U.S. Pat. No. 2,960,847 incorporates such massive wicking means into heat exchangers, also for attitude control. This latter reference recognizes the advantages offered by fiber glass as a wicking material, and appreciates the fact that wicking material in contact with a heated surface provides uniform wetting thereof while breaking up the vapor film which usually formed on such a heated surface.

There are two other vapor phase cooling apparatuses of specialized utility worthy of brief mention here. One is termed a thermosyphon which is used in cooling gas turbine blades. In such devices a wick is used for returning condensate when more conventional and effective means are unavailable. The other device comprises a set of continuous curved surfaces defining capillary void channels disposed normal to and extending above the level of a liquid pool wherein each surface is composed of a heat conducting material and means for supplying heat thereto. This device is used in diffusion pumps to vaporize liquids almost instantaneously without eruptive boiling, and as a means of collimating and superheating the vapor. surface. 1,100°

Each of the above-described devices apply a liquid having a temperature near its boiling point for its pressure to a heat-conductive, heated surface. Under such conditions it has been found that the quantity of heat dissipated is proportional to the temperature of the surface from which it is dissipated. Their relationship is expressed as a plot of power per unit area against the temperature of the surface. Such plot, which is known as Nukiyama's Curve, reveals that the temperature of the surface is a direct function of the power per unit area dissipated until the surface acquires a temperature in the order of 125° C. at standard atmospheric pressure. At this point the functional relation inverses. Not until a surface temperature of some 1,100° C. is subsequently obtained has the power dissipation reverted to a direct proportion and surpassed the prior point of inversion. As the temperature of the surface must usually be maintained relatively low, the attainment of the critical temperature at which inversion occurs usually results in heat runaway and device destruction.

Heretofore a principal way of dissipating more power while avoiding overheating has been to increase the pressure and rate of circulation of the cooling liquid thereby removing vapor bubbles more swiftly. This has had the effect of raising the temperature point along the Nukiyama Curve for the surface involved at which inversion and heat runaway occurred.

Another principal manner in which runaway has been avoided when any surface section surpassed the point of inversion has been by surface geometric designs which have taken the form of cooling fins or radiators. Much work in this area has been pioneered by M. Charles Beurtheret of St. Germain en Laye, France, to whom many United States patents have been issued. In U.S. Pat. No. 3,235,004 M. Beurtheret theorized that cooling fins of the disclosed design result in a continuous tracing of Nukiyama's Curve for the hotter surface elements rather than an abrupt quantitative upsurge in surface temperature once the initial point of inversion has been surpassed. Though these particular surface sections now dissipate less power for their unitary areas, adjacent surface elements in such non-isothermal structures have shown a temperature rise along the directly proportional portion of the curve offsetting the dissipation loss of the unitary area. This has resulted in an increase in total surface heat dissipation without destructive runaway. It should be realized, however, that variances in surface design have not altered Nukiyama's Curve itself. Obviously any discovery of means achieving this would be a major contribution to the art of vapor cooling.

ELECTRON TUBE COOLING TECHNIQUES

All three of the general types of heat transfer means, i.e., radiation, convection and conduction, have been widely used in cooling electron tubes. Internal anode tubes having a glass outer envelope are usually cooled by radiation. Cooling by conduction has been achieved through the use of heat sinks. Convection cooling has taken two forms, namely conventional air or water cooling, and the relatively new vapor phase cooling. It is, of course, this last general category with which the present invention is concerned.

In a conventional electron tube vapor cooling system an external anode is inserted through either an opening in the top or bottom of a boiler leaving the tube socket outside thereof where it is available for electrical connection. The boiler is largely filled with a liquid having a high latent heat of vaporization such as water. The boiler has a conduit at or near the top for steam egress which communicates to a condenser. A return conduit communicates between the condenser and the bottom of the boiler. The system, which usually is maintained at atmospheric pressure, also contains a control box for maintaining a proper water level in the boiler, a water reservoir, and some means for separating water vapor and liquid in the steam egress conduit.

Upon operation of the electron tube the interior surface of the anode is bombarded with electrons producing heat which is conducted to the exterior surface of the anode. Water abutting the exterior surface is vaporized thereby liberating 540 calories of heat per gram of water from the anode. The vapor bubbles rise and emerge from the water surface, exit the boiler, and flow via the vapor egress conduit to the condensor. There heat is extracted causing the water vapor to condense. The condensate then returns to the boiler thereby completing the liquid-to-vapor-to-liquid cycle.

Major engineering problems of fluid dynamics have been those of prevention of gross nucleations, prevention of adherence by the vapor bubbles once formed to the anode surface, and rapid replenishment of all bubbles with additional water regardless of where they have formed along the anode surface. Weirs placed laterally about the anode for this purpose have met with some success, namely due to the resulting velocity increase in the ebullient fluid. Apertures and vanes have been introduced longitudinally into these weirs to allow replenishing water to flow directly from a reservoir located circumferentially about the weirs to all areas of surface nucleation. In many cases in which a finned anode is cooled, the weir actually abuts the ends of the fins. In a few designs the cooled agent is made to flow through conduits within the anode structure itself. In all of these particular designs, however, the fundamental problems of nucleation size, surface adherence, rapid liquid replenishment, and maintenance of a predetermined water level during ebullition have remained in varying degrees.

SOME OBJECTS OF THE INVENTION

Accordingly it is a general object of the present invention to provide improved novel vapor cooling means.

It is a prime object of the invention to provide means achieving a higher rate of vapor cooling of a heated surface than has heretofore been believed possible at corresponding surface temperatures.

A more specific object of the invention is to alleviate the limitations represented by Nukiyama's Curve thereby achieving greater cooling at specified surface temperatures.

It is also an object of the present invention to provide improved means for restricting the size of vapor bubbles generated along a heated surface being vapor cooled, and for swiftly liberating the bubbles from the surface without impeding the flow of replenishing liquid.

It is another object of the invention to combine the principles of vapor cooling and capillarity into a functional device for cooling surfaces of between 100° C. and 400° C. at standard atmospheric pressure.

It is another object of the invention, of particular utility, to dissipate more thermal power from an external anode electron tube than has heretofore been done with vapor cooling techniques without overheating and tube destruction.

Another object of the invention is to provide means to substantially reduce the size, weight and cost of electron tube external anodes without reducing their vapor cooling capacity.

Yet another object, more of a by-product nature, is to alleviate the need for relatively accurate liquid level control in the boilers of vapor cooling systems.

SUMMARY OF INVENTION

Briefly described, the present invention is improved means for vapor cooling a surface submersed in a liquid cooling agent, said means comprising a fibrous layer held in intimate relation with the surface. The fibrous layer defines a plurality of spacial paths communicating between opposite sides thereof, said paths comprising interspersed vapor conduits and capillaries.

Although the fibrous layer may be made of vitreous or organic material, inorganic metallic fibers are preferred having less thermal conductivity than, and an EMF slightly positive with respect to, the surface to be cooled. Though the fibrous layer may comprise either a random or an organized array of fibers, a single layer of fabric comprising fibers spun into yarns which are woven or knitted together, is recommended.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an elevational view of a typical vapor cooling system in which certain components are shown broken away to reveal their interior.

FIG. 2 is an elevational view of an external anode electron tube having an improved vapor cooling means in accordance with the present invention affixed thereabout. FIG. 2A is an enlarged elevational view of a portion of the improved means. FIG. 2B is another enlarged elevational view of a portion of an alternate form of the improved means. FIG. 2C is another enlarged elevation view showing a portion of the preferred form of the improved means.

FIG. 3 is a cross-sectional view of a heated body undergoing vapor cooling while employing means of the present invention, portions of the figure being represented diagramatically.

FIG. 4 is a graphic illustration of Nukiyama's Curve compared with a performance curve which has resulted from the use of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now in more detail to the drawing, there is illustrated in FIG. 1 a typical vapor cooling system for an external

anode electron tube **10**. A cylindrical anode **12**, shown with the improved means of the present invention attached thereto, is sealed within boiler **14** by a rubber O-ring. The boiler is filled to a level **16** near the upper end of the anode with a liquid having a high latent heat of vaporization such as distilled water. Anode **12** is thus largely submersed in water within boiler **14** while socket end **18** of the tube is outside the boiler where it is available for electrical connection.

A vapor exhaust conduit **20** links the upper portion of boiler **14** at boiler throat **22** with condenser **24**. Dielectric member **26** electrically insulates the condenser from the boiler which acquires the potential of anode **12** during tube operation. A water return conduit **28**, having an electrically insulating member **30** and an open vent **32**, links condenser **24** with the lower portion of boiler **14** thereby completing the boiler-to-condenser-to-boiler circuit.

The vapor cooling system also contains a relatively complex device for maintaining water level **16** relatively constant in boiler **14** during system operation. This device comprises a control box **34** having a conduit **36** linking the lower portion thereof with that of boiler **14**. A small diameter pressure equalization line **38** communicates between the upper portion of control box **34** and vapor exhaust conduit **20**. The control box is also provided with an overflow pipe **40** and with an auxiliary water reservoir **42**. The auxiliary reservoir, linked to the control box by conduit **44** through valve V, serves to replenish water that is slowly lost to the system through the departure of water vapor from vent **32**.

When power is applied to electron tube **10**, anode **12** commences to heat rapidly. Water adjacent the anode vaporizes thereby dissipating some **540** calories of heat per gram of water from the anode. Vapor bubbles rise to surface **16** where they are liberated into the air, and in so doing produce severe water surface turbulence. Water vapor then exits boiler **14** through boiler throat **22** and ascends through vapor exhaust conduit **20** to condenser **24** where it transfers heat and condenses back to water. From there the condensed water returns by gravity to boiler **14** via return conduit **28**.

Within the exhaust conduit air-borne water decelerates as it is carried upward by the vapor, and falls back into boiler throat **22**. The presence of air-borne water however impedes the flow of the exiting vapor. This impedance and the normal water surface turbulence cause water level **16** in boiler **14** to fluctuate. Control box **34** with its appendages and connecting conduits serves to damp these variations. This prevents a significant lowering of level **16** which would expose an area of anode **12** that requires greater heat dissipation than that possible through air convection.

FIG. **2** illustrates an electron tube having a fibrous layer **50** surrounding a cylindrical external anode. Portions of the fibrous layer appear without detail through numerous circular apertures in a thin, metal girdle **52** which is clamped tightly about the fibrous layer. Girdle **52** thus serves to keep the fibrous layer in intimate contact with the anode surface during tube operation; the apertures therein provide free passage for liquid and vapor therethrough.

FIG. **2A** depicts a portion of fibrous layer **50** in detail as comprising punctured fibers. Fiberglass fibers, steel wool and copper wool have all been used quite successfully. To date there are no known fibrous layers which do not produce some increase in the vapor cooling rate. Even organic materials such as cotton cloth have improved thermal dissipation. However for longevity and contamination avoidance, the use of an inorganic fibrous layer is recommended. Furthermore, it has been found that the use of fibrous materials having less thermal conductivity than that of the anode, which typically is copper, aids in improving the rate of heat dissipation. It is believed that this reduces the incidence of vapor nucleation along the outer surface or within the fibrous layer. Vapor nucleation thus occurs at the anode surface itself, which of course, increases anode heat dissipation.

The material shown in FIG. **2A** comprises punctured fiberglass fibers. This material provides multitudes of paths of capillary size through which water may be circumferentially drawn to the anode surface once the device is submersed. The punctured holes provide greatly enlarged paths through which vapor bubbles may pass in leaving the anode surface without impeding the incoming flow of water. However these punctured holes are by no means mandatory: Where the fibrous layer does not contain such, the vapor seeks, and passes out through, the larger paths within the layer.

FIG. **2B** illustrates an alternate form of the fibrous layer. Here the fibers are closely woven together into a flexible, planar structure which may easily be made to assume a cylindrical shape. This embodiment does not contain the punctures of that shown in FIG. **2A**; rather here the spaces between the fibers themselves provide the liquid and vapor paths.

FIG. **2C** illustrates the preferred form of the fibrous layer, namely that of a knitted fabric. The fabric comprises stainless steel fibers spun into yarns measuring 0.016 to 0.018 inches in diameter. The yarns are in turn knitted together forming interstices therebetween measuring 0.024 to 0.026 inches across. Small spacings between the stainless steel fibers themselves form capillaries while the interstices provide vapor paths. As the fabric is flexible it may be stretched and placed tightly about a cylindrical anode or nuclear fuel rod. It may also be placed about a finned anode in which case a cage is placed thereover having wires running between adjacent fins to hold the fabric tightly against the entire surface being vapor-cooled.

Fabrics made of other fibrous metals may be used. The selected metal however should have less thermal conductivity than that of the surface being cooled. Furthermore, the fibrous metal should have an EMF of positive potential with respect to that of the surface to prevent the slow wasting away of the cooled surface by electrolysis. The EMF differential between that of the fibrous metal and the surface should not exceed 2.2 volts when submersed in a liquid coolant for fabric longevity. The individual yarns may be either knitted or woven together in forming the fabric. Although several layers of fabrics may be beneficially used in practicing the invention, a single layer of fabric is preferred to avoid both the creation of long, tortuous capillary paths and restriction of the vapor exit paths.

To summarize, most any fibrous material may be used in increasing the rate of thermal dissipation. The material should, however, not be decomposable at operating temperatures in the particular cooling agent used, should be closely meshed to form paths of capillary size, and should have less thermal conductivity than that of the anode. For best results the fibrous material should be a layer of fabric comprising metallic fibers spun into yarns which are woven or knitted together. The metallic fibers should have an EMF close to, but positive with respect to that of a metallic surface being cooled. Incorporation of such a structure into vapor cooling systems has resulted in a net increase of average thermal dissipation per unit surface area of over 400 percent. Though experimental work is continuing on materials, to date a stable power dissipation level of 200 watts per square centimeter of anode surface area has been achieved through the use of a woven fiberglass mass secured about a copper anode. Even better results have been obtained from the use of stainless steel fabrics.

The fibrous layer must be held in intimate contact with the surface being cooled. This can be accomplished in any number of ways including the use of wires or a form-fitting fibrous structure. In FIG. **2** girdle **52** is used which is placed and clamped about fibrous layer **50**. The girdle has numerous apertures through which water and water vapor flow.

A practical application of this discovery is the ability to reduce the size, weight and cost of external anode electron tubes by decreasing the thickness of the anode and in some cases abolishing the need for anode fins.

In the description of FIG. **1** the importance of, and the apparatus required for maintaining level **16** relatively constant, was discussed. The use of a fibrous layer in accordance with the present invention has the by-product advantage of alleviat-

ing this problem to a great extent. FIG. 3 shows in cross section a portion of a heated body 60 having a surface 62 to which is held a fibrous layer 64 having punctured holes 66 providing a vapor path between surface 62 and a liquid cooling agent 68. The illustration depicts in dynamic form active vapor cooling. Surface 70 of the cooling agent is thus shown in a state of turbulence. Vapor bubbles 72 are shown exiting holes 66 and rising to surface 70. Arrows 74 diagramatically indicate the flow of liquid cooling agent within fibrous layer 64. Note that those arrows located substantially below surface 70 are disposed normal to heated surface 62. On the other hand the arrows located just below surface 70 have vertical components. This is due to normal capillary attraction much like that which occurs in an ordinary wick. In this manner cooling liquid flows to both the portion of surface 62 disposed below and above level 70. As a result fluctuations in level 70 do not cause areas of surface 62 located near the level to be deprived of liquid cooling agent. This substantially mitigates the danger of a hot spot formation in this area of level vacillations. Thus, although layer 64 will be substantially wholly immersed in coolant, it is to be understood that this description of the degree of immersion includes those cases in which, by accident or design, a substantial portion of layer 64 is above level 70. In these latter cases, the non-immersed portion is adequately supplied with liquid coolant both by the above described effect of capillarity and also by liquid coolant splashed onto the non-immersed portion by the relatively violent boiling occurring in the liquid coolant.

Upon comparison several significant distinctions will be noted between the means of the present invention and that of the prior art. The heat pipe, for example, is an enclosed, unitary structure having a self-contained vaporization-condensation cycle whereas the vapor cooling system of FIGS. 1, 2 and 3 is not. The heat pipe operates in an evacuated state whereas the present system operates at normal atmospheric pressure with a boiler mostly filled with fluid. The flow of water is longitudinally through the capillary lining of the heat pipe parallel to the surface being cooled. In the present invention however water flows through the width of the fibrous mass essentially normal to the surface being cooled. It is only in the emersed portion of the fibrous mass that water flows longitudinally. These distinctions between the heat pipe and the present invention naturally result from their varied, functional roles: Where the heat pipe efficiently transfers heat between two remote points, the present invention aids in cooling an overall surface.

In the case of vaned weirs the "mass" is spaced from the anode surface; furthermore the vapor bubbles are restricted to paths essentially parallel to the surface. No capillary action exists either above or below the level of the liquid cooling agent. In the case of packaged electronic equipment or heat exchangers where massive wicking material is used for equipment attitude versatility, liquid refrigerant is drawn by capillary action from a reserve supply to the surfaces of electronic components where it evaporates, the vapors then being released to the atmosphere. In cooling such relatively low powered components by evaporative cooling, one is not confronted with the problem faced by applicant, namely the vapor cooling of high powered electron tubes or nuclear fuel elements. Thus the problem of increasing the rate of thermal dissipation without surpassing run-away surface temperatures is neither attacked nor solved. Furthermore, the use of such massive material in a vapor cooling system boiler housing a high powered electron tube would impede the exit of vapor from the anode surface which in turn would create system back pressure. Massive material would also provide such long capillary paths, while simultaneously impeding direct gravitational flow, as to severely restrict the replenishment of vaporized liquid with additional liquid at the heated surfaces.

Turning now to FIG. 4 there is graphically illustrated a plot of power dissipation per unit of area of a surface exposed on one side to a heat source and on the other to a liquid at boiling point, against the temperature of that surface. The resulting curve labeled "A" is known as Nukiyama's Curve. This curve shows that at a surface temperature of approximately 125° C. at standard atmospheric pressure, some 135 watts per square centimeter of power are dissipated. Beyond this point, however, no further increase in power dissipation occurs until the surface temperature exceeds approximately 1,100° C. Indeed there is even a sharp decrease in thermal dissipation. At 1,100° C. most devices being vapor cooled have been vastly overheated and destroyed. Consequently 135 watts/cm.^{2} has been believed to be an ultimate vapor cooling limitation on segments of heated surfaces submersed in static liquids at standard atmospheric pressure without overheating. Applicant, however, has achieved with the present invention the power dissipation shown by curve "B." Reference to this curve reveals that 200 watts/cm.^{2} has been achieved at a surface temperature of but 108° C. This alteration of Nukiyama's Curve and resulting increase in power dissipation at operative temperatures is thus a major contribution to the vapor cooling art. The peak power level and surface temperatures at which the functional relationship therebetween becomes inverse has yet to be measured empirically.

It should be understood that the above-described embodiments are merely illustrative of applications of the principles of the invention. Obviously many modifications may be made in these specific examples without departing from the spirit and scope of the invention as set forth in the following claims.

What is claimed is:

1. Apparatus for vapor cooling a heated body, said apparatus comprising of fibrous layer in abutment with a portion of said heated body, said fibrous layer being a fabric formed of strands of yarn, said yarn comprising a plurality of fibers, the interstitial regions between said fibers comprising capillaries for the conduction of liquid, said strands being so arranged in said layer as to provide between adjacent strands line-of-sight vapor conduits extending from the surface of said heated body through said layer, and container means containing a volume of liquid cooling agent in contact with said fibrous layer, said layer being substantially wholly immersed in said liquid cooling agent, whereby said capillaries conduct said liquid cooling agent to the surface of said heated body and said vapor conduits provide substantially unrestricted exits for vaporized cooling agent.

2. The vapor cooling apparatus of claim 1 wherein said fibers are made of materials of lesser thermal conductivity than said heated body.

3. The vapor cooling apparatus of claim 1 wherein said fibrous layer comprises fiberglass fibers.

4. The vapor cooling means of claim 1 wherein said fibers are stainless steel.

5. The vapor cooling apparatus of claim 1 having means holding said fibrous layer in abutment with at least a portion of said heated body.

6. The vapor cooling apparatus of claim 1 wherein said vapor conduits are parallel to one another and are essentially normal to the surface of said heated body.

7. The vapor cooling apparatus of claim 1 wherein said heated body is the anode of an external anode electron tube.

8. The vapor cooling apparatus of claim 7 wherein a portion of said anode is disposed above said level, and another portion of said anode is disposed below said level and wherein said fibrous layer abuts both of said portions.

9. The improved vapor cooling means of claim 1 wherein said fabric consists of one layer of woven yarn.

10. The improved vapor cooling means of claim 1 wherein said fabric consists of one layer of knitted yarn.

11. The improved vapor cooling means of claim 1 wherein said fabric is flexible whereby it may be fitted about said metallic surface when that surface is curved.

12. The improved vapor cooling means of claim 7 wherein said external anode has a generally cylindrical external surface with massive protuberances extending radially therefrom.

13. A vapor cooling means in accordance with claim 1 wherein said flexible fabric is held tightly to the side walls of

said radially extending massive protuberances by a wire harness.

* * * * *