

Sept. 25, 1962

C. A. E. BEURTHETER
HEAT EXCHANGERS

3,055,643

Filed Aug. 1, 1957

4 Sheets-Sheet 1

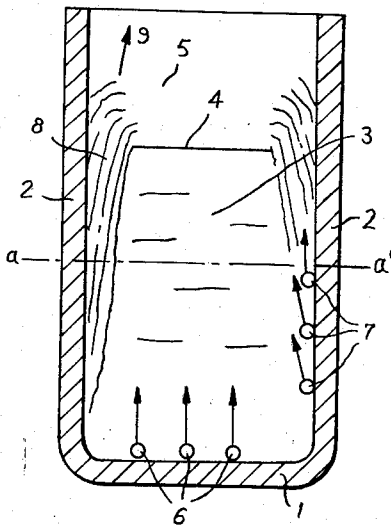


Fig. 1a

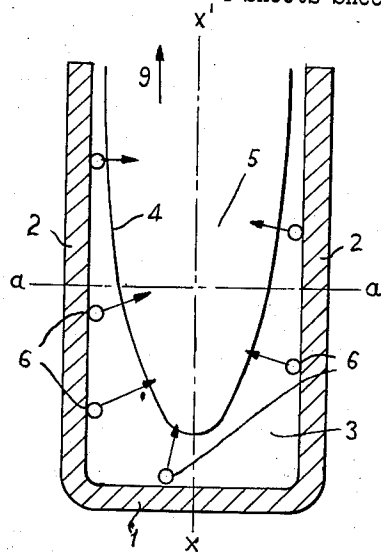


Fig. 2a

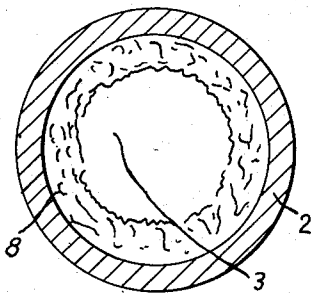


Fig. 1b

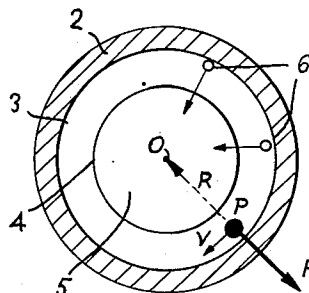
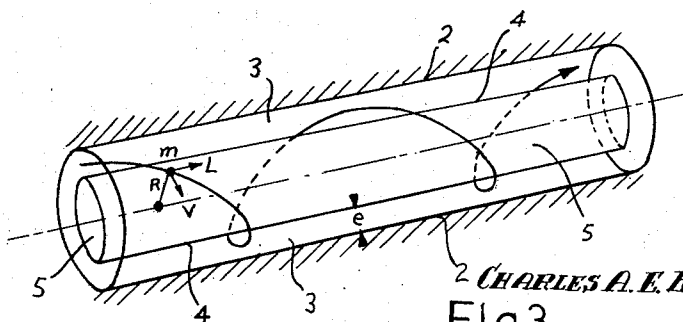


Fig. 2b



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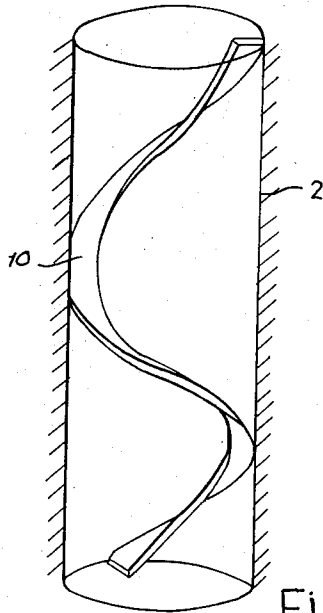


Fig. 4

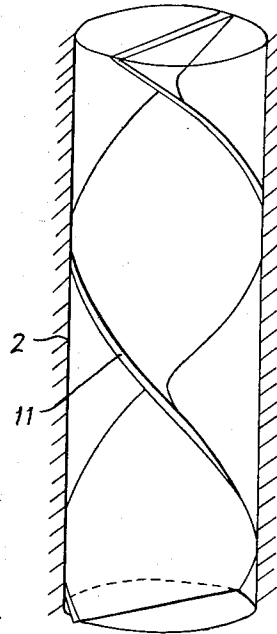


Fig. 5

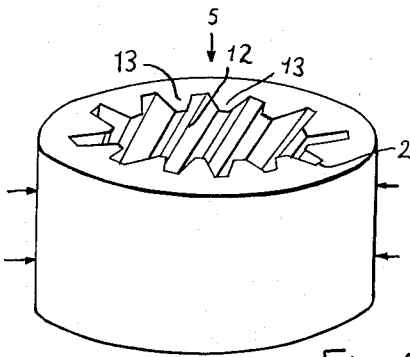


Fig. 6

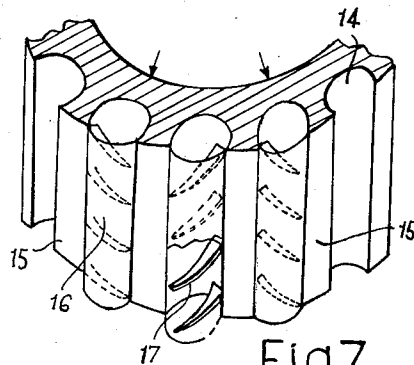


Fig. 7

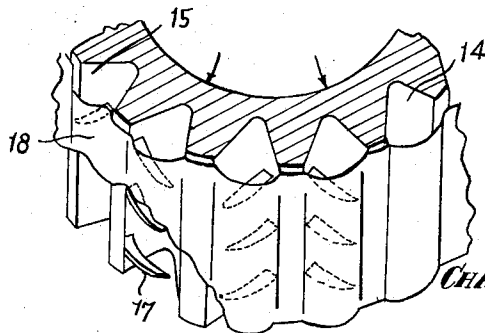


Fig. 8

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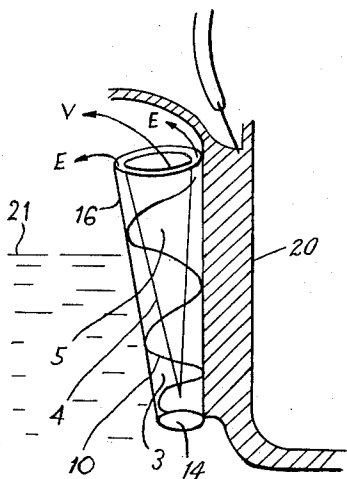


Fig. 9

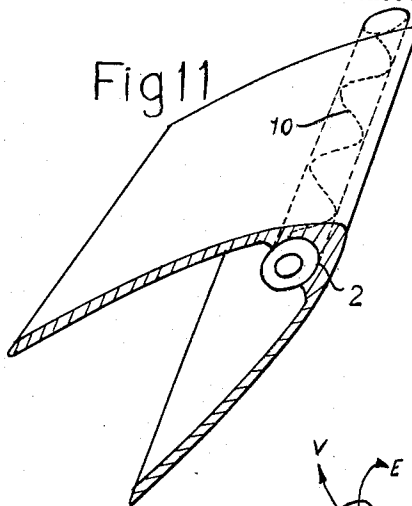


Fig. 11

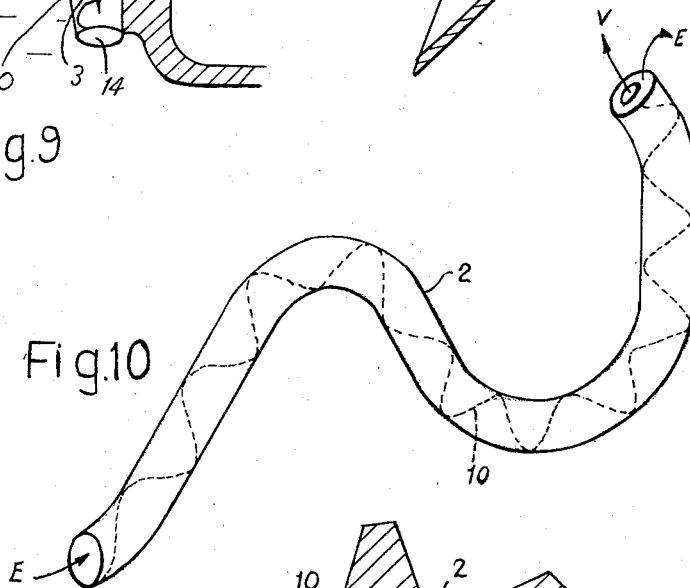


Fig. 10

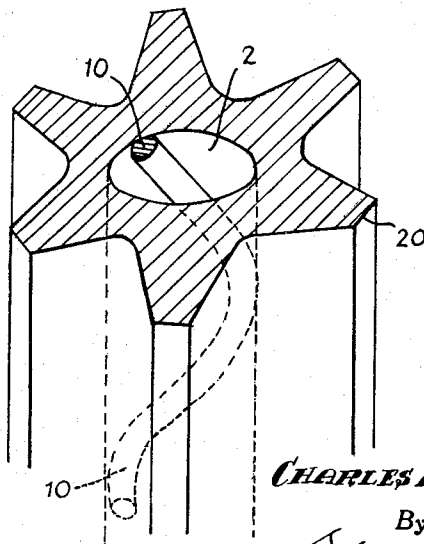


Fig. 12

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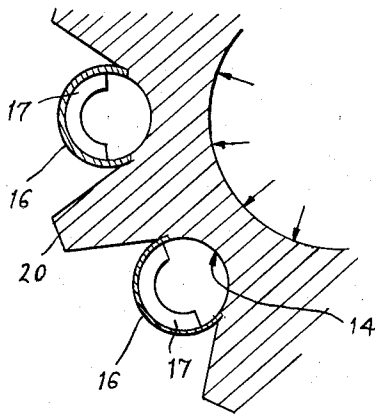


Fig. 13

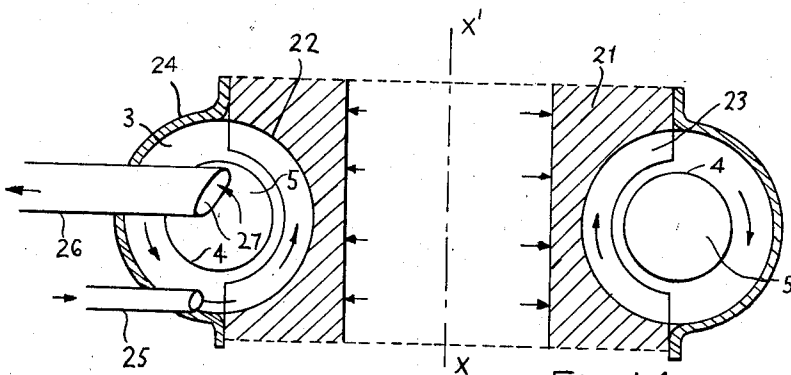


Fig. 14

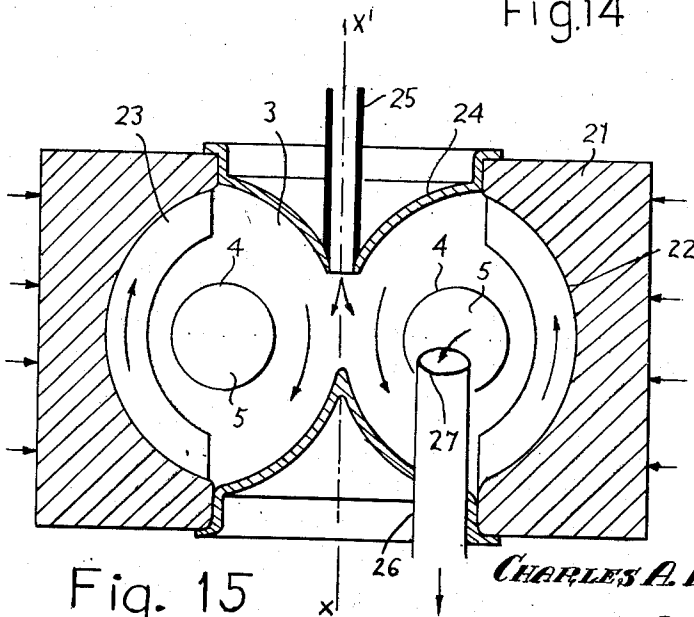


Fig. 15

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HEAT EXCHANGERS

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Filed Aug. 1, 1957, Ser. No. 675,612

Claims priority, application France Aug. 6, 1956

9 Claims. (Cl. 257—250)

The invention relates to heat exchange arrangements designed to transmit a high flux of heat from metallic surface to a circulating liquid, which, on account of this fact, is taken to boiling point and partially vaporized.

The field of application of the invention is very extensive, its use in heating plants which produce vapor is not excluded, but the apparatus is so efficient that it exceeds by ten times the possibilities of heating by any heater using the classical combustible materials.

This is so in the case where the flow of heat to be transmitted is so high that it reaches the previously known limits of the normal region of usage of the apparatus. For example the invention may be employed in:

The anode cooling of powerful electronic tubes, of classical or ultra-high frequency design,

The transfer of heat at the surface of fissile metal bars used as "fuel" in certain types of nuclear reactors,

The local cooling of the elements of powerful heat motors, notably internal combustion turbo-machines,

The cooling of certain elements of the external surface of supersonic aircraft,

The cooling of certain fixed elements or rotating elements of electric machines.

To summarise, the heat exchange arrangements of the invention may be used in all equipments in which a considerable flow of heat has to be transmitted from a metallic surface to a liquid of which the object is to dissipate it, or to utilise it, and in particular those in which the exchange surface has to be maintained at a temperature lower than the threshold of appearance of the phenomenon of calefaction.

In order to explain the characteristics of the invention reference will now be made to the drawings in which:

FIGURES 1 to 3 are explanatory diagrams showing the basis of the invention,

FIGURES 4 and 5 show simple embodiments of the invention,

FIGURES 6 to 9 and 13 to 15 show the application of the invention to electronic tubes,

FIGURE 10 shows an embodiment in the form of a pipe,

FIGURE 11 shows an example of the use of the embodiment of FIGURE 10, and

FIGURE 12 shows the invention applied to a reactor fuel element.

Considering FIGURE 1a there is shown a metallic receiver including a horizontal base 1 and a cylindrical vertical wall 2 and containing water 3. This receiver, placed in a heater, receives the heat through its external wall. The water becomes heated at the contact of the receiver and starts to boil. The bubbles form at the contact of the hot wall and rise to the surface 4 following more or less vertical trajectories. The result of this fact is that the base 1, releasing bubbles 6 which leave it perpendicularly, is ceaselessly wetted by the water which replaces them, while the sides 2 are encumbered by added vapor formed by the accumulation of the bubbles 7 which rise parallel to the hot wall. In the same way, a vertical cylindrical surface heated on the inside and plunged into water would be surrounded by a conical accumulation of vapor. The vertical surface 2 is obviously less well wetted by the liquid than the horizontal surface 1. The transfer of heat across this vertical surface is more of a chance

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if the point considered—placed higher—is masked by a denser accumulation of vapor.

The phenomenon of calefaction which appears in the case of water at atmospheric pressure—if the temperature of the wall exceeds the temperature of the water by 25° C., thus particularly threatens the vertical wall when the transfer of heat reaches high fluxes.

A tested solution is already known which permits the limits of the appearance of calefaction to be delayed. It consists on the one hand in thickening the vertical wall in such a manner as to lower the transverse thermal resistance between the various points of the surface and to hollow out grooves or vertical channels leaving between them massive partitions, or better still cross channels defining between them protuberances which are individually massive and good conductors of heat, and on the other hand in canalising the natural movement of the thermosiphon at the contact of these elements which would break the continuity of the accumulation of vapor in the vicinity of the heated surface. The speed and the turbulence of the water vapor emulsion tends to break off the bubbles and to wet the surface, thus permitting the transmission of a flow of heat much superior to the natural limit of the thermal contact between the liquid and an extended vertical surface which is not organised in this manner. Such a device, known by the name of "Vapotron," has been used for several years with success, chiefly on the anodes of powerful electronic tubes.

The present invention brings to this problem a different solution which is as efficacious as the better of the known processes and whose use is more flexible and extensive. It will be easily understood upon reference to the FIGURE 1a on which can be seen the horizontal surface 1 which is situated, as far as thermal exchange is concerned, in a much more favorable position than the vertical surface 2. This advantage is due entirely to the fact that the weight exercised perpendicularly to the heated wall applies the liquid to its contact and promotes, by difference of density, the rapid evacuation of the bubbles perpendicularly to this wall towards the surface 4 of the liquid from which the vapour 9 escapes into the open space 5.

The invention consists in putting the vertical walls 2 in this favorable situation and substituting for the weight the forces of inertia which arise in the depths of the liquid upon which is imposed a speed of displacement which includes a curvature of displacement conveniently orientated with respect to the wall 2. The invention will be better understood upon reference to FIGURE 2, in which is represented a receiver similar to that of the preceding figure, but in which the liquid 3 is made to turn about the axis X—X' in such a way that the centrifugal force applies the liquid to the wall 2 while its free surface 4 takes up, as is known, a hollow shape which is parabolic if the angular speed of rotation of the liquid is uniform. Under these conditions the bubbles which take shape at the contact of the wall 2 as a result of an exchange of heat between this wall and the liquid, escape across the surface 4, that is to say that they are rapidly removed from the wall 2.

The FIGURE 1b, representing a section of the receiver of FIGURE 1 and which shows the wall 2 hidden behind an accumulation of vapor 8, can be compared with FIGURE 2b, which represents a transverse section of the FIGURE 2a along a plane a—a', perpendicular to the axis X—X', where will be seen the cylindrical wall 2, the liquid 3, the surface 4 of this liquid and the internal atmosphere 5; several bubbles 6 have been shown and the arrows indicate the direction of the force which tends to remove them from the hot surface. In fact this centripetal movement of the bubbles combines with the tangential speed of rotation V of the liquid. The trajectories

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followed by the bubbles are thus oblique with respect to the surface but the bubbles tend to disengage themselves rapidly from the wall and to re-assemble in the central free space of the liquid 5. This comparison between the FIGURES 1b and 2b shows quite plainly the interest of the invention.

It is possible to verify that the realisation, in a tubular space of a certain length, of a state of statistical equilibrium equivalent to that represented in FIGURE 2b, is perfectly possible. Indeed, if an element of liquid P is considered, of mass m animated with a tangential speed V , at a distance R from the centre O , the force F which is exercised on the element of liquid, has a value

$$F = \frac{mv^2}{R}$$

This force is great; for example, if the liquid in movement presents a speed of which the tangential component V is equal to 1 metre per second in a tube 2 of which the radius R is equal to one centimetre, this force F is equal to 10 times the weight of the liquid element P considered. Under these conditions it can be seen (FIGURE 3) that the statistical equilibrium of the liquid in the tube is almost independent of the orientation of the latter with respect to the field of gravity, that is to say that the wall 2 can have any position provided the magnitude of the orientation with respect to this wall of the speed imposed on the liquid shall be suitable.

FIGURE 3 represents a portion of a tube 2 in which circulates the liquid, centrifuged against the wall 2 by a tangential speed V of sufficient magnitude. The total section of the tube before being divided as required between a central part reserved for the vapor and an annular part reserved for the liquid, may be considered to have a state of equilibrium established therein as a function of the power dissipated, in the sense that the thickness e of the layer of liquid diminishes while the longitudinal speed L of the liquid increases when the increase of power forces the section of the central hole to enlarge in order to allow the vapor produced to escape.

The longitudinal movement of the liquid may be obtained by a circulation imposed for example by a pump or by an equivalent hydraulic device, or even by the thermo-siphon effect or by a combination of these causes, according to the conditions of usage.

The rotation of the liquid could be obtained by any adequate device, and chiefly by fixed deflectors, continuous or discontinuous, placed at any convenient place of the channel of flowing liquid.

The cylindrical form of circular section represented in FIGURE 3 is only a particular case, any concave section is suitable for the embodiment of the invention.

Any apparatus comprising a, or several, metallic tubular elements 2 receiving heat from outside and in which is organized the circulation of a liquid maintained in contact with the wall by centrifugal forces and bounding by cavitation a central free space for evacuation of the vapor, will be in accordance with the invention.

A metallic wall including concave surface elements at the contact of each one of which such a circulation of liquid is organized by the use of auxiliary deflectors participating or not in the heat exchange, will also be in accordance with the invention.

The internal wall for the exchange of heat can be smooth or can have corrugations designed, as is known, to promote a local turbulence on the trajectory of a liquid in circulation.

In certain particular cases it might be of advantage to construct all or part of the deflector elements designed to promote the rotation as a whole of the flowing liquid by protuberances which are individually massive, and which play at the same time a part in the thermal exchange.

It will easily be understood that devices in accordance with the invention present a very great efficiency since they combine additively the effect of the detachment of

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the bubbles by difference of density in an intense gravitational field, and the circulation in a rapid manner of the liquid at the contact with the heated wall with a speed which increases automatically with the power; this apparatus constitutes among other things a vapor separator which is very efficient in the immediate vicinity of the surface producing the ebullition, even in the depths of the liquid.

Additional apparatus also enters into the idea of the invention, because they are provided to facilitate embodiment in particular cases, we will cite chiefly:

The grouping of several elementary devices in accordance with the invention at several points of a hot metallic mass with a view to assuring the cooling of the assembly.

The addition of piping which permits on the one hand, the supply of liquid to various elements, and, on the other hand, the re-assembly of the vapor in a general collector either from the extremities of the elementary elements, or even by multiple samples distributed along the length of the collector space 5 as will be seen later.

The following figures give, as examples of a non-limiting character, several characteristic uses of heat exchange arrangements according to the invention.

FIGURE 4 represents schematically a tubular element in accordance with the invention in which the deflector element is constituted by a ribbon, which may be metallic or non-metallic, wound in the form of a helix in contact with the heated surface 2. The flat form of this element is given as an example, and another form is to be seen in FIGURE 9. The pitch of the helix will be fixed according to the use which will be made of the invention, in the most usual case the optimum pitch will be relatively great so as to communicate to the liquid a tangential speed V of rotation which will be of the same order of magnitude as the longitudinal speed L of the liquid. For certain uses it is possible to use a non-uniform pitch, as can be seen for example in FIGURE 10.

FIGURE 5 represents a variation of the preceding apparatus in which the helical element is constituted of a thin band 11 simply twisted in a helix of long pitch and arranged inside a cylindrical wall 2.

FIGURE 6 represents the application of the invention to a massive metallic member receiving the heat from the outside, which will be the case for example, for an anode of an electronic tube of high power of the special type having an internal anode. This massive member has a central cavity of which the wall has, for example, deep helical grooves 12 separated by massive edges 13 acting as deflectors in accordance with the invention and actively participating in the thermal exchange by vaporization and also as the massive protuberances already known. All similar dispositions of protuberances arranged as a family of helices parallel to each other would be equally suitable.

Such an apparatus could be supplied with liquid either from below or from above, in this case by means of a coaxial tube not shown, passing through the middle of the space 5 which is empty of liquid and serves for the evacuation of the vapor.

FIGURE 7 shows a metallic body receiving heat from the inside, such as, for example, an anode of a powerful electronic tube of the type having an exterior anode, or the collector of a high power "Klystron" etc.

All around the metallic block has been shown a certain number by channels constituted of the concave elements 14 with vertical axes separated by massive vertical edges 15, each of these concave surfaces being completed in tubular form by an external element 16, which may be metallic or non-metallic and comprising deflector elements 17 in accordance with the description of the invention.

FIGURE 8 represents a similar apparatus differing from the embodiment of FIGURE 7 by the fact that the individual concavities 14 are not closed individually but collectively by the envelope 18 of convenient form and

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having deflector elements 17 on the internal surface. In such an apparatus the thermal contact between the extremities of the sides 15 and the external envelope 18 only makes a small contribution to the cooling of the hot body and it would be preferable, in certain applications of the invention, to make the auxiliary elements 18, 17 as a separate and movable mechanical part.

The deflector elements 17 of FIGURES 7 and 8 arranged opposite the successive concavities are preferably orientated alternately according to inverse steps in such a way that the movements of rotation of the liquid in the successive vertical channels are established in opposite directions. Such an arrangement facilitates the separation of the liquid and the vapor at the upper part of the element in accordance with the invention.

The right section of the tubular elements may without inconvenience present a non-uniform curve: it is even possible to profit from the variations of curvature in order to increase the efficiency of operation at the contact of those parts of the heated surface which are most fully charged as has been represented in FIGURE 8 in which the shortest curvature is at the base of the throat.

Elements similar to those shown in the preceding figures or any nearly similar arrangement established with the same idea, may present a right section which is non-uniform all along their axis.

For example, in FIGURE 9 can be seen a tubular element of which the section is greatest near the vapor outlet. In other applications it might be of advantage to introduce the liquid tangentially at the side where the section is greatest in order to profit by the acceleration of the movement of rotation which is produced spontaneously when the radius of curvature of the liquid is reduced. In this case particularly it would be of advantage to make the liquid and the vapor circulate in opposite directions.

The vertical sides 15 of the apparatus of FIGURE 8 might, if desired, be cut in the form of teeth at one part of their length without appreciably disturbing the operation in accordance with the invention.

All the apparatus in accordance with the invention can be supplied directly or indirectly by means of a pump or any equivalent hydraulic device.

Certain devices in accordance with the invention and chiefly those represented in FIGURES 7 and 8 can function simply upon being plunged into a liquid, the circulation of the assembly produced by thermo-siphoning being sufficient to determine, with the aid of deflecting elements, the rotation of the liquid in the inside of the channels and the formation of the hollow swirl for the evacuation of the vapor in the axial cavity.

Thus it can be seen that, in FIGURE 9, there is a view in partial section of the anode body of an electronic tube with vertical axis in which the anode 20, equipped in the manner shown in FIGURE 7, is partially plunged into a tank containing water up to the level 21 nearly up to the upper part of the structure 16. The emulsion of water and vapor which is formed inside the chimney 14 being lighter than liquid water, it rises in this chimney as is known by hydrostatic effect, overflows and falls back again into the tank. The speed thus acquired by the water in the chimney 14 is of the order of a metre per second: orientated by the deflectors, according to the invention it takes up a helicoidal motion, assuring a method of operation in accordance with FIGURE 3, and separates the vapor which escapes at high speed through the central hole 5 as is indicated by the arrow V, while the excess of water escapes tangentially to the upper part as is indicated by the arrow E. This method of operation is extraordinarily efficacious. The liquid lying as a thin layer along the tubular wall, very largely frees the central cavity for the passage of vapor. Moreover, the column of liquid being very light, the circulation of liquid is very active even when the level 21 is relatively low.

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For certain dimensions of the tubular elements these natural movements may put into play too great a quantity of liquid and this is liable to promote a periodic obstruction of the chimney thus creating a longitudinal oscillation of low frequency. According to an improved embodiment of the invention, this harmful tendency is suppressed as well as the parasitic vibrations which might result by arranging at the input of each of the tubular elements a contraction for the section of the passage designed to slow down the liquid and to limit the maximum delivery to an adequate value remaining slightly greater than the demands of the vaporization within the element. A particularly advantageous arrangement consists in arranging this contraction either in the form of a bulge or several bulges tangential to the concave surface acting in a way similar to the tube 25 of FIGURES 14 and 15, or else in the form of a helical conduit of small pitch or any equivalent structure with the aim of inducing, in accordance with the invention, a rapid rotational movement in the tubular element.

In certain embodiments of the invention comprising tubular elements of small length, this latter arrangement may constitute by itself the deflecting element in accordance with the invention, whether the apparatus is supplied by thermo-siphon or with a liquid delivery imposed by other means.

An anode equipped in accordance with FIGURES 7, 8, 9 or in a similar manner, should be furnished with the known accessory elements, such as an external jacket, an insulating pipe system of large diameter for the vapor and of small diameter for the resupply of water and a condenser device allowing the recovery of the liquid condensed and the eventual use of the heat of condensation for any useful purpose, notably for local heating, as well as constant level hydraulic devices etc.

All the arrangements in accordance with the invention can be provided so as to function either at a pressure near to that of the atmosphere, or at a pressure such as may be judged necessary for any external reason, such as the eventuality of providing a machine of high performance, to recover the thermal energy in a mechanical form.

Certain forms of the device according to the invention notably in the case where the exchanger element is constituted by a pipe of a certain length in which the speed of rotation is assured by forced circulation, may allow special embodiments in which the orientation of the elements can be any desired and chiefly in order to provide high and low points as shown in FIGURE 10, the section of the tube being in accordance with FIGURE 3, as a result of an equipment as shown in FIGURE 4 or 5 or similar.

Such a tube of any form, capable of evacuating considerable quantities of heat carried to its external surface, can find numerous uses in the cooling of special machines, and chiefly, as FIGURE 11 shows, represented as a very schematic example, the use of such a tube for the cooling of the leading edge of an aerofoil surface of a supersonic aircraft. This kind of application of the invention to evacuate considerable quantities of heat to the desired points in any machine, thermal or electric, is within the range of competence of those versed in the art of showing the particular properties of this process.

The use of the invention to improve the heat exchange in nuclear reactors can be applied to the surface of the fuel elements in various forms according to the type of the elements.

In the case of tubular cylindrical bars (FIGURE 12) the process is applied in obvious manner to the internal surface. The exterior of the bar can be equipped in a similar way to that represented in FIGURE 8 or by any other means, for instance as described in my patent application Serial No. 564,768 filed on February 10, 1956, for "Improvements to Nuclear Reactors." As is shown schematically in FIGURE 12 the massive corrugations 20 are characteristic of that invention.

Such an apparatus permits the doubling of the energy which it is normally possible to derive from each of the bar equipments of a nuclear reactor-independent hydraulic supply apparatus, not shown, being provided if desired for the inside and the outside of the bars.

FIGURE 13 shows another example of the use of the two systems in combination. At the surface of an external anode of the electronic tube can be seen in the figure: on the one hand the channels conforming for example with those of FIGURE 7 and, on the other hand the massive protuberances 20, scored or toothed, designed to evacuate transient excess loads which may overstep the limits of the power for dissipation of the concave surfaces 14 equipped in accordance with the invention.

The application of the invention is not confined to elements having a general tubular form, and all heat exchange surfaces of concave form or presenting concave elements in which an exchange of heat takes place, at least at higher degrees of operation, essentially by vaporization of a liquid of which the artificial or spontaneous movement is organized so that the centrifugal forces are systematically directed towards the heated surface so as to promote a separation of vapor at these surfaces by difference of density, also come within the scope of the invention.

It would be the same if the use of a sufficiently cold cooling liquid and in excessive quantity had the effect of promoting condensation of the vapor in the excess of liquid employed.

FIGURES 14 and 15 show as schematic examples the use of the apparatus in accordance with the invention for cooling a metallic mass of small axial height, with a circulation induced within a toroidal space.

In these two figures, X—X' being the axis of symmetry, FIGURE 14 refers to a massive metallic member 21 receiving heat through the interior, while FIGURE 15 shows a massive metallic member 21 receiving the flow of heat from the outside. This latter case will chiefly concern the anode of an electronic tube of high power of the particular type known as "with interior anode."

The heated piece 21 is hollowed out in the form of a throat 22 of generally toroidal character presenting a concave surface in accordance with the invention, this surface being scored or granulated but presenting, in general preferably massive sides 23 directed in the radial plane or slightly inclined to the axis X—X'.

A casing 24 completes the toroidal form of the cavity. One or several tubes 25 arranged tangentially to the toroidal surface and approximately in the plane of a right section, introduces the cooling liquid with a speed sufficient to induce a movement of general rotation of the liquid 3 at the contact of the toroidal wall 22, 24 as indicated by the arrows.

The liquid is centrifuged at the contact of these walls and its surface 4 provides an internal torus 5 empty of liquid in which the vapor collects in accordance with the invention.

One (or several) outlet tubes 26 arranged in such a manner that its extremity 27 extending into the interior space 5 defines a level of too great evacuation of vapor and excess of liquid.

The pipe systems, such as 25 and above all 26, which traverse the jet of liquid in rapid motion, are preferably profiled in such a manner as to disturb as little as possible the flow of the liquid into the useful part 22.

I claim:

1. In apparatus including heat exchange means for transferring a high heat flux from a surface of a thick hot body of good heat conducting material to a liquid in contact with said surface, said surface being at a temperature above the boiling point of the liquid and the heat transference at least partially vaporizing said liquid, the combination of at least one generally concave channel in said heat dissipating surface, an additional generally concave wall portion positioned opposite said channel to form

with said channel a tubular passage through which the liquid is caused to flow, means to impart a helical movement to said liquid as it flows through said passage whereby it is centrifugally urged into contact with the walls of said passage, and means regulating the rate of supply of cooling liquid to said passage in relation to the rate of vaporization so as to maintain a centrifugally formed annular layer of liquid over the walls of the passage with a central liquid-free cavity along the passage into which vapor released by the boiling liquid layer escapes.

2. In apparatus including heat exchange means for transferring a high heat flux from a surface of a thick hot body of good heat conducting material to a liquid in contact with said surface, said surface being at a temperature above the boiling point of the liquid and the heat transference at least partially vaporizing said liquid, the combination of a plurality of generally concave channels in said heat dissipating surface, said channels extending substantially vertically, a plurality of additional generally concave wall portions positioned respectively opposite said channels to form with said channels a plurality of substantially vertical tubular passages through which the liquid is caused to flow by thermo-syphon action, at least one deflector element located in each of said passages to impart a helical movement to said liquid as it flows upwardly through said passage whereby it is centrifugally urged into contact with the walls of said passage, and means regulating the rate of supply of cooling liquid to said passages in relation to the rate of vaporization so as to maintain in each passage a centrifugally formed annular layer of liquid over the walls of the passage with a central liquid-free cavity along the passage into which vapor released by the boiling liquid layer escapes.

3. The combination as claimed in claim 2, wherein said at least one deflector element in a passage is carried from the associated additional wall portion.

4. The combination as claimed in claim 3, including plural deflector elements in each passage carried by said additional wall portions.

5. The combination as claimed in claim 2, wherein said additional wall portions are constituted by a single sleeve member surrounding the hot body.

6. The combination claimed in claim 3, in which the tubular passage is of toroidal form, the liquid being fed to the passage through an opening extending substantially tangential to the concave wall of the passage to impart the centrifugal motion to the liquid layer, and the vapor escaping through an outlet pipe connecting with the central liquid-free cavity.

7. In apparatus including heat exchange means for transferring a high heat flux from the outer surface of a thick walled hollow hot body of a good heat conducting material to a liquid in contact with said surface, said surface being at a temperature above the boiling point of the liquid and the heat transference at least partially vaporizing said liquid, the combination of a plurality of generally upwardly extending channels formed in the external surface of said body, a sleeve surrounding said surface and forming with said channels a plurality of upwardly extending tubular passages open at their lower and upper ends, said hot body being partially immersed in the liquid whereby the liquid is caused to flow through said passages from the bottom to the top thereof by thermo-syphon action, at least one deflector element located in each said passage to impart a helical movement to said liquid as it flows upwardly through a passage whereby the liquid is centrifugally urged into contact with the walls of said passage and forms an annular layer of liquid over the walls of the passage with a central liquid-free cavity into which vapor released by the boiling liquid layer escapes and passes out of the passage through the upper end of said cavity and means regulating the rate of supply of liquid to said passage in relation to the rate of vaporization.

8. In apparatus including heat exchange means for

transferring a high heat flux from the outer surface of a thick walled hollow hot body of a good heat conducting material to a liquid in contact with said surface, said surface being at a temperature above the boiling point of the liquid and the heat transference at least partially vaporizing said liquid, the combination of a plurality of generally upwardly extending channels formed in the external surface of said body, a plurality of additional generally concave wall portions respectively positioned opposite said channels to form with said channels a plurality of upwardly extending tubular passages open at their lower and upper ends, said hot body being partially immersed in the liquid whereby the liquid is caused to flow through said passages from the bottom to the top thereof by thermo-syphon action, a plurality of helical deflector elements carried by each said additional wall portion and located in each said passage to impart a helical movement to said liquid as it flows upwardly through a passage whereby the liquid is centrifugally urged into contact with the walls of said passage and forms an annular layer of liquid over the walls of the passage with a central liquid-free cavity into which vapor released by the boiling liquid layer escapes and passes out of the passage through the upper end of said cavity and means regulating the rate of supply of liquid to said passage in relation to the rate of vaporization.

9. In apparatus including heat exchange means for transferring a high heat flux from a thick hot body of good heat conducting material to a liquid of which the boiling point is lower than the temperature of the hot

body whereby the heat transference at least partially vaporises said liquid, the combination of a concave channel in the surface of said hot body, a metal tube fitting in said channel with its outer surface in good heat-conducting contact with the surface of said channel, means for causing a liquid to flow through said tube, at least one helical deflector element located in said tube to impart a helical movement to said liquid as it flows through said tube whereby it is centrifugally urged into contact with the walls of said tube, and means regulating the rate of supply of liquid to said tube in relation to the rate of vaporization so as to maintain a centrifugally formed annular layer of liquid over the walls of the tube with a central liquid-free cavity along the tube into which vapor released by the boiling liquid layer escapes.

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