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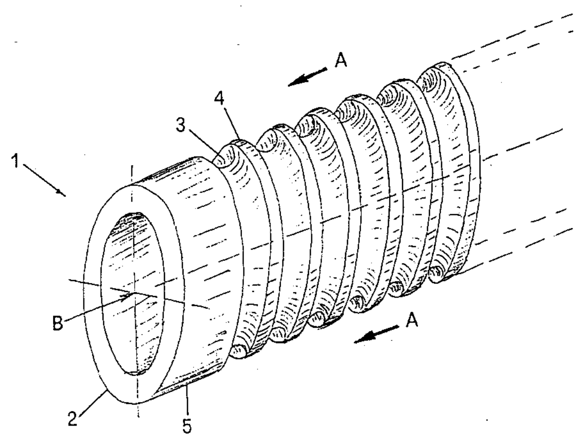
(54) **Fluid-dynamic device, particularly for heat exchange.**

(57) Fluid-dynamic device (11), particularly for thermal exchange, comprising a thermally conductive body (2), along at least one surface of which a fluid flows at any speed, said surface having series of shapes (3,4,19,19',19'') formed in such a way as to generate an induced turbulence in said fluid and to disturb the formation of boundary layers on said surface.

Fig. 1



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The present invention relates to a fluid-dynamic device, particularly for heat exchange, capable of inducing a new type of turbulence on the thermal exchange surfaces washed by a fluid, and of preventing, or at least reducing, formation of boundary layers on the surface itself.

The constant progress of modern technology has determined new needs, which require thermal flows of totally new magnitudes, which can with difficulty be reached using traditional concepts and components, as, for example, in the case of turbines for combined cycles, Stirling engines, hot gas generators, air exchangers, cooling towers.

The reduction of space in heat exchangers between two liquids, which causes increase of the density of transferable power follows the trend of modern technologies and needs, as has been seen for example in the technology of computer storage, which only a few years ago required relatively huge spaces.

In the face of the amount of energy which heat transfer is called upon to resolve daily and in almost all processes, the progress which has been made in large machines employing thermal energy appears modest, in particular when compared with the amount of research which has been carried out following notable investments.

In order to conceive machines of new concept capable of increasing the thermal flow, in the past the increase of surface area using fins has been resorted to.

The direction to follow is therefore substantially that of acting on the parameter which limits thermal flow between two fluids separated by a wall, that is to say the so-called "boundary layer", which forms a layer with high thermal resistance.

The boundary layer on which, as mentioned above, it is considered possible to intervene, generally forms the main hindrance to industrial heat transfer.

At the inlet to the tube bundles the boundary layer has a consistency practically nil and, consequently, the thermal flow is greater; it increases rapidly as it moves away from the inlet itself, as a sort of ordered settling of the fluid particles is formed in the vicinity of the walls, following which there is the formation of molecular type cohesive forces greater that those in the bulk, which represent a high thermal resistance to the flow of heat.

Actions to disrupt the boundary layer have been performed in relation to plate exchangers of a compact type, in which corrugation of the surfaces has been introduced, also for reasons of increased mechanical resistance, in order to increase the turbulence, given the ease of manufacture offered by molds and presses.

Finned surfaces for tubes have been dealt with as from the earliest scientific approaches to solving thermal exchange problems, with correlations to describe the behaviour of the fins during heat transfer. However, the geometry alone of the fin was taken into consideration, without finding an efficient method of preventing the formation of, or destroying the boundary layer in view of a substantial increase in flow, said geometry having, among other things, characteristics of low resistance to motion.

As regards commercial fins, it can be said that there has been development of a prevalently cut-and-try type with modest innovative ideas, without reference to the type of motion.

Design of the fins has been more accurate in the case of applications using gas in a natural or forced convection condition; unfortunately, due to the modest thermal exchange coefficient, in this case also the fluid-dynamic view of the design appears scarce, and concepts of constructive simplicity prevail.

The object of the present invention is to provide a thermal exchange device structured in such a way as to provide thermal flows of a totally new magnitude, which are hard to obtain using similar conventional devices.

More particularly, an object of the present invention is to provide a thermal exchange device which adopts a geometry of the heat exchanger surfaces capable of eliminating, or at least reducing, the harmful effects of the boundary layer, and at the same time to penalize flow resistance as little as possible.

A further object of the present invention is to provide a thermal exchange device in which, on at least one of the surfaces on which the fluids flow, shapes have been conceived capable of taking advantage of the axial motion of the fluid so as to induce in an intrinsic manner a turbulent motion in the fluid such as to give increased heat transfer thanks to the removal of part of the thermal resistance to heat flow.

The present invention, which refers to the principles of fluid dynamics, provides internal or external alterations to the wall separating the fluids, both of which are aimed at making use of the fluid-dynamic characteristics of the fluids to intrinsically perform a disturbing action in the formation of boundary layers.

The present invention will be better illustrated in the following description of its examples of embodiment, given as non-limiting examples, with reference to the enclosed figures, in which:

figure 1 is a perspective view of a first embodiment of the thermal exchange device in reference, shown in part, in its tubular version with cavity shapings;

figures 2, 3 and 4 are longitudinal section plan views of thermal exchange devices in reference, in their tubular version, with a first, second and third embodiment of cavities, respectively, designed for different fluid characteristics;

figure 5 is a cross section view of a cavity in the device in reference, shown in part, to illustrate generation of the vortical motion in the fluid;

figure 6 is a perspective view of a second of embodiment of the thermal exchange device in reference, with parts removed, in a flat version with cavities;

figure 7 is a schematical view in perspective of a third embodiment of the thermal exchange device in reference, shown partially, in a tubular version with fin shapings;

figure 8 is a view similar to that of figure 7 of a fourth embodiment of the thermal exchange device in reference;

figure 9 is a view similar to those of figures 7 and 8 of a fifth of embodiment of the thermal exchange device in reference;

figure 10 is a schematical view in perspective of the thermal exchange device of figure 7 in which the turbulent motion generated in the fluid on contact with the fins according to the invention is shown; and

figure 11 is an assembly plan of a heat exchanger using finned tubes according to the invention.

Reference is made to figure 1, which shows a first example of a structural embodiment of a thermal exchange device according to the present invention, generally indicated in 1.

The device 1 comprises a tube, made of a heat conductive material, forming the separation surface between two fluids, having an adequate thickness, on the external and internal surfaces of which are formed using mechanical processes a succession of circumferential cavities 3, annular or helicoidal, with a fluid-dynamically rounded cross-section, suitable for creating a series of fins 4 arranged substantially perpendicular to the longitudinal axis of the tube 2 and therefore to the direction of movement of the fluid. The cylindrical end portions, of which only one is illustrated in figure 1 and indicated in 5, of the tube 2 can be left smooth, that is to say without cavities 3, for optional welded connection to the tube plates, as in the conventional assembly method.

In the device 1, heat exchange takes place between fluids moving concurrently or countercurrently on the outside and the inside of the tube 2, respectively in the directions of arrows A and B.

With the above described structure of the device 1, the flow of fluid A is made to undergo, thanks to the cavities 3, toroidal turbulence which increases thermal exchange.

In figures 2, 3 and 4, given that the elements described above will be indicated using the same reference numerals, different embodiments of the cavities 3 are shown, here again on a tube 2 which makes up as a whole the thermal exchange device 1 of the present invention, in which the flow of the external fluid occurs in the direction of the arrows.

As can be seen from the figures in question, in figure 2 the cavities 3 are of a substantially semi-circular shape, with the opposite sides of the fins 4 concave, and they are of the restricted aperture type; in figure 3 the cavities 3 have a substantially semi-elliptic shape with the opposite sides of the fins 4 concave, and they are of the wide aperture type; finally, in figure 4 the cavities 3 have a rounded shape on the outlet side and on the bottom, whereas their inlet side is flat and they are of the type with an intermediate aperture with respect to that of the first two, it being specified that, according to working conditions, in the latter case, obviously with the fluid flow in the opposite direction to that indicated by the arrows, the inlet side can be that with the rounded shape and the flat side can form the outlet side.

Reference is now made to figure 5, wherein is illustrated the flow dynamics of a fluid moving in the direction of the arrows along the separating wall 6 on which cavities are formed, of which one only is shown and indicated with 7, according to the present invention.

In the above figure the number 8 indicates the leading edge of the downstream fin 9 formed by the cavity 7, in 10 is indicated a first mouthpiece section, in 11 is indicated a second transition section, which prepares for deviation of the fluid vein towards the cavity, and in 12 is indicated a third section, in correspondence with the opening of the cavity 7, in which transfer of heat and momentum between the bulk fluid and the fluid in said cavity takes place. With the above indicated arrangement, a stable toroidal vortical motion 13 is set up in cavity 7, with its center of rotation situated approximately at 14.

As the cavity 7 is of an asymmetrical shape, conceived, as stated, to obtain in the section 11 a deviation of the motion of the fluid towards the inside of the cavity itself, and as the tip 8' is lower down than the point 8, the fluid mass encountering the edge at point 8 is cut into two parts, of which one part penetrates into the cavity 7, deviated by the curved wall of the latter which has fluid-dynamic characteristics, rotating due to the intrinsic action of the energy it possesses, whereas the other part continues in an axial direction, licking against the section beyond point 8 which has the entry thermal exchange coefficient, notoriously higher than that of smooth tubes.

The toroidal vortical motion thus created within the cavity of the thermal exchange device according to the present invention gives following advantages:

- it reduces formation of stabilized boundary layers on the reduced external surfaces of the fins facing towards the main current, due to the shortness of the section, and inside the cavity, due to the vortical motion;
- it causes the fluid to flow on a sort of series of axial bearings, in which the races of ball-bearings are represented by the fluid within the cavities, in vortical toroidal circulation;
- it notably increases the heat transfer surface and thermal exchange coefficient;
- it raises the relative fluid/wall speed within the cavities themselves and the thermal uniformity of the surfaces;
- it forces the hottest parts of the fluid into the center of the cavities, due to centrifugal forces. In supercooled boiling thermal exchange this moves the microbubbles away, forcing them towards the center, where they implode, bringing fluid which is always fresh into contact with the hot wall;
- the hot fluid in the cavity exchanges heat and momentum with the bulk fluid by means of a mechanism using turbulent conductivity.

Reference is now made to figure 6, which illustrates a second example of structural embodiment of a thermal exchange device according to the invention.

As can be seen from the figure in question, the heat exchanger surface is formed in this case by a flat element 15, of thermally conductive material, on one surface of which a series of transversal cavities 3 is formed, said cavities being parallel, with a rounded cross-section, capable of creating, as described above, a vortical motion within the heat exchanger fluid which flows in the direction of the arrow.

In the present embodiment the flat element 15 is associated with a tubular body 16 for channeling of said fluid. In the example the fluid with lower thermal conductivity flows inside the tube.

It must be specified that the heat exchanger surfaces of the device according to the present invention, according to working conditions, can take on forms differing from those illustrated in the structural embodiments described above, so long, obviously, as suitably positioned cavities are formed therein, for creation of the vortical motion of the contact fluid.

It must furthermore be specified that said cavities can be formed on a single side of the heat exchanger surface, or on both opposite sides thereof.

With reference now to figure 7, a third example of structural embodiment of a thermal exchange device according to the present invention is shown, generically indicated with 17.

In the embodiment illustrated, the heat exchanging surface of the device 17 has the shape of a tubular body 18, in which the exchange of heat takes place between fluids moving axially on the outside and inside of said body.

According to the present invention, on the external circumferential surface of the tubular body 18, respective series of spaced fins 19 are provided along equidistant generatrixes, the fins of one series being offset with respect to those of the adjacent series in such a way as to be in correspondence with the gaps between the latter.

As can be seen from the figure in question, the fins 19 have a particular outline, conceived with the aim of using the characteristics of the fluid or the motion to induce intrinsically actions disturbing the formation of boundary layers on the cylindrical external wall of the tubular body 18 and in the bulk during axial motion of the fluid running in contact with said wall, and at the same time with the aim of generating in said fluid a turbulent motion to improve heat transfer between said fluids.

In particular, in the example of figure 7, each fin 19 comprises in a single piece a widened base section 20 having an almost rectangular outline, destined to disturb the formation of boundary layers which tend to form along the cylindrical wall of the tube, and an upper section 21 which narrows as it goes up until it terminates in a substantially pointed end, destined to cut the vein of fluid and to generate turbulence and a high thermal exchange entry coefficient on the whole of the surface of the fin, guaranteeing transfer of a greater amount of heat with respect to the continuous surfaces, where boundary layers are formed.

In the fourth structural embodiment shown in figure 8, for which what has been stated above regarding the structure of figure 7 is also valid and in which components similar to those previously described will be indicated using the same reference numerals primed, it can be noted that the difference with respect to the embodiment of figure 7 lies in the shape of the fins 19', which in this case likewise have a widened base section 20' having a rectangular outline, forming one piece with an upper section 21' which narrows as it goes up until in terminates in a line. In this structural embodiment the fins are axially cut in an asymmetrical manner to assist the characteristics of the fluid and the motion better in specific cases.

In the fifth structural embodiment of figure 9, in which components similar to those previously described for the embodiments of figures 7 and 8 will be indicated using the same reference numerals primed twice, each fin 19'' forms a single piece made up of a widened base section 20'' with a rectangular outline, similar to that of fins 19 and 19' above, destined, as in the case of the latter, to disturb the formation of boundary layers and to form turbulence on the fluid mass. The upper section 21'' narrows as it goes up until it takes on an aerodynamic shape such as to deviate the fluid from the axis of the tube, sending it towards adjacent tubes so as to mix the fluid in the various subchannels in an intrinsic manner, creating toroidal type turbulence.

A system for obtaining, in a surprisingly practical and functional manner, the series of fins of the device according to the present invention in the above described embodiments is that of using tubular bodies obtained by extrusion with continuous fins, then performing successive cold working operations to remove parts of each continuous fin in a symmetrical manner to obtain fins 19 of figure 7, in an asymmetrical manner to obtain fins 19' of figure 8, and in a more elaborate manner to obtain fins 19'' so as to follow the fluid-dynamics of the application in a better way.

Independently of the outline of the fins 19, 19' and 19'' illustrated above, it is obvious that different shapes of fins can be obtained for different purposes, by means of appropriate mechanical working on numerical control machine tools, the various geometries arising from the fluid-dynamic parameters in the various application, and that is to say the type of fluid, the temperature, the speed, the viscosity, etc.

As schematically illustrated in figure 10, the geometry of the fins in the device according to the present invention continuously presents the contact fluid with the inlet conditions according to the following dynamics: due to the action within the threads of fluid joining up at the end of a fin, when they encounter the next fin restore the first fit thermal exchange situation; due to the effect of the deviation of fluid along the sides of the fins which performs a disturbing action in the layers close to the heat exchanger surface and the surrounding fins.

The presence of instability appears to be desirable for the beneficial action with respect to the intrinsically induced turbulence.

Using suitable geometrical solutions for the fins it is possible to favour the presence of said instability by altering, as far as the fins themselves are concerned, the ratios between full-empty and height-thickness, as well as the leading angles according to the type of fluid, the temperature, etc.

Figure 11 illustrates an original and surprisingly functional arrangement of tubes, shown in part, provided with fins according to the present invention, for the formation of heat exchangers, in which are provided numerous series of thermal exchange tubes 22, parallel and spaced, connected at their ends to respective headers 23, of which only those in correspondence with one end are shown. Each tube 22 is formed with fins 24, shaped according to the teaching of the present invention and roughly shown here for simplicity without the required shape, said fins being arranged in such a way that the fins 24 on one tube 22 are set at intervals between pairs of adjacent fins 24 on contiguous tubes 22, thus giving, due to the effect of the deviation of fluid generated by the fins of the invention, an optimal disturbing action on the layers close to the surface of the tubes 22, as well as of the fins 24 as a whole, thanks to the offset spacing of the fins of adjacent series.

Although in the above described embodiments regarding figures 7-10 of the device according to the present invention the heat exchanger surfaces have been illustrated using a tubular version, it must here be specified that said surfaces can take on different forms, for example flat, according to the working conditions, as long as they include, parallel to the direction of flow of the contact fluid, the series of fins with the geometrical characteristics mentioned above.

It must furthermore by specified that said series of shaped fins can be formed on one face only of the associated heat exchanger surface, as in the examples described above, or, if considered necessary, on both opposite faces of the heat exchanger surfaces themselves.

Although in the present discussion the principles of the present invention have been referred exclusively to the field of thermal exchange, it should be noted that said principles can be efficaciously applied, at least in part, to fluid engineering fields, such as, for example, the lift surfaces of aircraft, as said principles modify the boundary layer situation.

Claims

1. A fluid-dynamic device, particularly for thermal exchange, comprising a thermally conductive body in which, along one surface or two opposite surfaces, a respective fluid flows, said device being characterized in that on at least one of said surfaces of said body are formed, in the direction of flow of said fluid, shapes (3, 4, 19, 19', 19'') with a configuration such as to generate in an intrinsic manner an induced turbulence in said fluid and to disturb the formation of boundary layers on said at least one of said surfaces of said body.

2. A device according to claim 1, characterized in that said shapes are formed by a series of cavities (3) having an asymmetrical cross-section and a fluid-dynamic profile, with axes arranged substantially ad right angles with respect to the direction of flow of the fluid, said

arrangement being such that the flow of the fluid induces disturbance of the formation of surface boundary layers and a vortical motion of the fluid.

3. A device according to claim 1, characterized in that said shapes are formed by spaced series of fins (19, 19', 19'') set at intervals, each of which is formed by a base portion (20, 20', 20'') having a geometry such as to disturb the formation of boundary layers and to create local turbulence in said fluid, and by an upper portion (21, 21', 21'') having a geometry such as to transfer to the inside of the mass of said fluid the thermal conditions of said surface of said thermally conductive body on which said fins (19, 19', 19'') are situated, and to create in said fluid an induced turbulence, so as to increase the overall heat transfer.

4. A device according to claim 2, characterized in that said cavities (3) form a series of parallel, spaced fins (4), substantially perpendicular to the direction of flow of the fluid.

5. A device according to claims 2 or 4, characterized in that said cavities (3) are of a more or less semicircular shape, asymmetric, with a fluid-dynamically shaped section, the opposite sides of each of said fins (4) being concave.

6. A device according to claims 2 or 4, characterized in that said cavities (3) are of a substantially asymmetric and semi-elliptic shape, the opposite sides of each of said fins (4) being concave.

7. A device according to claims 2 or 4, characterized in that said cavities (3) are of a rounded shape on the outlet side and on the bottom, and have a flat inlet side.

8. A device according to claims 2 or 4, characterized in that said cavities (3) are of a rounded shape on the inlet side and on the bottom, and have a flat outlet side.

9. A device according to one or more of claims 2 and 4-8, characterized in that said series of cavities (3) is formed on one surface of said thermally conductive body.

10. A device according to one or more of claims 2 and 4-8, characterized in that said series of cavities is formed on two opposite surfaces of said thermally conductive body.

11. A device according to claim 3, characterized in that said spaced series of fins (19, 19', 19'') set at intervals are parallel one to the other.

12. A device according to claims 3 and 11, characterized in that said fins (19, 19', 19'') in each series are offset with respect to the fins (19, 19', 19'') in the adjacent series.

13. A device according to one or more of claims 3, 11 and 12, characterized in that each of said fins (19) in said series is formed of a single piece made up of a widened base section (20) and an upper section (21) which narrows as it goes up until terminating in a substantially pointed manner.

14. A device according to one or more of claims 3, 11 and 12, characterized in that each one of said fins (19') in said series is formed of a single piece made up of a widened base section (20') and an upper section (21') which narrows until terminating in a line.

15. A device according to one or more of claims 3, 11 and 12, characterized in that each one of said fins (19'') in said series is formed of a single piece made up of a widened base section (20'') and an upper section (21'') which narrows as it goes up to form an aerodynamic shape.

16. A device according to one or more of claims 3, 11-15, characterized in that said series of fins are formed on one surface of said thermally conductive body.

17. A device according to one or more of claims 3, 11-15, characterized in that said series of fins are formed on two opposite surfaces of said thermally conductive body.

18. A device according to one or more of the preceding claims, characterized in that said thermally conductive body is a body of a tubular type (1, 18, 18', 18'', 22).

19. A device according to one or more of claims 1-17, characterized in that said thermally conductive body is a flat body (15).

20. A device according to one or more of claims 1-17, characterized in that said thermally conductive body is made up of one or more flat bodies (15) in combination with a tubular body (16).

21. A fluid-dynamic device according to one or more of claims 2 and 4-10, characterized in that said series of cavities is formed on a surface in order to modify the situation of the fluid boundary layer in contact with said surface.

Fig. 1

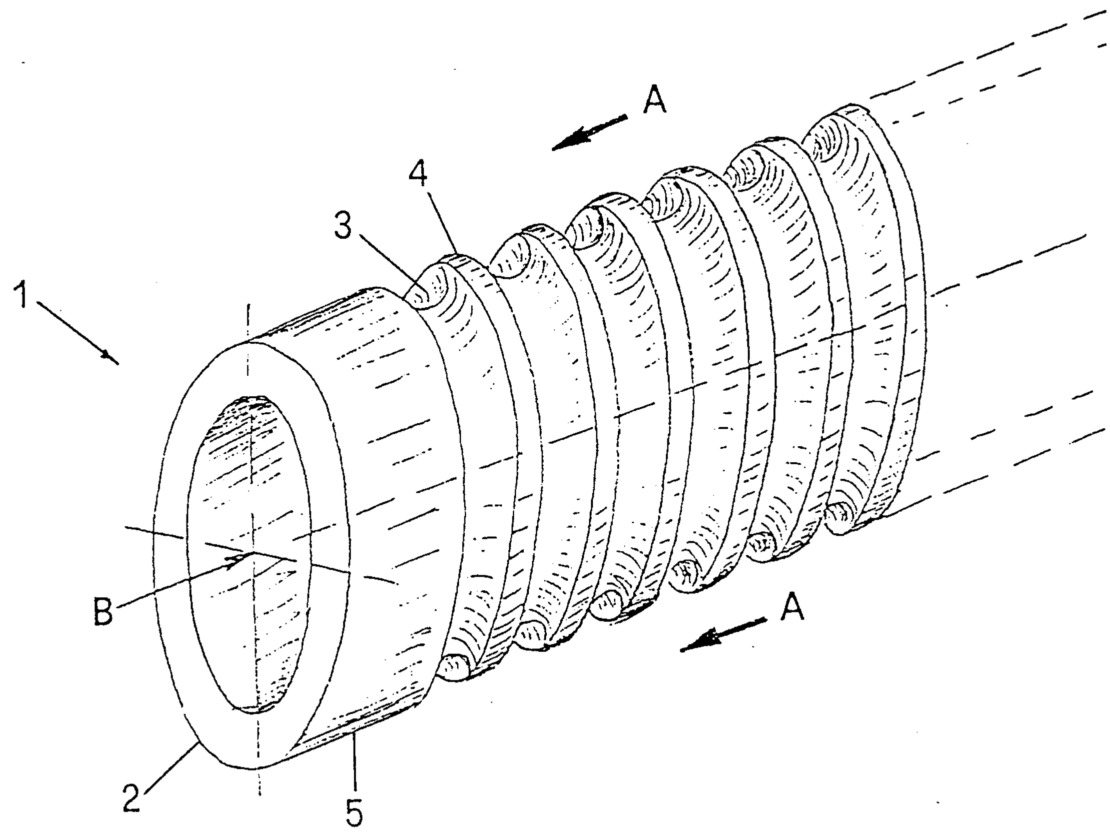


Fig. 2

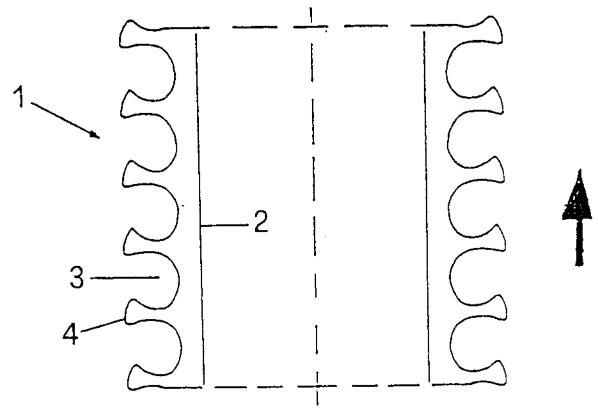


Fig. 3

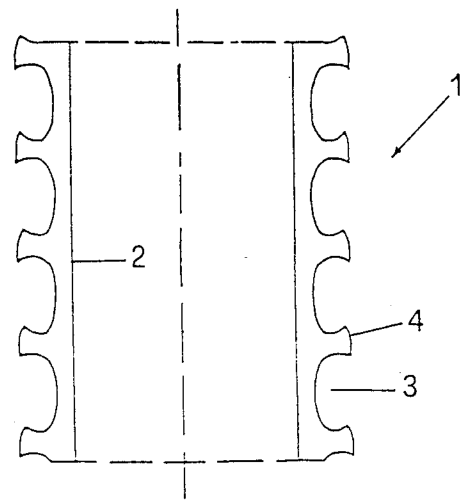


Fig. 4

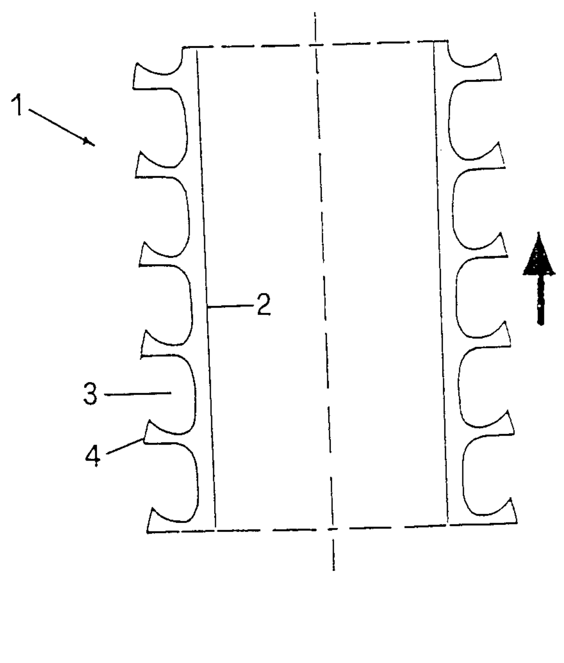


Fig. 5

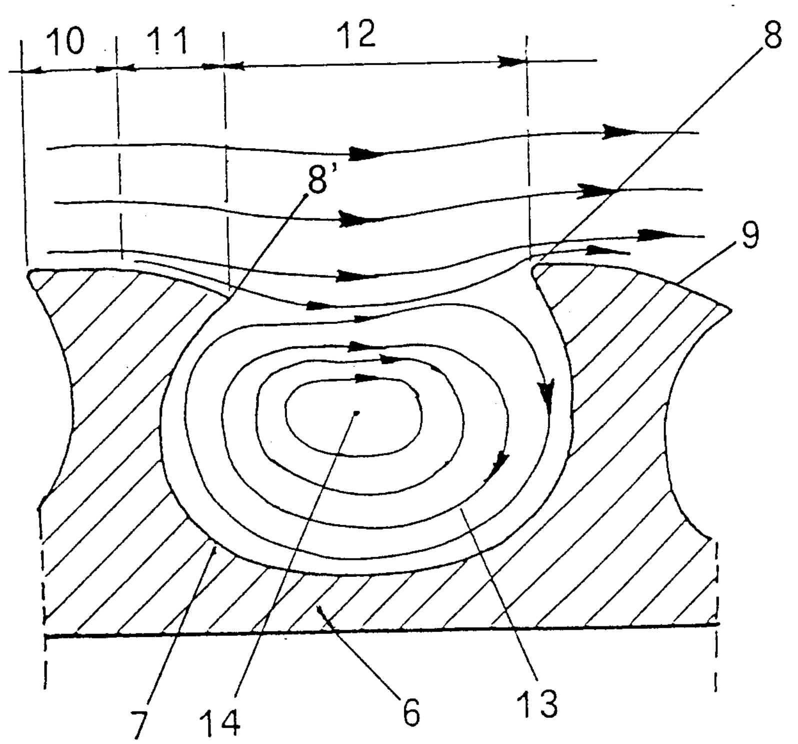


Fig. 6

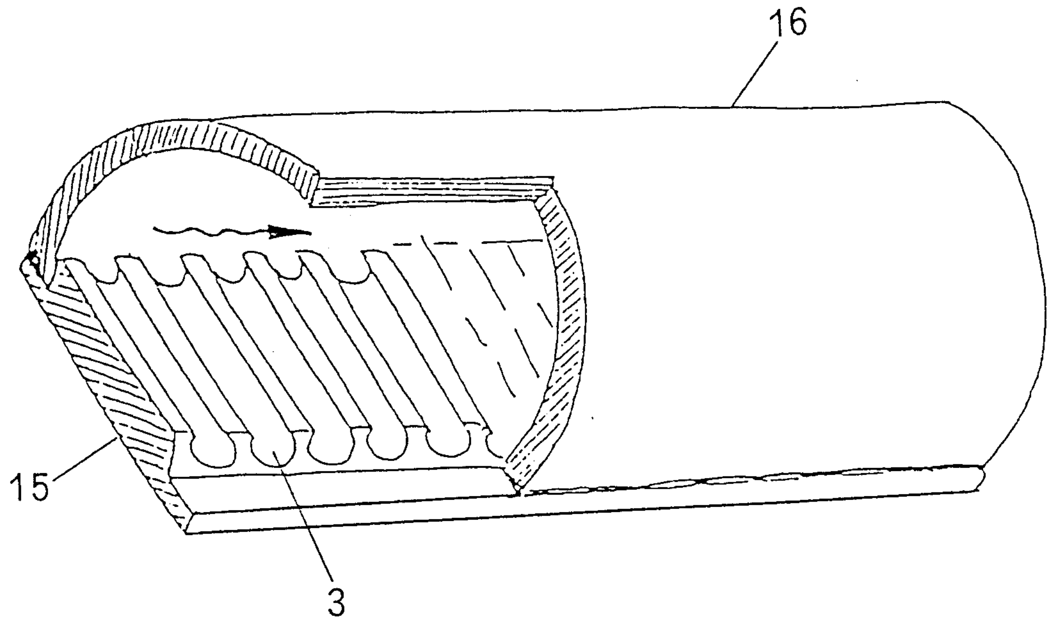


Fig.7

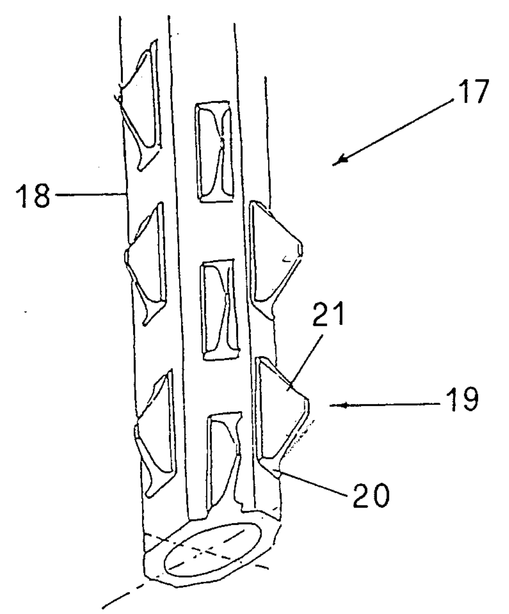


Fig.8

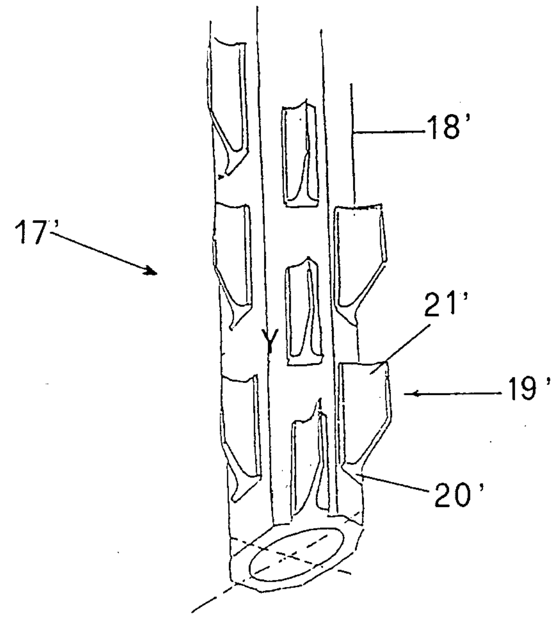


Fig.9

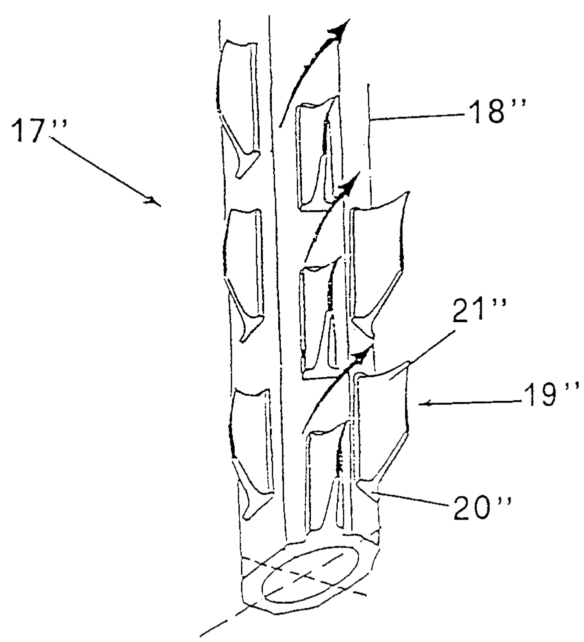


Fig.10

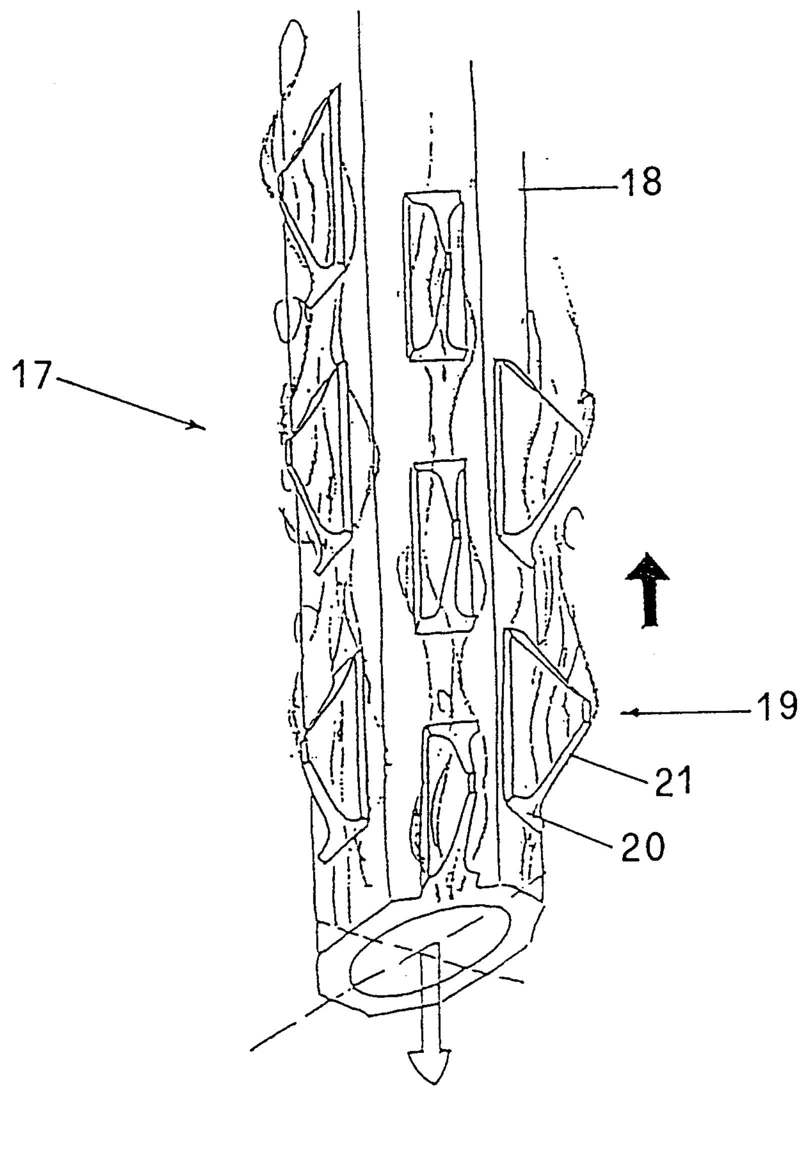
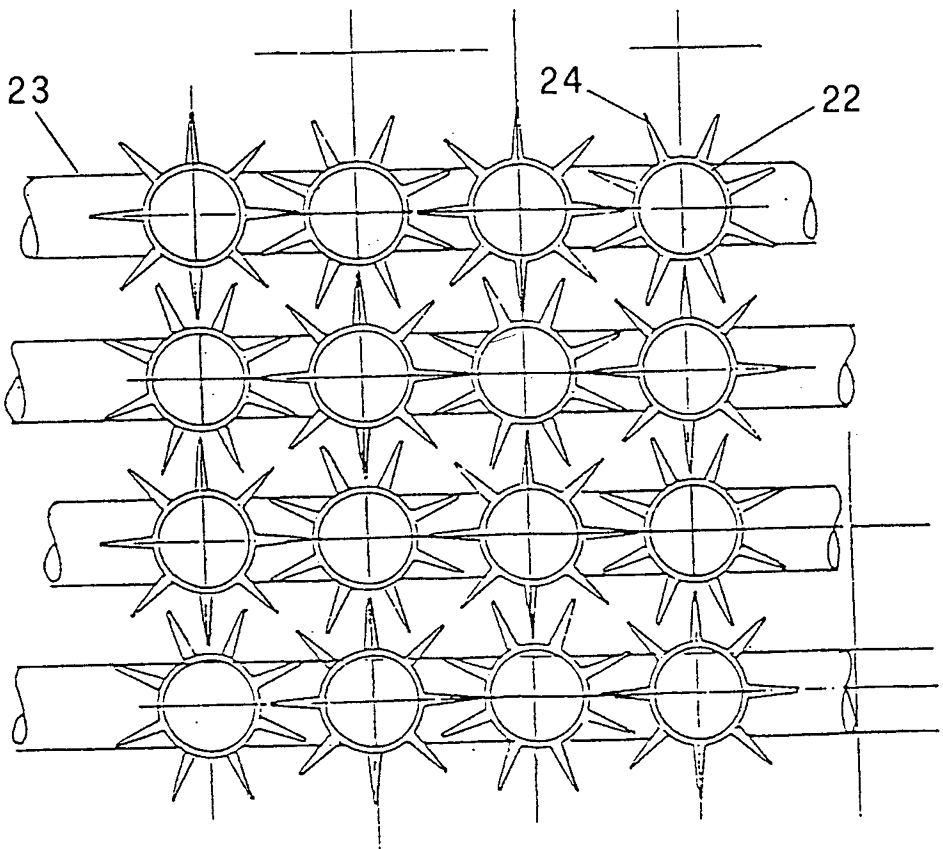


Fig.11



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EUROPEAN SEARCH REPORT

Application Number

EP 92 83 0320

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	US-A-4 438 807 (MATHUR ET AL.) * the whole document *	1,2,5,6, 7,8,9,21	F28F13/02 F28F13/18 F28F1/14
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A	FR-A-2 137 153 (SOCIÉTÉ ARTISTIQUE FRANÇAISE) * the whole document *	3,14,15, 16	
A	US-A-4 059 147 (THORNE) * the whole document *	1	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

F28F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	25 SEPTEMBER 1992	SMETS E.D.C.

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