

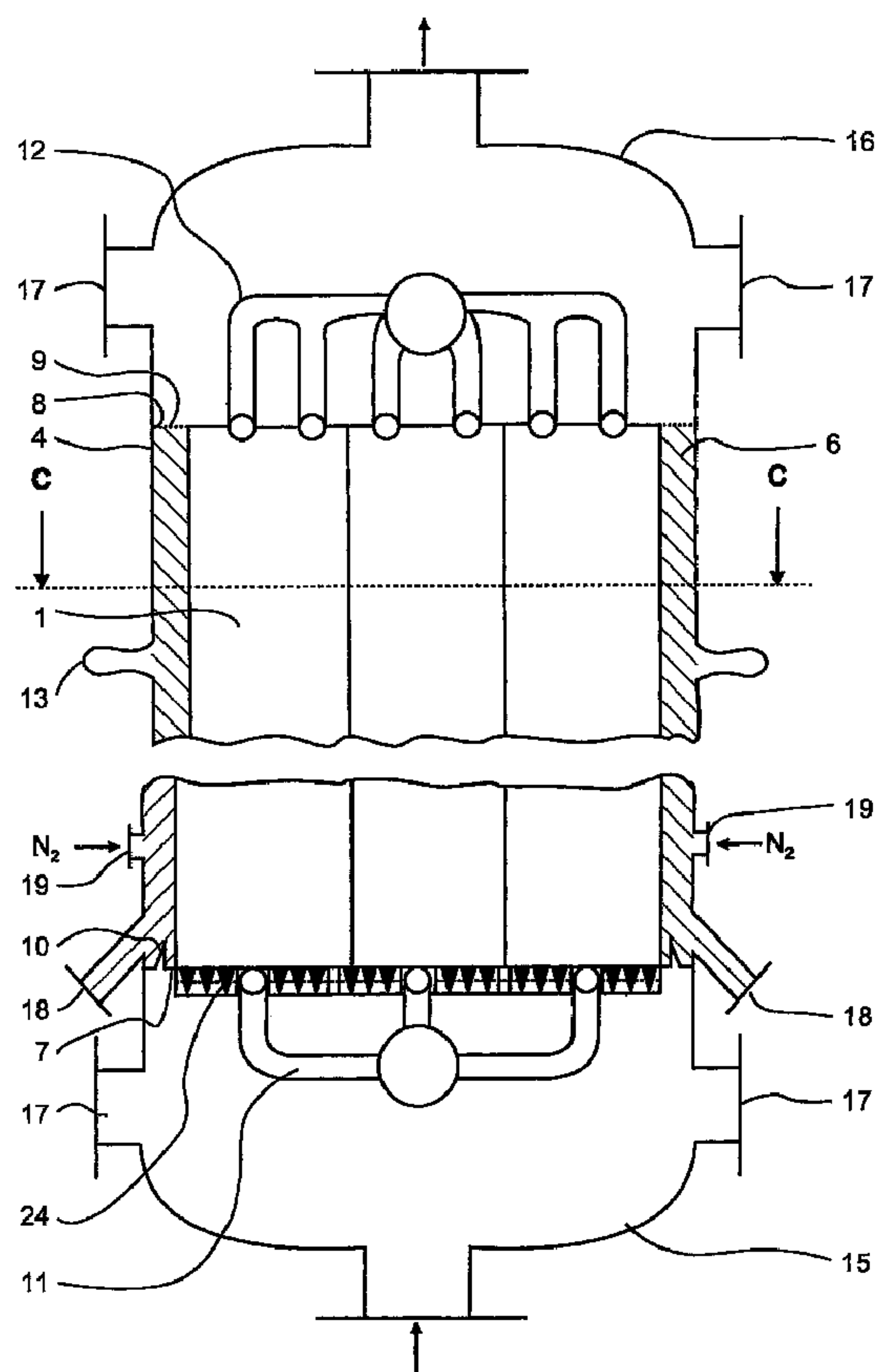


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(54) Titre : REACTEUR POUR OXYDATIONS PARTIELLES, EQUIPE DE MODULES FORMES DE PLAQUES DE TOLE
THERMIQUES

(54) Title: REACTOR FOR PARTIAL OXIDATION WITH HEAT-TRANSFER SHEET MODULES



(57) Abrégé/Abstract:

The invention relates to a reactor for partial oxidation of a fluid reaction mixture in the presence of a heterogeneous particulate catalyst. Said reactor comprises one or several cuboid heat-transfer sheet modules (1) which are each composed of two or several

(57) **Abrégé(suite)/Abstract(continued):**

right-angled heat-transfer sheets (2), arranged parallel to each other such as to form a slit (3) which can be filled with the heterogeneous particulate catalyst and through which the fluid reaction mixture flows, the heat of reaction being absorbed by a heat carrier which flows through the heat-transfer sheets (2) and at least partially evaporates. Said reactor also comprises a mainly cylindrical envelope (4, 15, 16) which depressurizes the heat-transfer sheet modules and fully surrounds said modules, said envelope being composed of a cylinder casing (4) and of caps (15, 16), closing said casing at both ends, the longitudinal axis of which extends parallel to the plane of said heat-transfer sheets (2). Said reactor finally comprises one or several sealing elements (7, 23), arranged so that the fluid reaction mixture flows only through the slit (3), except through the reactor interior spaces, defined by the caps (15, 16).

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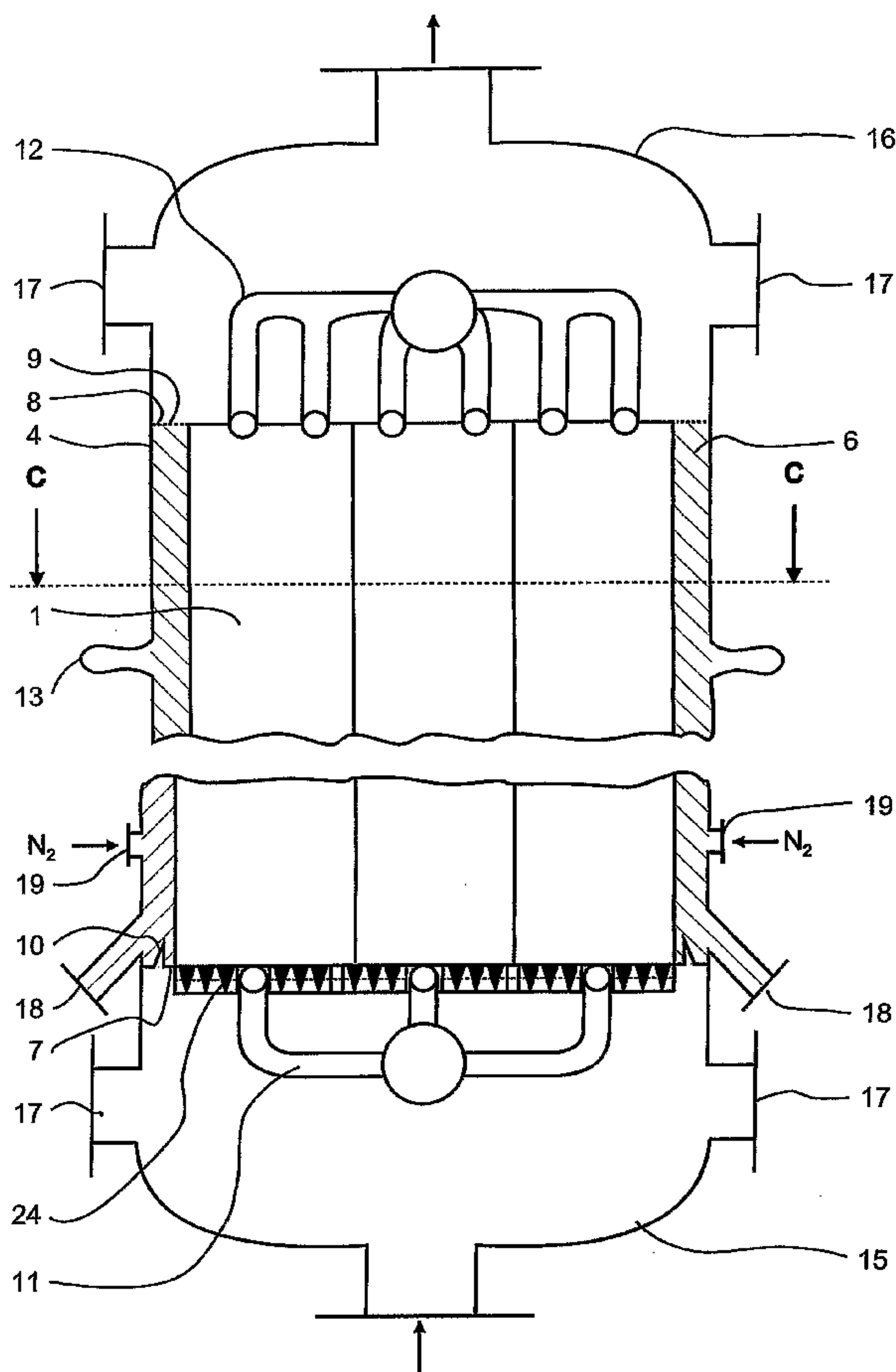
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(54) Title: REACTOR FOR PARTIAL OXIDATION WITH HEAT-TRANSFER SHEET MODULES

(54) Bezeichnung: REAKTOR FÜR PARTIALOXIDATIONEN MIT THERMOBLECHPLATTENMODULEN



(57) Abstract: The invention relates to a reactor for partial oxidation of a fluid reaction mixture in the presence of a heterogeneous particulate catalyst. Said reactor comprises one or several cuboid heat-transfer sheet modules (1) which are each composed of two or several right-angled heat-transfer sheets (2), arranged parallel to each other such as to form a slit (3) which can be filled with the heterogeneous particulate catalyst and through which the fluid reaction mixture flows, the heat of reaction being absorbed by a heat carrier which flows through the heat-transfer sheets (2) and at least partially evaporates. Said reactor also comprises a mainly cylindrical envelope (4, 15, 16) which depressurizes the heat-transfer sheet modules and fully surrounds said modules, said envelope being composed of a cylinder casing (4) and of caps (15, 16), closing said casing at both ends, the longitudinal axis of which extends parallel to the plane of said heat-transfer sheets (2). Said reactor finally comprises one or several sealing elements (7, 23), arranged so that the fluid reaction mixture flows only through the slit (3), except through the reactor interior spaces, defined by the caps (15, 16).

(57) Zusammenfassung: Es wird ein Reaktor für Partialoxidationen eines fluiden Reaktionsgemisches in Gegenwart eines heterogenen partikelförmigen Katalysators vorgeschlagen, mit einem oder mehreren quaderförmigen Thermoblechplattenmodulen (1), die jeweils aus zwei oder mehreren rechteckigen, parallel zueinander unter Freilassung jeweils eines Spaltes (3) angeordneten Thermoblechplatten (2) gebildet sind, der mit dem heterogenen partikelförmigen Katalysator befüllbar ist und der vom fluiden Reaktionsgemisch durchströmt wird, wobei die Reaktionswärme von einem Wärmeträger aufgenommen wird, der die Thermoblechplatten (2) durchströmt und dabei

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WO 2005/009608 A1

WO 2005/009608 A1



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Zur Erklärung der Zweibuchstaben-Codes und der anderen Abkürzungen wird auf die Erklärungen ("Guidance Notes on Codes and Abbreviations") am Anfang jeder regulären Ausgabe der PCT-Gazette verwiesen.

zumindest teilweise verdampft, sowie mit einer die Thermoblechplattenmodule druckentlastenden, dieselben vollständig umgebenden überwiegend zylinderförmigen Hülle (4, 15, 16), umfassend einen Zylindermantel (4) und denselben an beiden Enden abschließenden Hauben (15, 16) und deren Längsachse parallel zur Ebene der Thermoblechplatten (2) ausgerichtet ist, sowie mit einem oder mehreren Abdichtelementen (7, 23), die dergestalt angeordnet sind, dass das fluide Reaktionsgemisch außer durch die von den Hauben (15, 16) begrenzten Reaktorinnenräume nur durch die Spalte (3) strömt.

- 1 -

REACTOR FOR PARTIAL OXIDATION WITH HEAT-TRANSFER
SHEET MODULES

The invention relates to a reactor for partial oxidations of a fluid reaction mixture in the presence of a heterogeneous particulate catalyst, and also to its use.

In chemical process technology, a multitude of partial oxidation reactions of fluid, i.e. gaseous, liquid or gaseous/liquid, reaction mixtures are known and are carried out in the presence of heterogeneous particulate catalysts. Such reactions are generally exothermic, frequently strongly exothermic. On the industrial scale, they have hitherto been carried out
10 predominantly in tube bundle reactors having catalyst tubes, in which the heterogeneous particulate catalyst is installed and through which the fluid reaction mixture is passed, and the heat of reaction which is released is removed indirectly via a heat carrier which circulates in the intermediate space between the catalyst tubes. The heat carrier used is frequently a salt melt.

As an alternative, it is also possible to remove the heat of reaction via a heat carrier which is passed through plate-type heat transferors. The terms heat exchanger plates, heat transferor plates and thermoplates are used substantially synonymously for plate-type heat exchangers.

Heat transferor plates are defined predominantly as sheetlike structures which have an interior
20 provided with inlet and outlet lines and having a low thickness in comparison to the surface area. They are generally produced from metal sheets, frequently from steel sheets. However, depending on the application case, in particular the properties of the reaction medium and of the heat carrier, special, in particular corrosion-resistant, or else coated materials may be used. The inlet and outlet devices for the heat carriers are generally arranged at opposite ends of the heater exchange plates. The heat carriers used are frequently water, or else Diphyl[®] (mixture of from 70 to 75% by weight of diphenyl ether and from 25 to 30% by weight of diphenyl), which sometimes also evaporate in a boiling procedure; it is also possible to use other organic heat carriers having a low vapor pressure and also ionic liquids.

The use of ionic liquids as heat carriers is described in the German patent application 103 16
418.9 which was unpublished at the priority date of the present application. Preference is
30 given to ionic liquids which contain a sulfate, phosphate, borate or silicate anion. Also particularly suitable are ionic liquids which contain a monovalent metal cation, in particular

an alkali metal cation, and also a further cation, in particular an imidazolium cation. Also advantageous are ionic liquids which contain an imidazolium, pyridinium or phosphonium cation as the cation.

- 5 The term thermoplates is used in particular for heat transferor plates whose single, usually two, metal plates are joined together by point and/or roll welds and are frequently shaped using hydraulic pressure plastically to form pockets.

In the present context, the term thermoplates is used in the sense of the above definition.

10

Reactors for carrying out partial oxidations using thermoplates are known, for example, from DE-A 199 52 964. The arrangement is described of a catalyst for carrying out partial oxidations in a bed around heat transferor plates in a reactor. The reaction mixture is fed at one reactor end to the reactor interior between the heat transferor plates and removed at the
15 opposite end and thus flows through the interior between the heat transferor plates. As a result, there is constant transverse mixing of the reaction mixture with the consequence of high homogeneity thereof, and, for a predefined conversion, a substantially better selectivity is achieved compared to carrying out the reaction in a tube bundle reactor.

- 20 DE-C 197 54 185 describes a further reactor having indirect heat removal via a cooling medium which flows through the heat transferor plates, the heat transferor plates being designed as thermal plates which consist of at least two steel plates which are joined together at predefined points to form flow channels.

- 25 An advantageous development thereof is described in DE-A 198 48 208, according to which heat transferor plates which are configured as thermal plates flowed through by a cooling medium are combined to plate assemblies having, for example, rectangular or square cross section, and the plate assemblies have a casing. The encased plate assembly needs no adaptation on the circumferential side and is consequently used with predefined spacings to
30 the interior wall of the cylindrical reactor vessel. The free surfaces between the plate heat transferor or its casing and the vessel interior wall are covered in the upper and lower regions of the casing with guide plates, in order to prevent the reaction medium from bypassing the chambers filled with catalyst.

- 35 A further reactor having devices for removing the heat of reaction which are in the form of plate heat transferors is described in WO-A 01/85331. The reactor of predominantly cylindrical shape contains a continuous catalyst bed, into which a plate heat transferor is embedded.

Extended experiments on reactors having thermoplates have shown that problems occur in particular by deformation as a consequence of high stress on one side of the thermoplates at too high a pressure differential between the reaction mixture and the external environment, and also mechanical
5 stability problems as a result of deformation under high thermal stress. These problems can occur when the reaction mixture is under elevated pressure, but also when the reaction is operated at reduced pressure.

It is an object of the present invention to provide a reactor which has removal of the heat of reaction via a heat carrier which flows through thermoplates,
10 and can be operated in an economic and trouble-free manner, in particular avoiding the problems illustrated above. The invention should ensure the geometric stability of the thermoplate modules, particularly of the gaps designated to accommodate the catalyst.

We have found that this object is achieved by a reactor for partial oxidations
15 of a fluid reaction mixture in the presence of a heterogeneous particulate catalyst, comprising

- one or more cuboidal thermoplate modules which are each formed from two or more rectangular thermoplates arranged parallel to each other while in each case leaving a gap which can be filled with the heterogeneous
20 particulate catalyst and is flowed through by the fluid reaction mixture, the heat of reaction being absorbed by a heat carrier which flows through the thermoplates and thus at least partly evaporates, and also having

- a predominantly cylindrical shell which releases the pressure at the thermoplate modules, completely surrounds them and comprises a cylinder
25 jacket and hoods which seal it at both ends and whose longitudinal axis is aligned parallel to the plane of the thermoplates, and also having

3a

- one or more sealing elements which are arranged in such a way that the fluid reaction mixture, apart from flowing through the reactor interior spaces bounded by the hoods, only flows through the gap.

5 An embodiment of the invention relates to a reactor for partial oxidations of a fluid reaction mixture in the presence of a heterogeneous particulate catalyst, comprising:

- 10 • at least one cuboidal thermoplate module that includes at least two rectangular thermoplates arranged parallel to each other such that a gap in the at least one cuboidal thermoplate module between
15 respective adjacent rectangular thermoplates is configured to be filled with the heterogeneous particulate catalyst and is configured to receive a flow of the fluid reaction mixture, the at least two rectangular thermoplates being configured to receive a flow of a heat carrier that is configured to absorb a heat of reaction between the fluid reaction
20 mixture and the heterogeneous particulate catalyst and at least partly evaporate;
- 25 • a cylindrical shell configured to release a pressure formed at the at least one cuboidal thermoplate module, the shell completely surrounding the at least one cuboidal thermoplate module and including
 - a cylinder jacket,
 - a bottom hood configured to seal a bottom end of the shell,
 - a top hood configured to seal a top end of the shell,
 - a longitudinal axis that is aligned parallel to a vertical plane of
the at least two thermoplates,

3b

- a first interior space between the bottom hood and a bottom portion of the at least one cuboidal thermoplate module, and
 - a second interior space between a top portion of the at least one cuboidal thermoplate module and the top hood; and
- 5 • at least one sealing element arranged to limit the flow of the fluid reaction mixture within the shell from the first interior space to the second interior space to only flow through the gap.

Another embodiment of the invention relates to a reactor as defined in the above-mentioned embodiment, wherein the reactor includes at least two
10 cuboidal thermoplate modules each having the same dimensions. More preferably, the reactor may comprise 4, 7, 10 or 14 thermoplate modules.

Another embodiment of the invention relates to a reactor as defined in the above-mentioned embodiment, wherein the at least two thermoplates include two rectangular metal sheets joined at longitudinal and end sides by roll seam
15 welding, and wherein an edge of the two rectangular metal sheets that protrudes over the roll seam is removed at an outer edge of the roll seam or in the roll seam itself. More preferably, each of the at least one cuboidal thermoplate modules may be arranged in a pressure-stable rectangular stabilization frame. Much more preferably the reactor may include at least two
20 cuboidal thermoplate modules, and rectangular stabilization frames of adjacent cuboidal thermoplate modules may be welded and sealed together.

Another embodiment of the invention relates to a reactor as defined in the above-mentioned embodiment, wherein the at least one sealing element is a holding base which seals an intermediate space between the at least one
25 cuboidal thermoplate module and the cylindrical shell at the bottom portion of the at least one cuboidal thermoplate module. More preferably, a metal sheet cover may seal the intermediate space between the thermoplate modules and

the cylindrical shell at the top portion of the at least one cuboidal thermoplate module. Much more preferably, the metal sheet cover may include a plurality of orifices.

5 Another embodiment of the invention relates to a reactor as defined in the above-mentioned embodiment, wherein an intermediate space between the at least one cuboidal thermoplate module and the shell is filled with an inert material. More preferably, the inert material may be expanded perlite or expanded vermiculite.

10 Another embodiment of the invention relates to a reactor as defined in the above-mentioned embodiment, wherein pressure is applied to an intermediate space between the at least one cuboidal thermoplate module and the cylindrical shell with a gas. More preferably, the pressure applied may be constant. Much more preferably, the constant application of pressure may be effected by pressure-regulated feed and removal of nitrogen.

15 Another embodiment of the invention relates to a reactor as defined in the above-mentioned embodiment, wherein pressure is applied to an intermediate space between the at least one cuboidal thermoplate module and the cylindrical shell with a gas, and wherein the pressure is applied by continuously feeding the gas through the intermediate space, and wherein the
20 gas is inert or intrinsic to the process. More preferably, the gas may be combined with the fluid reaction mixture at an outlet from the thermoplate modules.

Another embodiment of the invention relates to a reactor as defined in the above-mentioned embodiment wherein compensators for radial expansion
25 are provided in or on the holding base.

Another embodiment of the invention relates to a reactor as defined in the above-mentioned embodiment wherein compensators for axial or radial expansion are provided in or on the metal sheet cover.

5 Another embodiment of the invention relates to a reactor as defined in the above-mentioned embodiment wherein each thermoplate module includes at least one distribution device and at least one collection device configured to receive the heat carrier.

10 Another embodiment of the invention relates to a reactor as defined in the above-mentioned embodiment wherein each thermoplate module includes one distribution device and two collection devices configured to receive the heat carrier.

15 Another embodiment of the invention relates to a reactor as defined in the above-mentioned embodiment further comprising a plurality of distribution and collection devices that are configured to receive the heat carrier and that have equal nominal widths.

Another embodiment of the invention relates to a reactor as defined in the above-mentioned embodiment further comprising a plurality of distribution devices and collection devices that are configured to receive the heat carrier and that are welded into a slotted base.

20 Another embodiment of the invention relates to a reactor as defined in the above-mentioned embodiment further comprising a plurality of distribution devices and collection devices that are configured to receive the heat carrier that flows through the thermoplates and that each include compensation for the accommodation of the thermal expansion of the thermoplate modules
25 relative to the cylindrical shell.

Another embodiment of the invention relates to a reactor as defined in the above-mentioned embodiment wherein a thermal expansion of the

thermoplate modules relative to the cylindrical shell is accommodated by a curved geometric design of a tubing of a plurality of distribution devices and collection devices that are configured to receive the heat carrier that flows through the thermoplates.

- 5 Another embodiment of the invention relates to a reactor as defined in the above-mentioned embodiment wherein each thermoplate modules includes two catalyst holding grates per thermoplate module.

Another embodiment of the invention relates to a reactor as defined in the above-mentioned embodiment further comprising manholes configured to
10 facilitate the introduction of a plurality of catalyst holding grates into the cylinder jacket.

Another embodiment of the invention relates to a reactor as defined in the above-mentioned embodiment, wherein the cylinder jacket includes at least one compensator configured to accommodate axial thermal expansion.

- 15 The invention therefore provides thermoplate modules which comprise thermoplates, through which a heat carrier flows, absorbs the heat of reaction and thus at least partly evaporates, and are configured with a cuboidal shape and are installed with pressure release in a predominantly cylindrical shell which completely surrounds them.

The plate modules are formed from in each case two or more rectangular thermoplates which are arranged parallel to each other while in each case leaving a gap.

5 The thermoplates are manufactured from corrosion-free materials, preferably from stainless steel, for example having the materials number 1.4541 or 1.4404, 1.4571 or 1.4406, 1.4539 or else 1.4547, or from other alloyed steels.

The material thickness of the metal sheets used for this purpose may be selected between 1 and 4 mm, 1.5 and 3 mm, or else between 2 and 2.5 mm, or as 2.5 mm.

10

In general, two rectangular metal sheets may be joined at the longitudinal and end sides to give a thermoplate, in which case a roll seam or lateral weld joint or a combination of both is possible so that the space in which the heat carrier is later disposed is sealed on all sides. The edge of the thermoplates is advantageously removed at or even in the lateral roll seam of the longitudinal edge so that the edge region, which is poorly cooled if at all, and in which catalyst is usually also installed, has a very low geometric expansion.

20 The metal sheets are joined together by point welding distributed over the rectangular surface. An at least partial connection by straight or else curved and also circular roll seams is also possible. It is also possible for the volume flowed through by the heat carrier to be divided by additional roll seams into a plurality of separate regions.

25 One possibility of arranging the weld points on the thermoplates is in rows with equidistant point separations of from 30 to 80 mm or else from 35 to 70 mm, although separations of 40 to 60 mm are also possible and a further embodiment has separations of from 45 to 50 mm and also from 46 to 48 mm. Typically, as a result of the manufacture, the point separations vary by up to ± 1 mm and the weld points of immediately adjacent rows, viewed in the longitudinal direction of the plates, are each arranged offset by half a weld point separation. The rows of the point welds in the longitudinal direction of the plates may equidistant with separations of from 5 to 50 mm, or else from 8 to 25 mm, although separations of from 10 to 20 mm and also from 12 to 14 mm, may also be used. Moreover, pairings of the weld point separations and row separations mentioned which are adapted to the application case are also possible. The row separations may be in a defined geometric relationship to the point separation, typically $\frac{1}{4}$ of the point separations or somewhat lower, so that there is a defined uniform expansion of the thermoplates in the course of the production. For predefined weld point and row separations, a corresponding number of weld points per m^2 of plate surface area is designated.

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The width of the thermoplates is limited substantially by manufacturing technology considerations and may be between 100 and 2500 mm, or else between 500 and 1500 mm. The length of the thermoplates is dependent upon the reaction, in particular upon the temperature profile of the reaction, and may be between 500 and 7000 mm, or else between
5 3000 and 4000 mm.

In each case two or more thermoplates are arranged parallel and separated from one another to form a thermoplate module. This results in shaftlike gaps forming between immediately adjacent plates which, at the narrowest points of the plate separation, for example, have a
10 width of between 8 and 150 mm, or else from 10 to 100 mm. One possible embodiment is also widths of from 12 to 50 mm or else from 14 to 25 mm, although from 16 to 20 mm may also be selected. A gap separation of 17 mm has also been tested.

Between the individual thermoplates of a thermoplate module, for example in the case of
15 large-surface-area plates, spacers can additionally be installed in order to prevent deformations which can change plate separation or position. To install these spacers, sections of the metal plates can be removed from the flow region of the heat carrier, for example by circular roll seams, in order, for example, to be able to introduce holes into the plates for securing screws of the spacers.

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The gaps may have the same separation, but, if required, the gaps may also be of different width when the reaction permits it or the desired reaction requires it, or apparatus or cooling technology advantages can be achieved.

25 The gaps of a thermoplate module filled with catalyst particles may be sealed with respect to each other, for example sealed by welding, or else be joined together on the process side.

To adjust the desired gap separation when joining the individual thermoplates together to form a module, the plates are secured in their position and in separation.

30

The weld points of immediately adjacent thermoplates may be opposite each other or offset from each other.

In general, preference is given for manufacturing reasons to configuring the arrangement with
35 two or more cuboidal thermoplate modules with in each case identical dimensions. In the case of arrangements of 10 or 14 thermoplate modules, it may be advantageous for the compactness of the overall apparatus to select two module types having different edge length or different edge length ratios.

Preference is given to arrangements of 4, 7, 10 or 14 thermoplate modules having in each case identical dimensions. The projection surface of a module which is visible in the flow direction may be square, or else rectangular is a side ratio of 1.1 or else 1.2. Combinations of 7, 10 or 14 modules having rectangular module projections are advantageous, so that the diameter of the external cylindrical shell is minimized. Particularly advantageous geometric arrangements can be achieved when, as detailed above, a number of 4, 7 or 14 thermoplate modules is selected.

- 10 It should advantageously be possible in this connection to exchange the thermoplate modules individually, for example in the case of leaks, deformations of the thermoplates or in the case of problems which affect the catalyst.

15 Advantageously, the thermoplate modules are each arranged in a pressure-stable, rectangular stabilization frame.

Each thermoplate module is advantageously kept in position by a suitable guide, for example by the rectangular stabilization frames, with a laterally penetrating wall, or, for example, by an angle construction.

20

In one embodiment, the rectangular stabilization frames of adjacent thermoplate modules are sealed with respect to each other. This prevents bypass flow of the reaction mixture between the individual thermoplate modules.

- 25 The installation of cuboidal thermoplate modules into a predominantly cylindrical pressure-rated shell results in relatively large free intermediate spaces remaining at the edge toward the cylindrical jacket wall of the shell, in which accumulation, side reactions or decomposition of the material product can take place. Cleaning or decontamination of product, for example in the event of the necessity of assembly operations, is only possible there with great difficulty.
- 30 It is therefore advantageous to separate this intermediate space from the reaction chamber, i.e. from the gaps between in each case immediately adjacent thermoplates.

To this end, the intermediate space between the thermoplate modules and the predominantly cylindrical shell is sealed at the lower end of the thermoplate module with a holding base. In order to prevent bypass flow of the reaction mixture, the bearing or holding base should seal the intermediate space gas-tight.

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Advantageously, the intermediate space between the thermoplate modules and the

predominantly cylindrical shell may also be sealed at the upper end of the thermoplate module by a metal sheet cover. However, a gas-tight seal is not necessary for this purpose; it is possible in one embodiment to configure the metal sheet cover with orifices.

- 5 The metal sheet cover at the upper end of the intermediate space between the thermoplate modules and the predominantly cylindrical shell may advantageously also be configured similarly to a valve tray.

10 The venting of the gas used to apply pressure may also be produced by means of an overflow unit, configured as a perforated plate, valve or force-loaded (for example with a spring or gas pressure), self regulating unit, also in combination with a blowback safeguard. These overflow units may also be disposed outside the cylindrical external shell.

15 The upper metal sheet cover may rest on struts which additionally stabilize the rectangular stabilization frames in which the thermoplate modules are installed.

20 The intermediate space between the thermoplate modules and the predominantly cylindrical shell may advantageously be filled with inert materials, in order to reduce the free gas volume there and in order to prevent gas convection which may lead, for example, to uncontrolled heat release.

25 In the cylindrical shell, it is advantageous to provide nozzles for the inlet and outlet of the inert bed material which are configured in suitable size and mounted at a suitable angle in such a way that blockage-free filling and emptying is possible under the force of gravity. Possible embodiments of the nozzles are nominal widths of 80, 100, 150 or 200 mm.

30 The inert material bed used may in principle be any chemically inert and sufficiently mechanically and thermally stable material, for example expanded perlite and/or expanded vermiculite.

It is possible to charge the intermediate space between the thermoplate modules and the predominantly cylindrical shell, which may be filled with inert material, with a gas pressure.

35 The application of pressure may be substantially constant and advantageously brought about by the pressure-regulated input and output of nitrogen. The regulation signal selected may be, for example, the pressure differential between the pressure in the intermediate space between the thermoplate modules and the predominantly cylindrical shell and the pressure at the lower end of the catalyst bed in the gaps of the thermoplate modules or at the upper end thereof.

Advantageously, the differential pressure signal may be corrected by an offset value; a mean value, in particular the arithmetic mean value, of the pressure over the height of the catalyst bed may preferably be selected as the regulation signal.

- 5 To apply pressure, appropriate nozzles and/or an internal ring line having small drillholes, which are preferably directed downward, may be provided in the predominantly cylindrical shell.

10 Alternatively, it is also possible to bring about the application of pressure with continuous flow through the intermediate space with a gas which is inert or intrinsic to the process, in particular nitrogen or cycle gas.

15 The gas used to apply pressure is advantageously combined with the fluid reaction mixture at its outlet from the thermoplate modules, generally still within the predominantly cylindrical shell of the reactor. The outlet points of the gas used for pressure charging are advantageously located in flow dead zones of the fluid reaction mixture, in order to purge them.

20 The flow rate of the gas used to apply pressure will generally be significantly less than the flow rate of the fluid reaction gas mixture and is advantageously selected in such a way that it is not harmful to the reaction in process technology terms.

25 The thermoplate modules should advantageously each be individually exchangeable, in order that, as already outlined above, problems which occur, for example leakages, deformations of the thermoplates or problems with the catalysts, can be remedied in a targeted manner. For this purpose, it is advantageous to configure the thermoplate modules with some play with respect to the wall of the rectangular stabilization frames.

30 Since the thermoplate modules in this advantageous embodiment rest in the rectangular stabilization frames without sealing, bypass flows of the reaction medium may occur. In order to prevent this, the sites between the thermoplate modules and the rectangular stabilization frames where there is no seal are sealed in a suitable manner, for example with metal sheet strips which are mounted on the exterior of the thermoplate modules and press onto the wall of the rectangular stabilization frame when inserted into it. Alternatively, gas-tight metal sheet covers and connections, for example in the form of weld lip seals are possible.

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Once the thermoplate modules have been inserted into the rectangular stabilization frames, they can be sealed with respect to the holding base, which seals the intermediate space between the thermoplate modules and the predominantly cylindrical shell at the lower end of

the thermoplate modules. It is possible in principle to use any known sealing means for this purpose. These may be, for example, conventional seals which, for example, are additionally screw-secured.

- 5 It is also possible to bring about the sealing by weld lips, for example, by a variant in which a weld lip is secured to the holding base and a second weld lip to the outer edge of the thermoplate module or of the rectangular stabilization frame. Both weld lips are configured in such a way that they fit together geometrically and can be welded together. To exchange the thermoplate module, the weld seam is separated and, if required, renewed.

10

The thermoplate modules can be tensioned from above with the rectangular stabilization frames by a device. Sufficient tensile pressure from above ensures adequate surface pressure on the seal and advantageous securing of the thermoplate modules.

- 15 It is not obligatory for the rectangular stabilization frames to be sealed with respect to each other, as long as an impermissible bypass flow past the gaps is prevented. It is also possible to connect the rectangular stabilization frames together with small drillholes, through which the inert gas can flow in from the intermediate space and between thermoplate modules and the predominantly cylindrical shell, which prevents reactions in the space between the thermoplate module and the rectangular stabilization frame.

20

The thermoplate modules may additionally have guiding and directing elements on the exterior. It is possible, for example, to provide corner brackets of any form on the corners of these elements and conical metal sheet strips on their side. It is also advantageous to mount attachment devices or attachment auxiliaries on the modules, such as eyes, loops or threaded drillholes, in order to enable simple insertion by means of a hoist or, for example, of a crane. To insert the thermoplate modules by crane, they can also be held on tie bars which reach vertically through the initially empty gap down to the lower edge of the plates and are connected there to a transverse support to take up the load.

25

In a particular embodiment, the outermost thermoplate of a thermoplate module, at the exterior thereof, is formed from a thicker and therefore more stable metal sheet than the other metal sheets used to produce the thermoplates.

30

To compensate for the thermal expansion, annular compensators in particular are advantageously provided in or on the holding base which seals the intermediate space between the thermoplate modules and the predominantly cylindrical shell at the lower end of the thermoplate modules. Annular compensation with an approximately z-shaped profile

35

viewed in the direction at right angles to the surface of the metal sheet base is particularly suitable. However, other conventional, wave-shaped compensators are equally suitable.

5 Preference is also given to also providing compensators for the axial and/or radial expansion in or on the metal metal sheet cover at the upper end of the intermediate space between thermoplate modules and predominantly cylindrical shell.

Each thermoplate module is supplied with the heat carrier by one or more distribution devices. The heat carrier, after flowing through the interior in the individual thermoplates, is removed
10 at the other end of the thermoplate module via one or more collection devices. Since, in accordance with the invention, a heat carrier is used which absorbs the heat of reaction released and thus partly evaporates, it is particularly advantageous for the adjustment of the flow rates to provide in each case one distribution device, but two collection devices, per thermoplate module.

15 The distribution and collection devices are preferably configured in such a way that they each have a compensation for the accommodation of the thermal expansion of the thermoplate modules relative to the surrounding predominantly cylindrical shell. Compensation is possible here, for example, by a curved pipeline design.

20 To accommodate the thermal expansion of the thermoplate modules relative to the surrounding predominantly cylindrical shell, it is possible to ensure a suitable curved or Z- or omega-shaped geometric configuration of the tubing of the distribution and collection devices for the heat carrier flowing through the thermoplates. In a further embodiment, this
25 compensation may be effected by axial or lateral compensators, in which case any pipe support required may be effected on an internal support structure.

Particular preference is given to configuring the collection tubes in the thermoplates for the feed and distribution, and also collection and removal, of the heat carrier by welding into a
30 slotted tray as follows: the individual thermoplates of a module are initially joined to a channel-shaped metal sheet which is curved toward the interior of the thermoplates and has an approximately semicircular cross section and also orifices or slits for the output of the heat exchanger. At this stage of manufacture, it is possible to check that the weldings into the slotted tray are free of manufacturing faults, even in a representative specimen or else in the
35 whole area, for example by X-ray. Subsequently, this first, approximately channel-shaped metal sheet is joined on both longitudinal sides to a second similarly shaped metal sheet, except having opposite curvature and no orifices or slots, in particular by longitudinal seam welding, to form a tubular component having virtually circular cross section. The two ends of

this tubular component are sealed by lids which may optionally be strengthened by an internal tie rod.

5 In a further embodiment, it is also possible to directly weld tube parts having a relatively small nominal width of, for example, from 4 to 30 mm, onto the thermoplates, frequently onto the metal sheet edges, to feed and remove the heat carrier.

10 The gaps between the individual thermoplates of each thermoplate module serve to accommodate the heterogeneous particulate catalyst.

In order to rule out flow of the catalyst particles out of the gaps under the influence of gravity, catalyst grates have to be provided at the lower end thereof. This may be effected, for example, with perforated or mesh plates, and it is particularly advantageous for this purpose to use edge gap sieves, which ensure good retention of the catalyst with simultaneously high
15 dimensional stability and low pressure drop for the reaction medium flowing through.

The catalyst retention grates may be installed, for example, in such a way that they can be swiveled.

20 It is particularly advantageous when the distribution devices for the heat carrier to the thermoplates are installed in such a way that the lateral separations from the distribution devices to the edge of the thermoplate assembly are the same, so that only a single type of catalyst-retaining grate is required. In each case two catalyst-retaining grates are provided per thermoplate module, i.e. on both sides of the distribution device for the heat carrier.

25 The catalyst-retaining grates are advantageously dimensioned in such a way that they can be installed and deinstalled via the manholes in the approximately cylindrical shell. The manholes frequently have an internal diameter of 700 mm. Correspondingly, preference is given to an edge length for the catalyst inlay grates of 650 mm.

30 In a further embodiment, it is possible to further divide these retaining grates into smaller units, but also to individually seal each gap or each gap half individually, so that it can also be emptied separately.

35 Alternatively, it is also possible to fill the thermoplate modules with catalyst before they are installed into the reactor, i.e. outside the reactor.

The shell surrounding the thermoplate modules has been described above as predominantly

cylindrical. In this context, this means that it has a cylindrical jacket with circular cross section which is sealed at both ends in each case by a hood.

The predominantly cylindrical shell is generally installed vertically.

5

The fluid reaction medium is passed into the reactor interior via one hood, frequently via the lower hood, flows through the gap which is filled with the heterogeneous particulate catalyst and is between the individual thermoplates, and is removed at the other end of the reactor, via the other, frequently the upper, hood.

10

The hoods are preferably manufactured from stainless steel or are stainless steel-plated.

15

The hoods may be connected to the cylinder jacket of the shell by secure welding or separably, for example via a flanged connection. The flange connection may be configured in such a way that it can be lowered by means of a hydraulic system.

20

It is advantageously possible to reach the circumference of the hoods on foot via one of more manholes which generally have a diameter of 700 mm. For this purpose, a widened cylindrical section is advantageous, which, like the hood, is, for example, manufactured from stainless steel or is stainless steel-plated.

25

It is possible via the manholes in the hoods to access the upper side of the modules, so that the catalyst can be introduced into the gaps between the thermoplates, and to the lower side of the modules, so that the retaining grids can be installed and de-installed easily.

30

To deinstall the catalyst, devices may additionally be installed in the lower hood to retain auxiliaries and to collect the catalyst, which may have already been installed in the course of operation, and also one or more nozzles to discharge the catalyst.

35

The material used for the holding base sealing the intermediate space between the thermoplate modules and the interior wall of the predominantly cylindrical shell, and for the rectangular stabilization frames for the thermoplate modules too, may be carbon steel. Alternatively, it is possible to use stainless steel for this purpose.

In one or both hoods, it is advantageous to install nozzles, through which multithermoelements can be introduced into the individual thermoplate modules. In addition, nozzles may be mounted there for further field instruments and process analytical devices.

Preference is given to providing, in the cylindrical jacket of the predominantly cylindrical shell, one or more compensators to accommodate preferably the axial thermal expansion.

5 The invention provides the use of a reactor for carrying out partial oxidations of a fluid reaction mixture, in which the heat of reaction is removed by a heat carrier flowing through the thermoplates which thus at least partly evaporates.

10 In this case, the reactor, especially in strongly exothermic reactions, is operated in such a way that the fluid reaction mixture is fed via the lower hood and removed from the reactor via the upper hood.

15 Since the heat carrier medium, which removes the heat of reaction in particular by evaporative cooling, is passed from below into the thermoplates, when the reaction mixture is fed from below, i.e. when there is cocurrent flow of reaction mixture and heat carrier, sufficient heat carrier is always available.

20 In addition, both in terms of construction and the flow control of the reaction medium and the operation, it has to be ensured that neither is the reaction medium excessively cooled by supercooled heat carrier before it reaches the active catalyst zone, nor is the heat carrier pre-evaporated to an impermissibly high degree.

25 The heat carrier medium used may be feed water as typically utilized in power stations for steam generation and corresponding to the prior art (Technische Regeln für Dampfkessel [Technical rules for vapor vessels] (TRD 611 of October 15, 1996 in BArbBl. 12/1996 p. 84, last altered on June 25, 2001 in BArbBl. 8/2001 p. 108). Typical parameters of the feed water may be: conductivity less than 0.4, or less than 0.2, microsiemens/cm, calcium and magnesium hardness less than 0.005 millimole per liter or below the detection limit, sodium less than 5 micrograms per liter, silicon dioxide less than 20 micrograms per liter, iron less than 50 micrograms per liter and oxygen less than 20 micrograms per liter, and a total content
30 of dissolved carbon of less than 0.2 milligram per liter. In addition, the feed water should be low in or free of halogen, in particular chlorine. It is also possible to condition the feed water in a targeted manner, for example by adding auxiliaries such as hydrazine, ammonia, and in particular to make it alkaline; in addition, corrosion inhibitors can be added to the feed water.

35 The upper hood, through which the reaction medium leaves the reactor in the above-described preferred process control, may consist of carbon steel.

In order to ensure access to the thermal plate modules for the purpose of repair or exchange, it

likewise has to be possible to remove the upper hood. When there is no flange connection, the upper hood can be removed and welded on again after module assembly.

It is possible to integrate the steam removed from the thermoplates into different steam rails.

5

The reactor may optionally be attached to two steam rails, one of which has a higher pressure and is utilized for the heating of the reactor to operating temperature.

It is advantageous to operate on only one steam rail.

10

The reactor can preferably be operated with natural circulation of the cooling medium, water, and a ratio of feed water to steam of generally from 3 to 12, preferably from 5 to 10.

It is possible to operate with forced circulation, in which case a wider load variation of the cooling is possible. To this end, the feed water is fed at a higher pressure than present in the cooling system, for example by means of a pump.

15

The feed water circulation rate in the distribution devices may be set between 0.5 and 3.0 m/s, or else from 1.0 to 2.0 m/s, and the water circulation number between 3 and 12. The flow rate of the biphasic flow (steam/water) in the collection devices may be between 0.5 and 15 m/s, or else between 2.0 and 6.0 m/s.

20

Particular preference is given to carrying out the heating of the thermoplate modules to start up the reactor from the same heat carrier network into which the heat is removed at by least partly evaporated heat carrier medium in the course of reaction operation.

25

The regulation of the steam pressure in the cooling system makes it possible to precisely adjust the cooling temperature. Experience has shown that the thermoplates can be operated up to a pressure of about 80 bar in the coolant. The reactor according to the invention enables direct steam generation at pressure levels up to 80 bar.

30

The reactor according to the invention can be used to carry out partial oxidations on the industrial scale.

Compared to the filling of a large number, frequently a five-figure number, of catalyst tubes, the provision of the catalyst and the filling with catalyst of a two- or three-figure number of gaps between the thermoplates is associated with distinctly reduced cost and inconvenience.

35

The modular configuration allows the reactor to be adapted flexibly to the required capacity. A relatively small number of thermoplate modules may be installed or operated in comparison to the maximum possible number restricted by the relative geometry of the shell and of the thermoplate modules. It is also possible when required to isolate individual modules from process gas flow and to operate the reaction with reduced capacity under the same external conditions.

It is possible to deliver the reactor in individual parts and assemble it at the use location.

10 The invention is illustrated in detail hereinbelow with the aid of drawings.

Specifically:

Figure 1 shows a longitudinal section through a preferred embodiment of a reactor according to the invention with the cross section C-C in Figure 1A, and also further preferred arrangements of thermoplate modules in cross section in Figures 1B to 1F,

Figure 2 shows a detailed illustration of a thermoplate module in cross section to the thermoplates, with longitudinal section illustrations in the planes A-A and B-B in Figure 2A and 2B respectively,

Figure 3 shows two possible embodiments of seals between holding base and stabilization frames,

Figure 4 shows a detailed illustration with drillholes in the rectangular stabilization frames,

Figures 5A, 5B and 5D to 5I show detailed illustrations with additional guiding and directing elements on the exteriors of the thermoplate module and

Figure 6 shows a detailed illustration of a tension device for securing the thermoplate modules in the rectangular stabilization frames.

15 The longitudinal section illustration through a preferred embodiment in Fig. 1 shows a reactor having thermoplate modules 1 which are surrounded by a predominantly cylindrical shell 4. The intermediate space 6 between the thermoplate modules 1 and the predominantly

cylindrical shell 4 is sealed gas-tight in the region of the lower end of the thermoplate module 1 by a holding base 7, and, in the region of the upper end of the thermoplate modules 1, by a sheet metal cover 8 which, preferred embodiment illustrated in the figure, has orifices 9. Also, the holding base 7 of said preferred embodiment illustrated in the figure, is further provided with compensators 10 for the radial expansion.

At the lower end of the thermoplate modules 1 is provided a distribution device 11 for the heat carrier, frequently feed water, and, in the region of the upper end of the thermoplate modules 1, a collection device 12 for the heat carrier, which is frequently present in this region as steam or as a water/steam mixture. The predominantly cylindrical shell 4 has compensators 13 for the thermal expansion.

In the preferred embodiment illustrated in Fig. 1, the fluid reaction medium is fed via the lower hood 15 and removed via the upper hood 16. In the region of the lower hood 15, and also in the region of the upper hood 16, is disposed in each case an additional cylindrical section with in each case two manholes 17. In the predominantly cylindrical shell 4 are provided nozzles 18 for the emptying of the inert material from the intermediate space 6 between the thermoplate modules 1 and the predominantly cylindrical shell 4, and also nozzles 19 for the feeding of nitrogen into the intermediate space 6. The catalyst is retained by catalyst grates 24 which are configured, for example, as edge gap sieves.

The cross-sectional illustration in the plane C-C in Fig. 1A shows a preferred arrangement of advantageously seven thermoplate modules 1 with intermediate space 6 between the thermoplate modules 1 and the shell 4, which is preferably filled with inert material.

Figure 1B shows a cross-sectional illustration having a single thermoplate module with square cross section which is arranged in the shell 4.

Figure 1C shows an embodiment with four thermoplate modules 1 having a square cross section in the shell 4.

Figure 1D shows an embodiment with seven thermoplate modules having a rectangular cross section and a side ratio of in each case 1 : 1.2.

Figure 1E shows an embodiment with eleven thermoplate modules having a rectangular cross section and a side ratio of in each case 1 : 1.1.

Figure 1F shows an embodiment with ten thermoplate modules 1 with in each case rectangular cross section and a side ratio of in each case 1 : 1.1.

Fig. 2 illustrates a section of a thermoplate module 1 with thermoplates 2 and gaps 3 between the thermoplates to accommodate the heterogeneous particulate catalyst. The figure illustrates the weld points between the metal sheets forming the individual thermoplates 2, and also the securing of the thermoplates 2 at their lateral edges in a lateral boundary 20. The thermoplate module is inserted into a rectangular stabilization frame 5.

The sectional illustration in the plane A-A in Fig. 2A illustrates the lateral roll seam weld 22 which seals the individual thermoplates, and also the sealing strips 23 between the thermoplates 2 of the thermoplate module 1 and the wall of the rectangular stabilization frame 5. The figure also shows a preferred arrangement of the weld points on the thermoplates 2.

The section B-B which is shown in Fig. 2B is located in a plane through the gap 3 filled with the particulate catalyst. Between the lateral boundary 20 of the thermoplate module 1 and the wall of the rectangular stabilization frame 5 are provided sealing strips 23.

Figure 3 shows two different variants for sealing the thermoplate modules with respect to the holding base. The left-hand side of the diagram shows a seal 25 between the holding base 7 and the lateral boundary 20 of a thermoplate module, and the connection is secured by a screw 26. The detail also shows a section of the edge gap sieve 24 used as a catalyst grate, and also a sealing strip 23 between the lateral boundary 20 of the thermoplate module and the rectangular stabilization frame 5.

The right-hand side of the diagram in Figure 3 shows a further variant of a seal between holding base 7 and thermoplate module, specifically by means of two weld lips 27, one of which is welded to the holding base 7 and the second to the lateral boundary 20 of the thermoplate module. The two weld lips are subsequently joined together with a weld seam.

Figure 4 shows an embodiment with drillholes 28 in the rectangular stabilization frames 5, which allows gas used to apply pressure to flow from the intermediate space between the thermoplate modules and the shell into the spaces between the thermoplate modules 1 and the rectangular stabilization frames 5.

Figure 5A shows a detailed illustration of a corner bracket 29 on the exterior of the lateral boundary 20 of a thermoplate module 1 for conducting and directing with respect to the rectangular stabilization frame 5.

The detailed illustration in Figure 5B shows, in addition to the corner bracket 29, conical metal sheet strips 30 on the side of the thermoplate modules 1 as guiding and directing

elements.

In addition, Figure 5B shows a possible embodiment for the outermost thermo plate 2 in the thermoplate module 1, and specifically the outer metal sheet of the outermost thermoplate 2 of
5 the thermoplate module 1 is thicker and thus more stable compared to the remaining metal sheets forming the thermoplates 2.

Figures 5D to 5I show schematics of different variants for securing the thermoplates 2 to the lateral boundary 20:

10

in the embodiment in Figure 5D, the thermoplates 2 are welded on;

in Figure 5E, two angles welded onto the lateral boundary 20 are provided to secure the thermoplates;

15

in the embodiment in Figure 5F, square tubes;

in the embodiment in Figure 5G, half tubes,

20 in the embodiment in Figure 5H, U-profiles; and

in Figure 5I, angled profiles.

Figure 6 shows a schematic of a tension device 32 for tensioning between thermoplate
25 modules and the rectangular stabilization frames 5.

We claim:

1. A reactor for partial oxidations of a fluid reaction mixture in the presence of a heterogeneous particulate catalyst, comprising:

- 5 • at least one cuboidal thermoplate module that includes at least two rectangular thermoplates arranged parallel to each other such that a gap in the at least one cuboidal thermoplate module between respective adjacent rectangular thermoplates is configured to be filled with the heterogeneous particulate catalyst and is configured to receive a flow of the fluid reaction mixture, the at least two rectangular thermoplates being configured to receive a flow of a heat carrier that is configured to absorb a heat of reaction between the fluid reaction mixture and the heterogeneous particulate catalyst and at least partly evaporate;
- 10 • a cylindrical shell configured to release a pressure formed at the at least one cuboidal thermoplate module, the shell completely surrounding the at least one cuboidal thermoplate module and including
 - 15 ○ a cylinder jacket,
 - a bottom hood configured to seal a bottom end of the shell,
 - 20 ○ a top hood configured to seal a top end of the shell,
 - a longitudinal axis that is aligned parallel to a vertical plane of the at least two thermoplates,
 - a first interior space between the bottom hood and a bottom portion of the at least one cuboidal thermoplate module, and

- a second interior space between a top portion of the at least one cuboidal thermoplate module and the top hood; and
 - at least one sealing element arranged to limit the flow of the fluid reaction mixture within the shell from the first interior space to the second interior space to only flow through the gap.
- 5
2. The reactor as claimed in claim 1, wherein the reactor includes at least two cuboidal thermoplate modules each having the same dimensions.
3. The reactor as claimed in claim 2, wherein the reactor comprises 4, 7, 10 or 14 thermoplate modules.
- 10 4. The reactor as claimed in claim 1, wherein the at least two thermoplates include two rectangular metal sheets joined at longitudinal and end sides by roll seam welding, and wherein an edge of the two rectangular metal sheets that protrudes over the roll seam is removed at an outer edge of the roll seam or in the roll seam itself.
- 15 5. The reactor as claimed in claim 1, wherein each of the at least one cuboidal thermoplate modules is arranged in a pressure-stable rectangular stabilization frame.
6. The reactor as claimed in claim 5, wherein the reactor includes at least two cuboidal thermoplate modules, and wherein rectangular stabilization frames
- 20 of adjacent cuboidal thermoplate modules are welded and sealed together.
7. The reactor as claimed in claim 1, wherein the at least one sealing element is a holding base which seals an intermediate space between the at least one cuboidal thermoplate module and the cylindrical shell at the bottom portion of the at least one cuboidal thermoplate module.

8. The reactor as claimed in claim 7, wherein a metal sheet cover seals the intermediate space between the thermoplate modules and the cylindrical shell at the top portion of the at least one cuboidal thermoplate module.

5 9. The reactor as claimed in claim 8, wherein the metal sheet cover includes a plurality of orifices.

10. The reactor as claimed in claim 1, wherein an intermediate space between the at least one cuboidal thermoplate module and the shell is filled with an inert material.

10 11. The reactor as claimed in claim 10, wherein the inert material is expanded perlite or expanded vermiculite.

12. The reactor as claimed in claim 1, wherein pressure is applied to an intermediate space between the at least one cuboidal thermoplate module and the cylindrical shell with a gas.

15 13. The reactor as claimed in claim 12, wherein the pressure applied is constant.

14. The reactor as claimed in claim 13, wherein the constant application of pressure is effected by pressure-regulated feed and removal of nitrogen.

20 15. The reactor as claimed in claim 12, wherein the pressure is applied by continuously feeding the gas through the intermediate space, and wherein the gas is inert or intrinsic to the process.

16. The reactor as claimed in claim 15, wherein the gas is combined with the fluid reaction mixture at an outlet from the thermoplate modules.

17. The reactor as claimed in claim 7, wherein compensators for radial expansion are provided in or on the holding base.

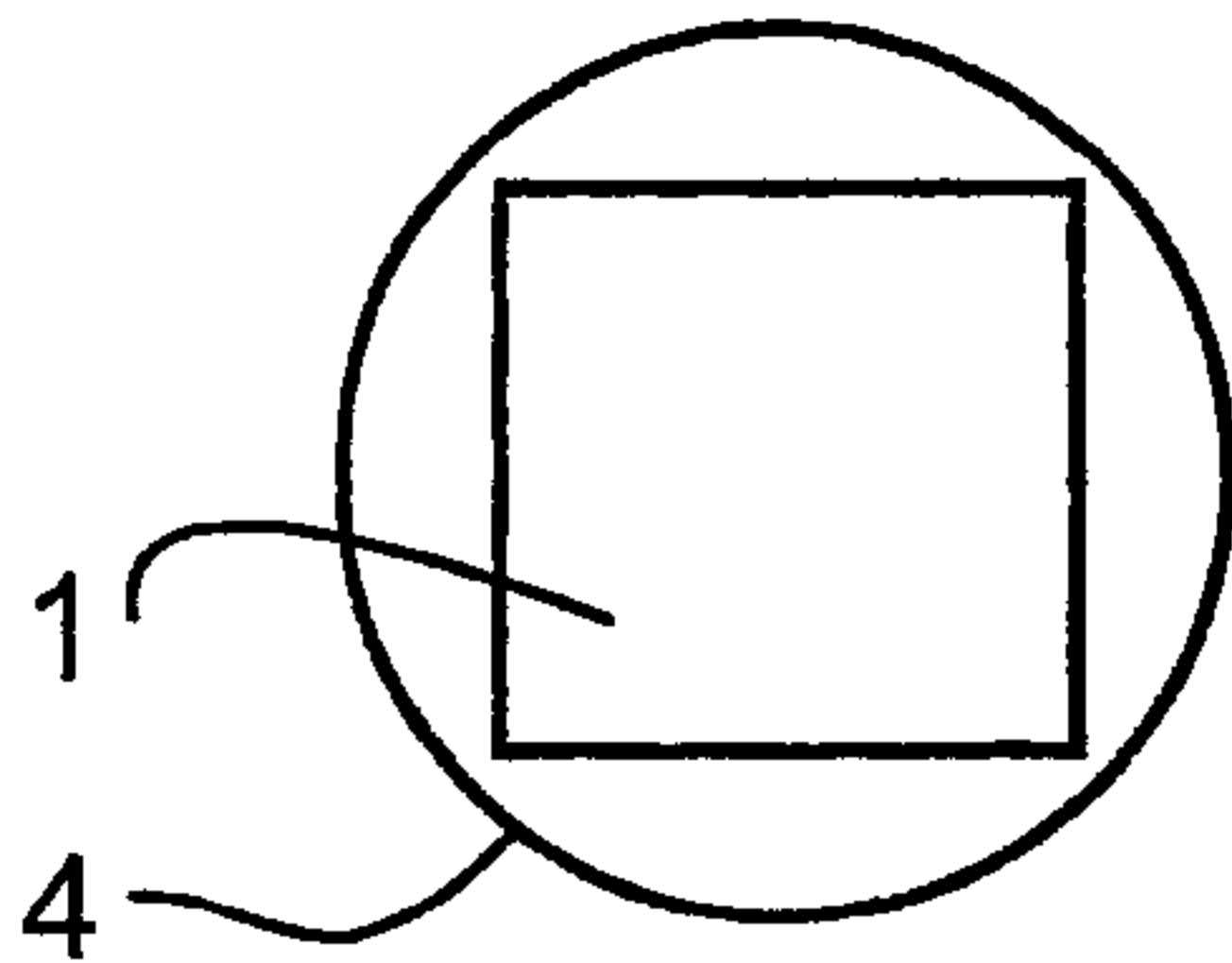
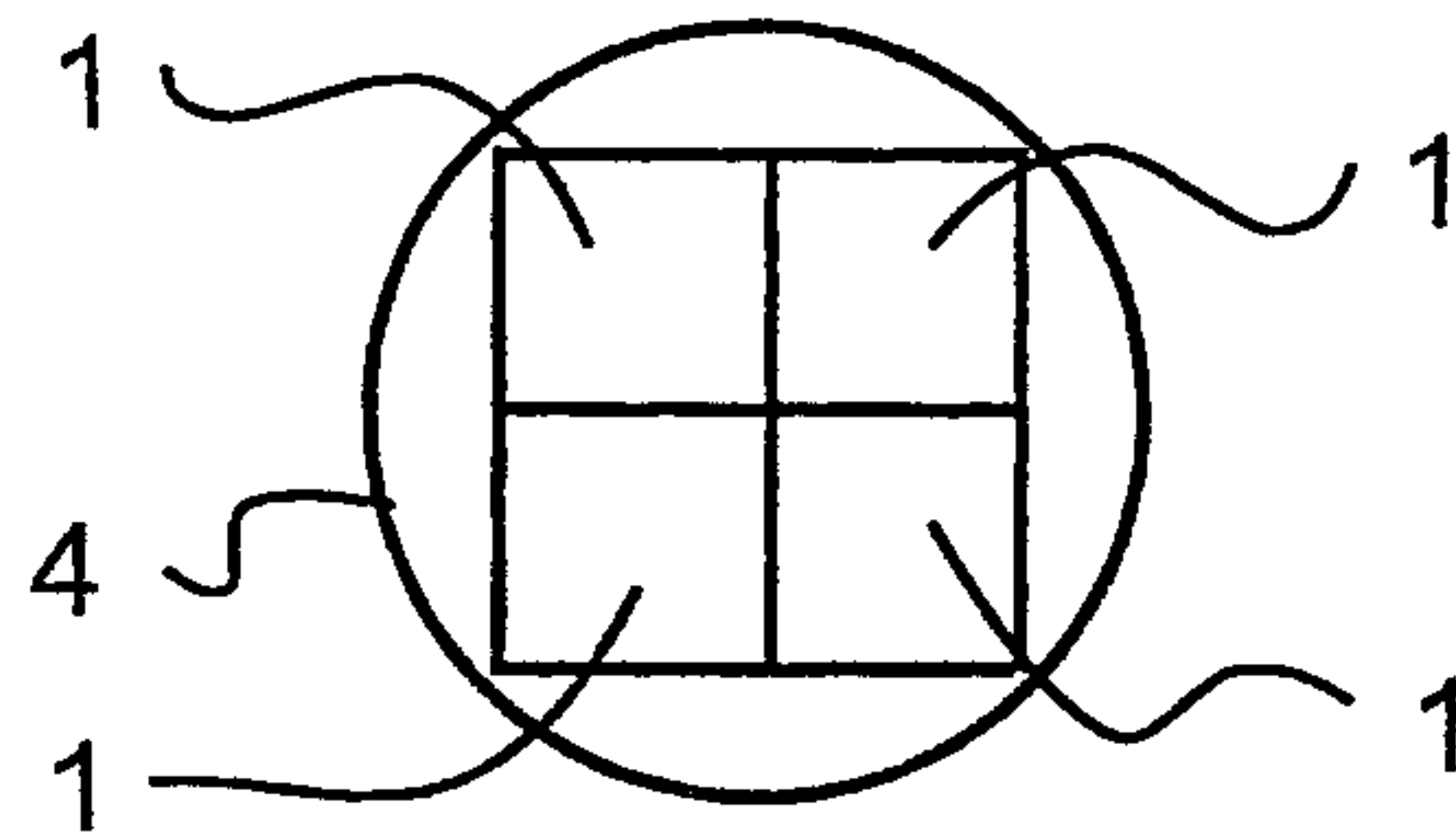
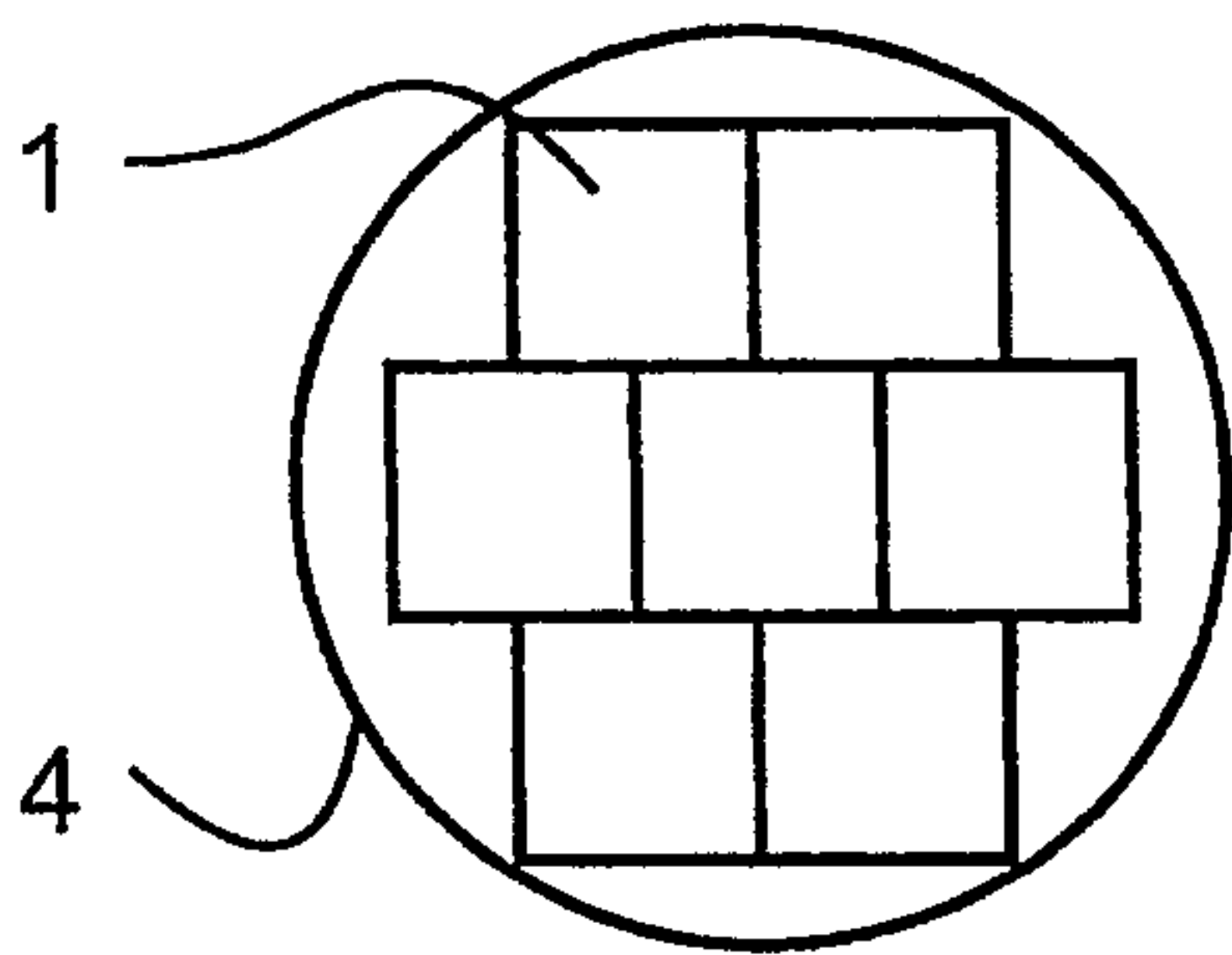
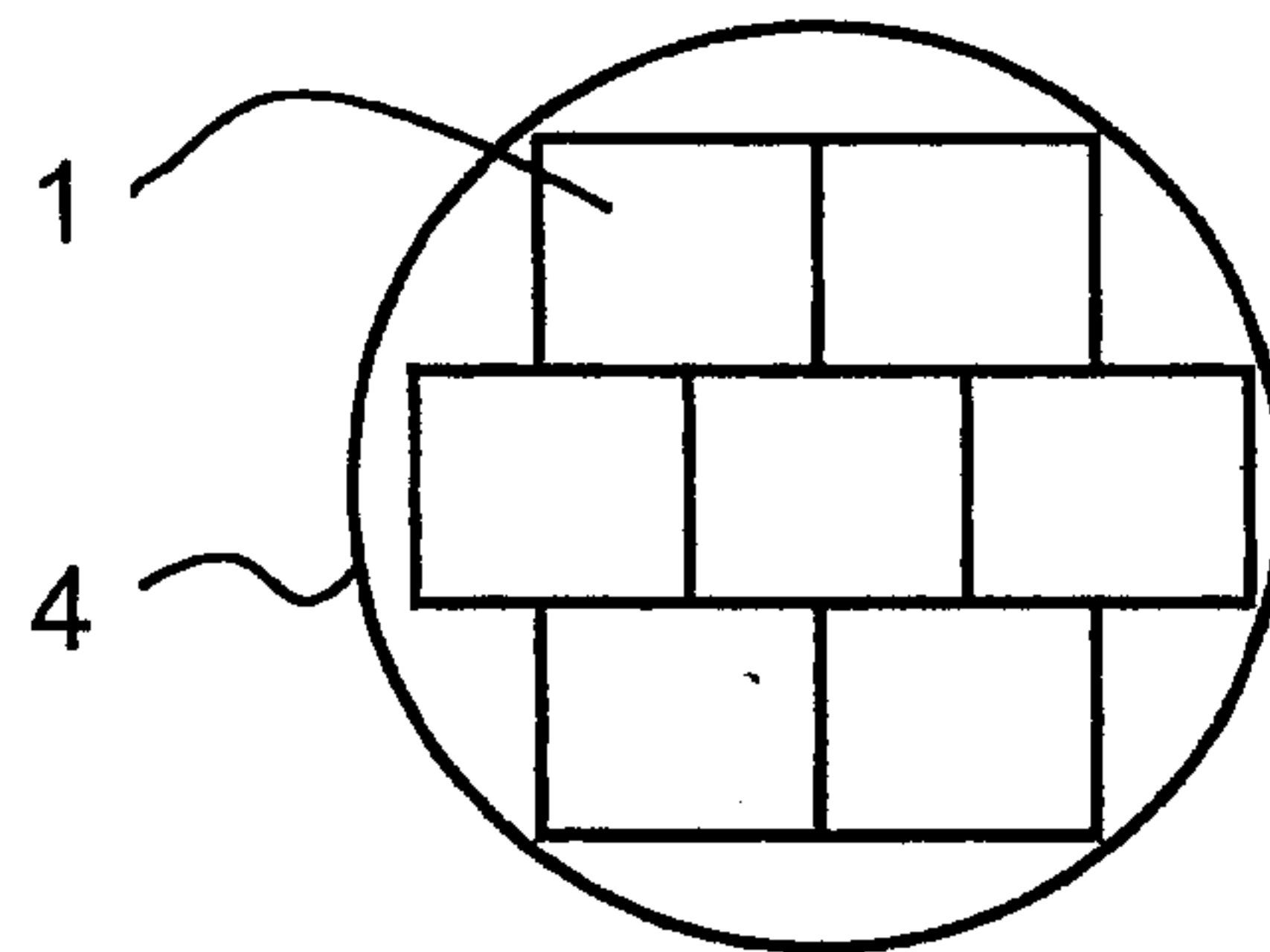
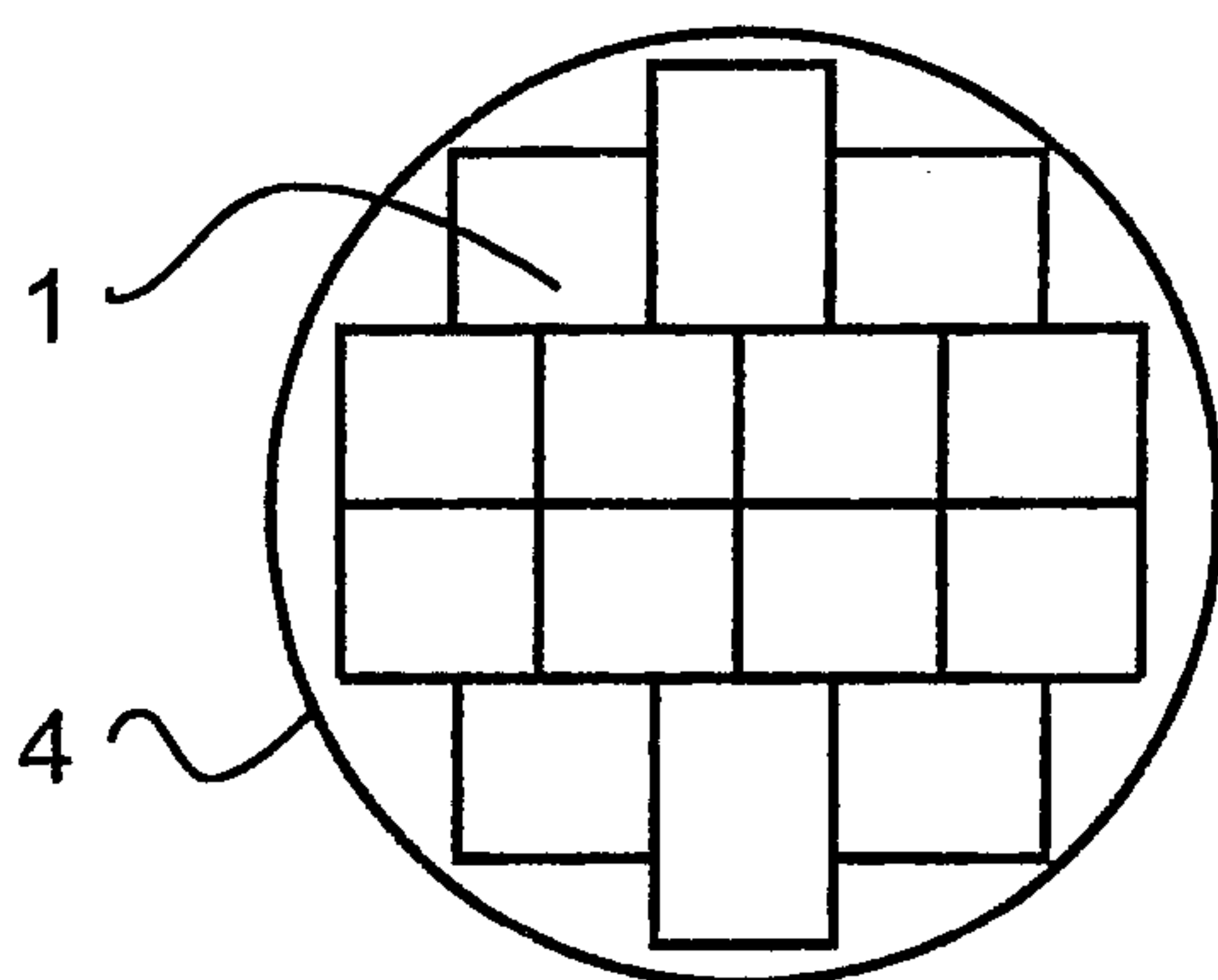
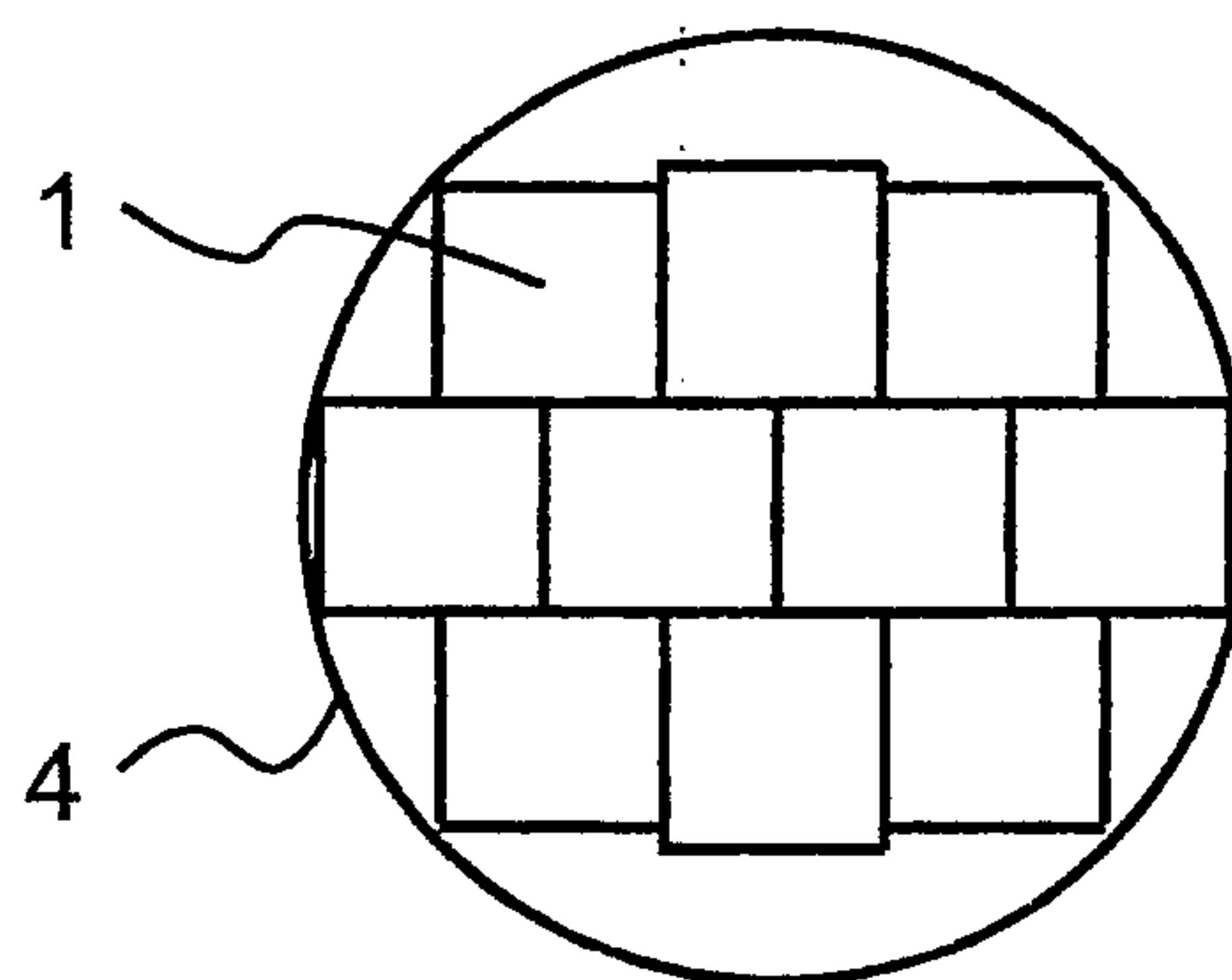
18. The reactor as claimed in claim 8, wherein compensators for axial or radial expansion are provided in or on the metal sheet cover.
19. The reactor as claimed in claim 1, wherein each thermoplate module includes at least one distribution device and at least one collection device
5 configured to receive the heat carrier.
20. The reactor as claimed in claim 1, wherein each thermoplate module includes one distribution device and two collection devices configured to receive the heat carrier.
21. The reactor as claimed in claim 1, further comprising a plurality of
10 distribution and collection devices that are configured to receive the heat carrier and that have equal nominal widths.
22. The reactor as claimed in claim 1, further comprising a plurality of distribution devices and collection devices that are configured to receive the heat carrier and that are welded into a slotted base.
- 15 23. The reactor as claimed in claim 1, further comprising a plurality of distribution devices and collection devices that are configured to receive the heat carrier that flows through the thermoplates and that each include compensation for the accommodation of the thermal expansion of the thermoplate modules relative to the cylindrical shell.
- 20 24. The reactor as claimed in claim 1, wherein a thermal expansion of the thermoplate modules relative to the cylindrical shell is accommodated by a curved geometric design of a tubing of a plurality of distribution devices and collection devices that are configured to receive the heat carrier that flows through the thermoplates.
- 25 25. The reactor as claimed in claim 1, wherein each thermoplate modules includes two catalyst holding grates per thermoplate module.

26. The reactor as claimed in claim 1, further comprising manholes configured to facilitate the introduction of a plurality of catalyst holding grates into the cylinder jacket.

27. The reactor as claimed in claims 1, wherein the cylinder jacket includes at
5 least one compensator configured to accommodate axial thermal expansion.

FIG. 1

The diagram illustrates a two-stage cryogenic refrigerator system. The upper stage (top) features a compressor (16) at the top, connected to a condenser (17) on the right and a vaporizer (12) on the left. The condenser is connected to a high-pressure liquid line (9) that leads to a high-pressure expansion valve (8). The low-pressure side of the high-pressure stage is connected to a vaporizer (4) and a low-pressure liquid line (13). The lower stage (bottom) features a compressor (15) at the bottom, connected to a condenser (17) on the right and a vaporizer (11) on the left. The condenser is connected to a high-pressure liquid line (19) that leads to a high-pressure expansion valve (10). The low-pressure side of the low-pressure stage is connected to a vaporizer (7) and a low-pressure liquid line (18). The two stages are connected in series, with the low-pressure liquid line (18) of the lower stage feeding into the high-pressure liquid line (9) of the upper stage. A dashed line (C) indicates the intermediate pressure level between the two stages. Nitrogen gas (N₂) is shown entering the system through ports (19) on both sides of the intermediate section.

FIG.1B**FIG.1C****FIG.1A****FIG.1D****FIG.1E****FIG.1F**

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FIG.2

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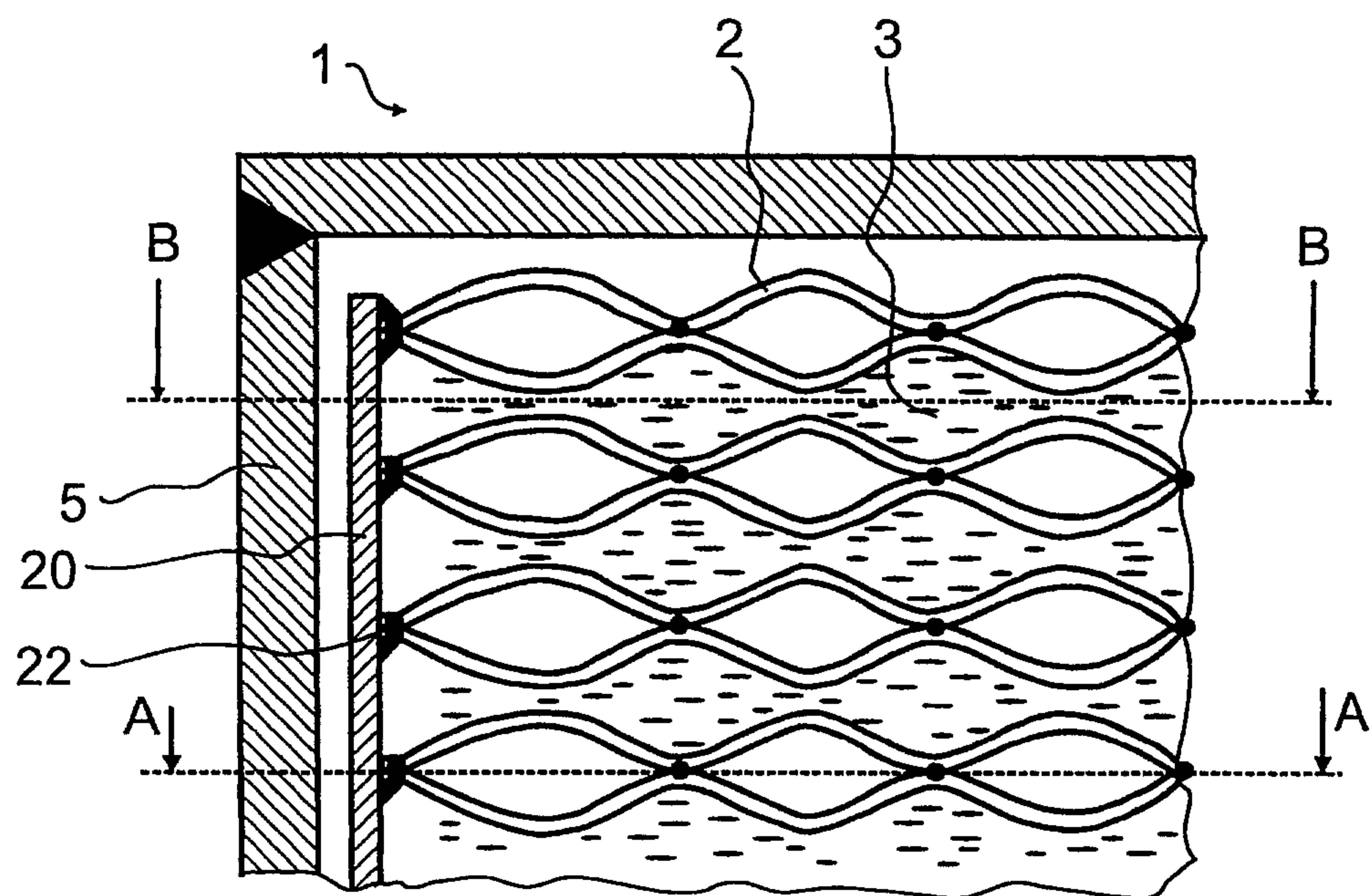


FIG.2A

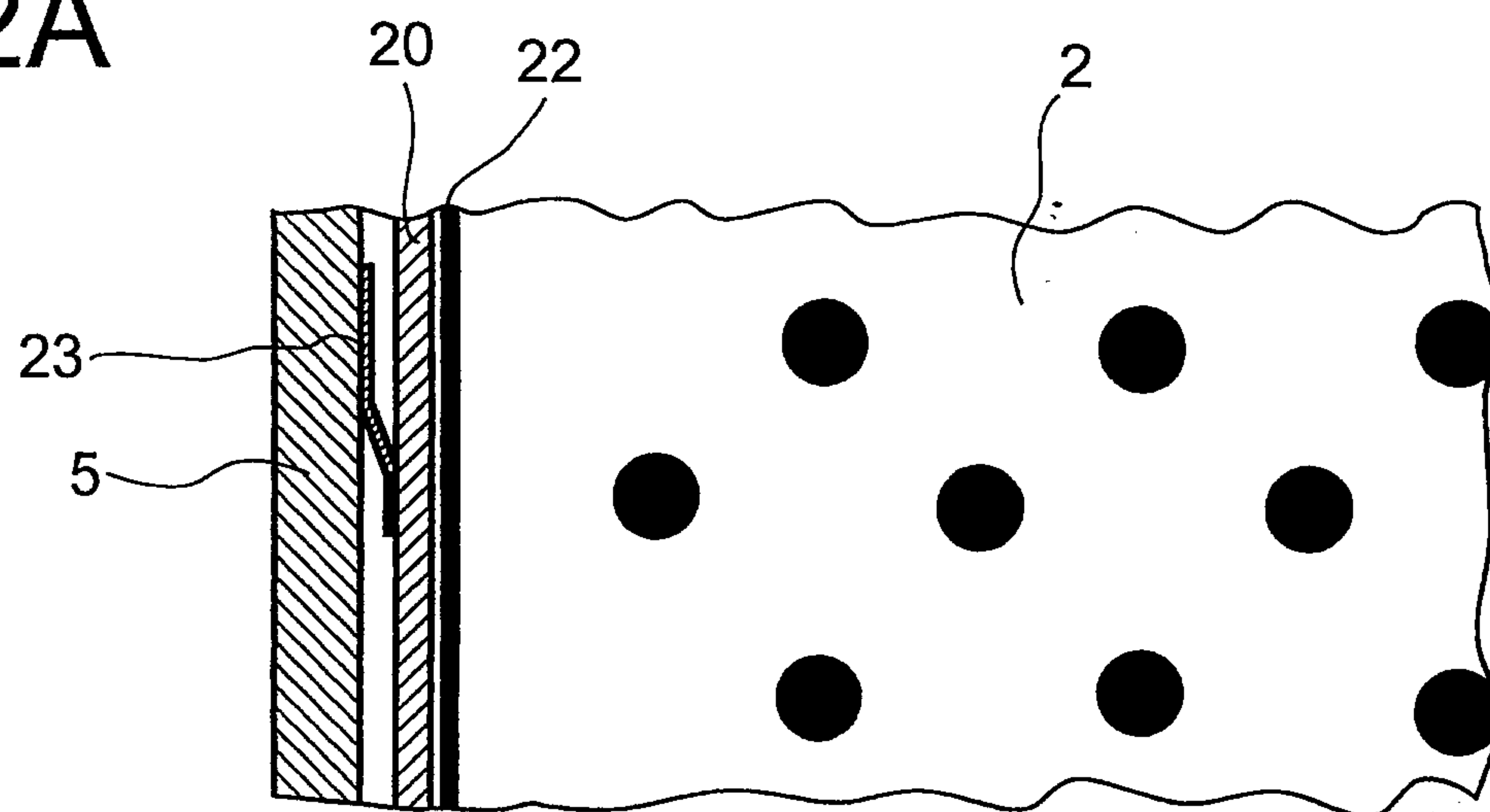


FIG.2B

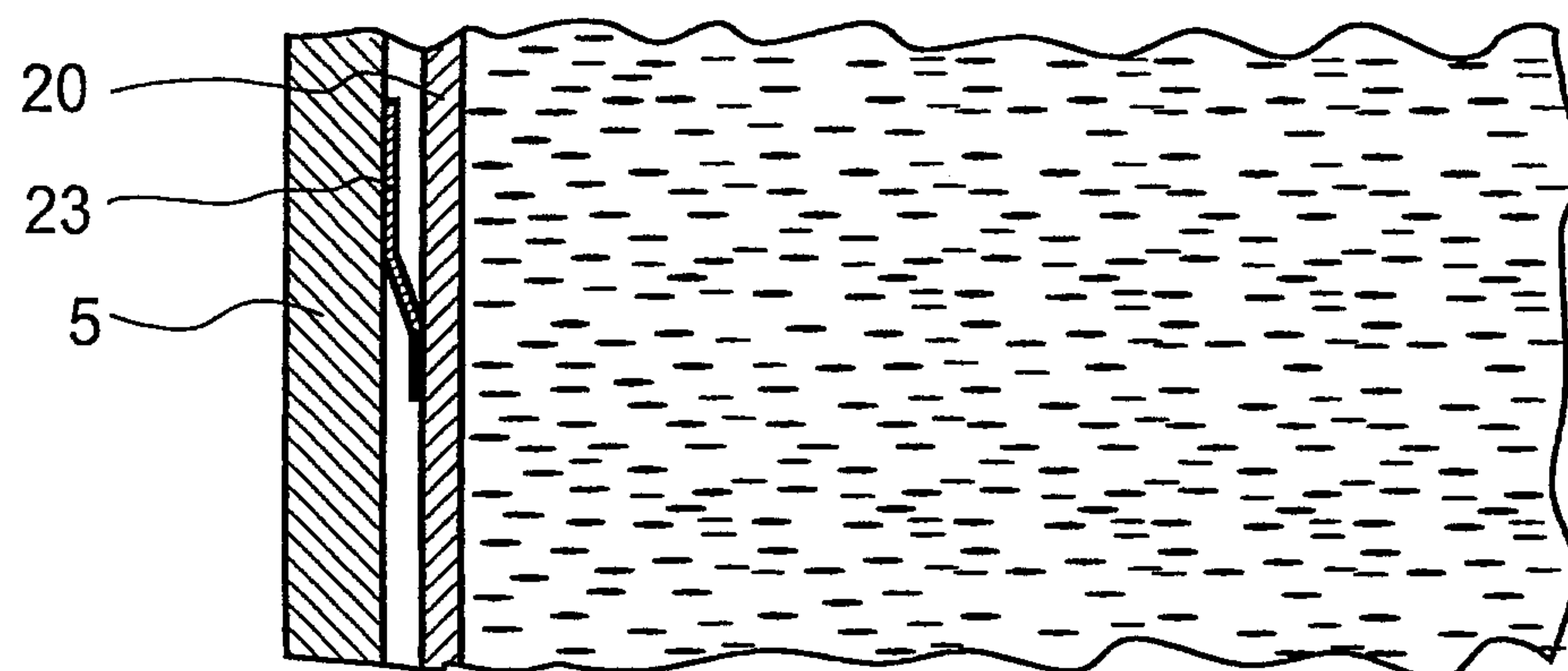


FIG.3

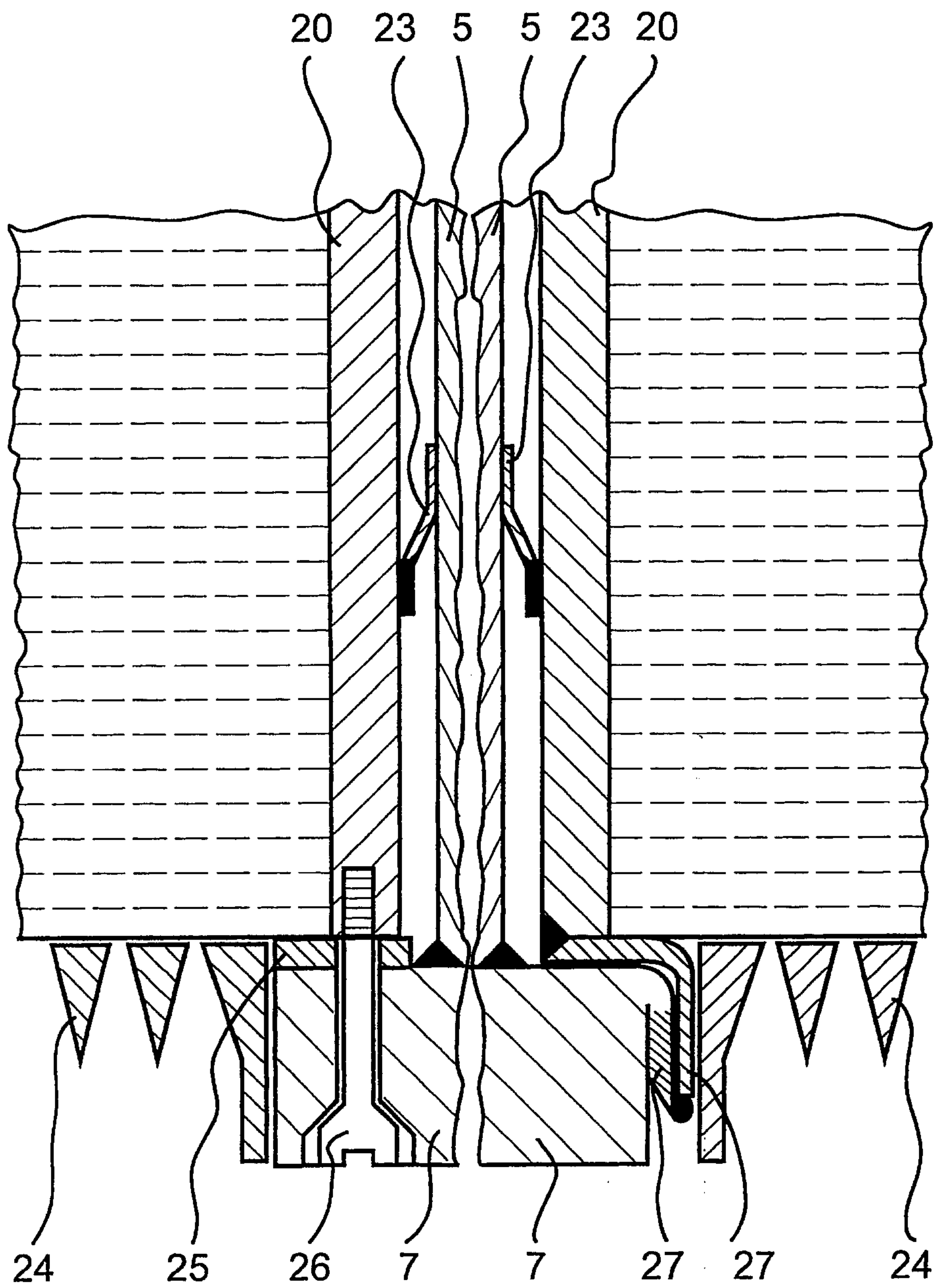
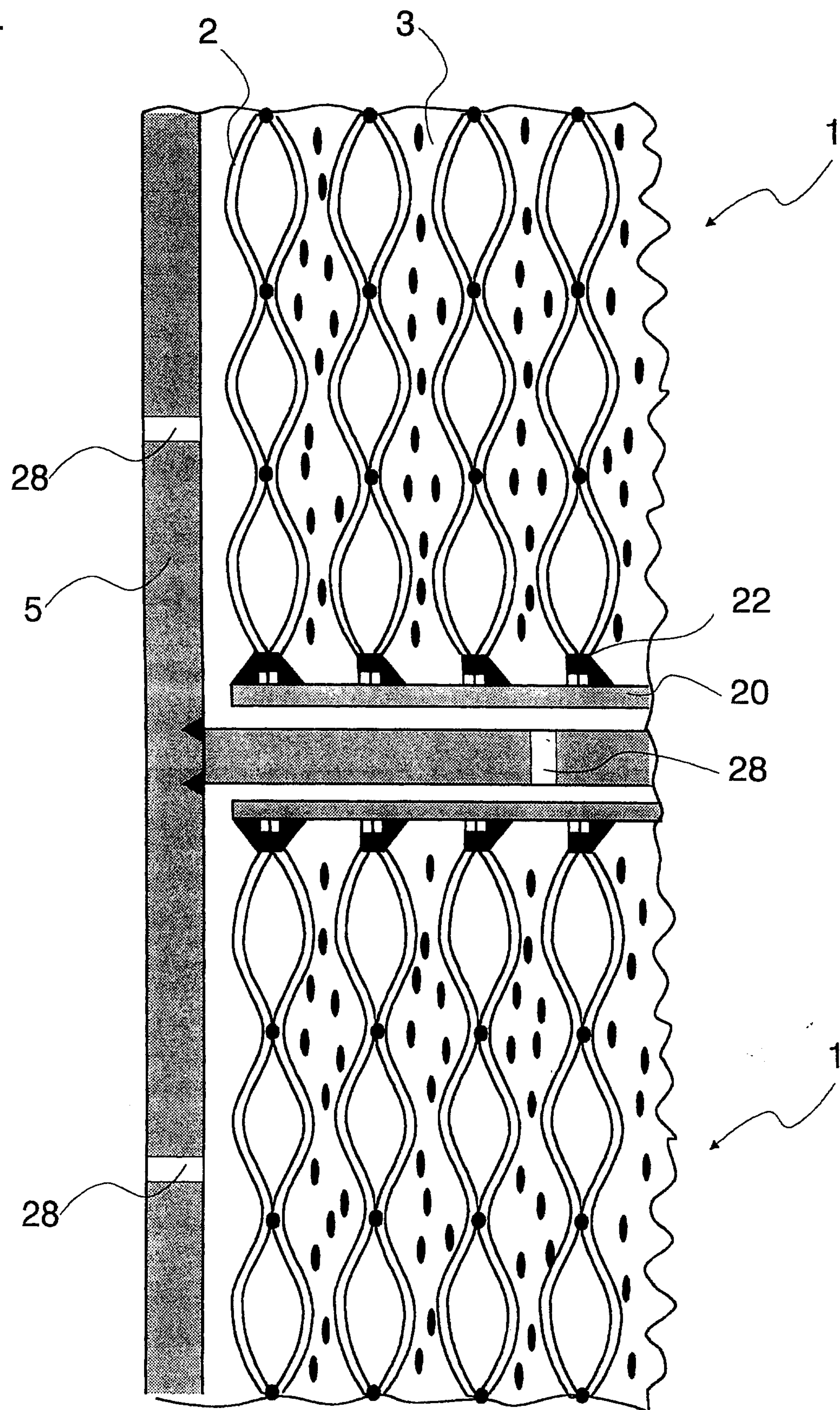


FIG. 4



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FIG. 5A

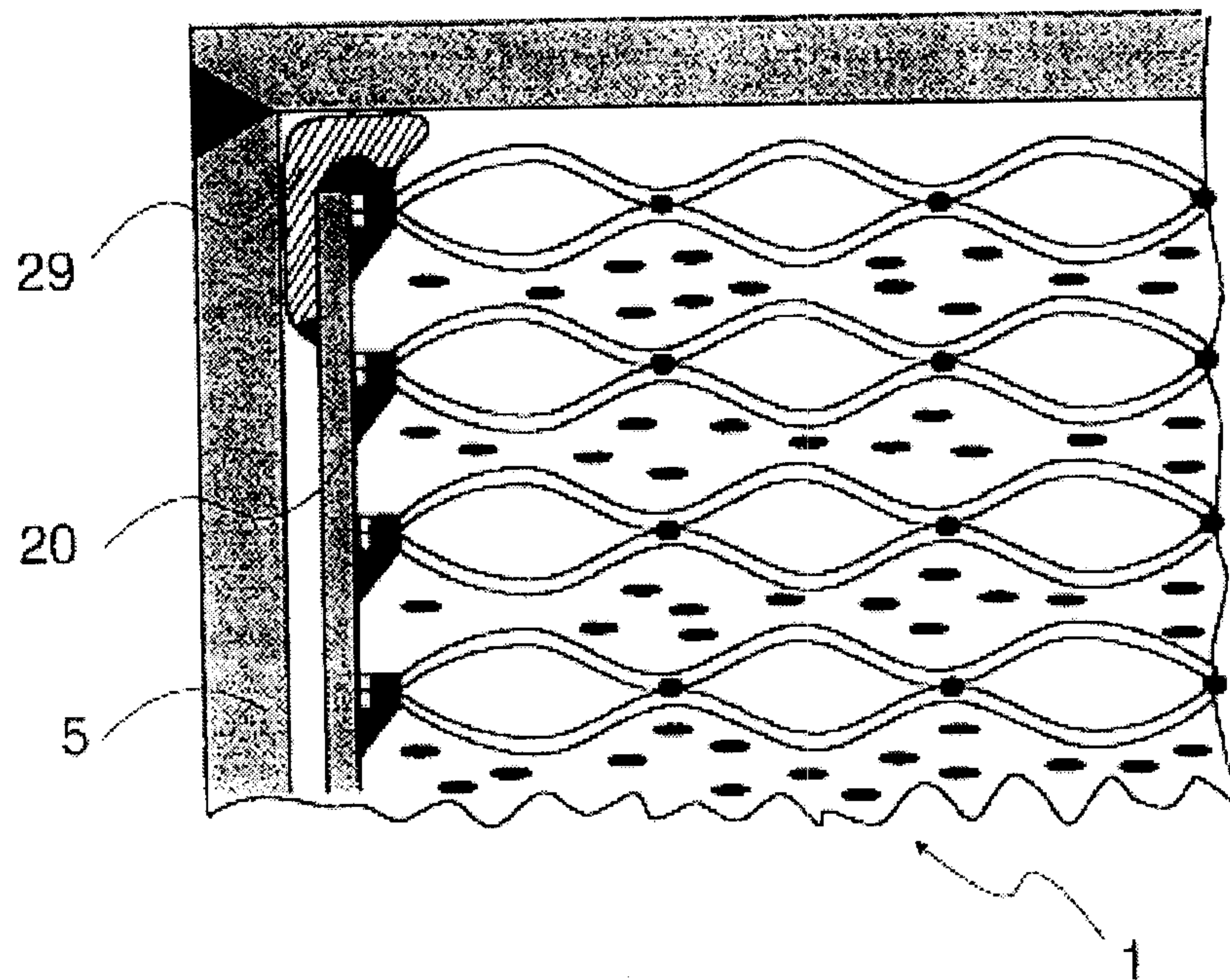


FIG. 5B

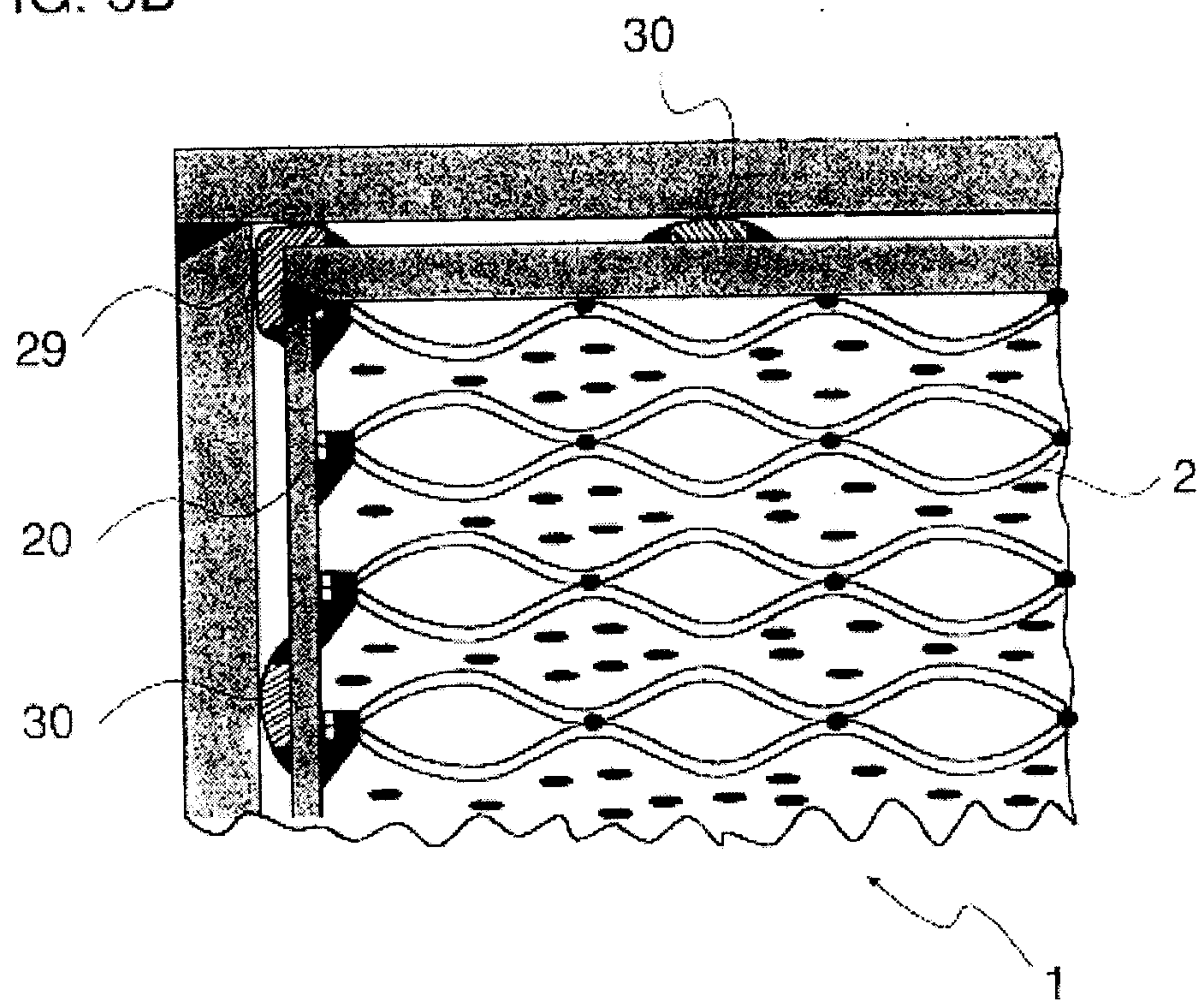


FIG. 5D

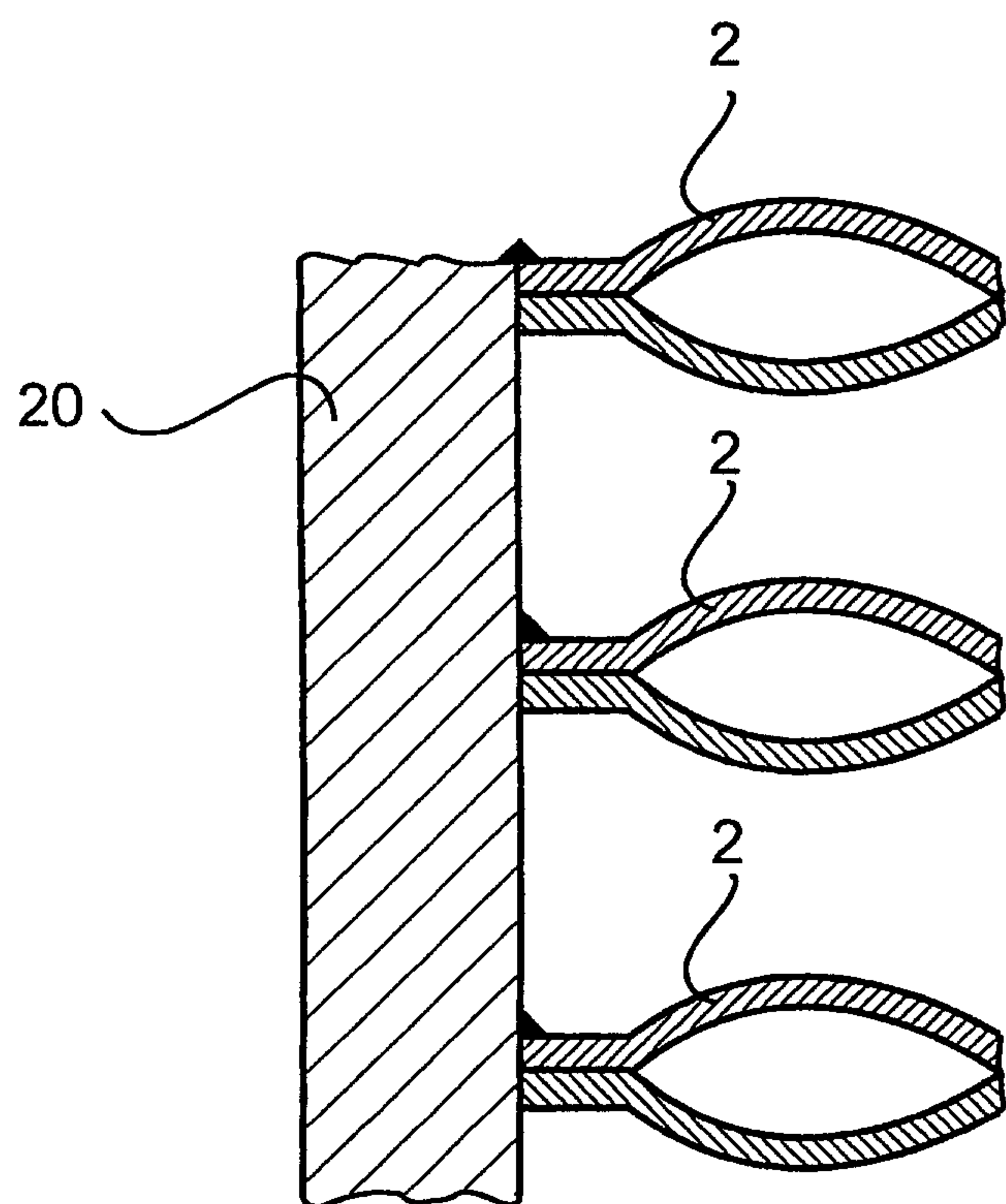


FIG.5E

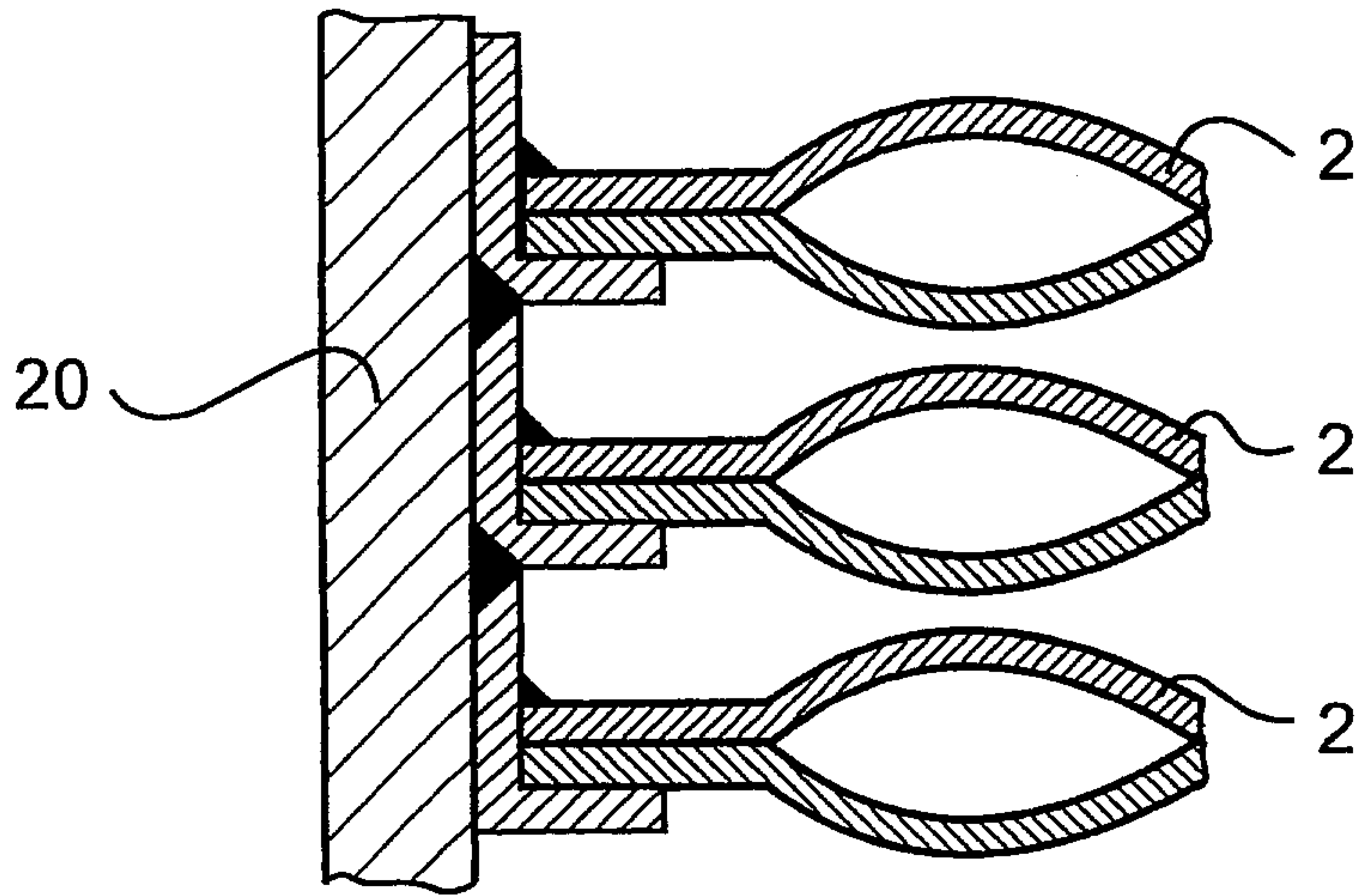


FIG.5F

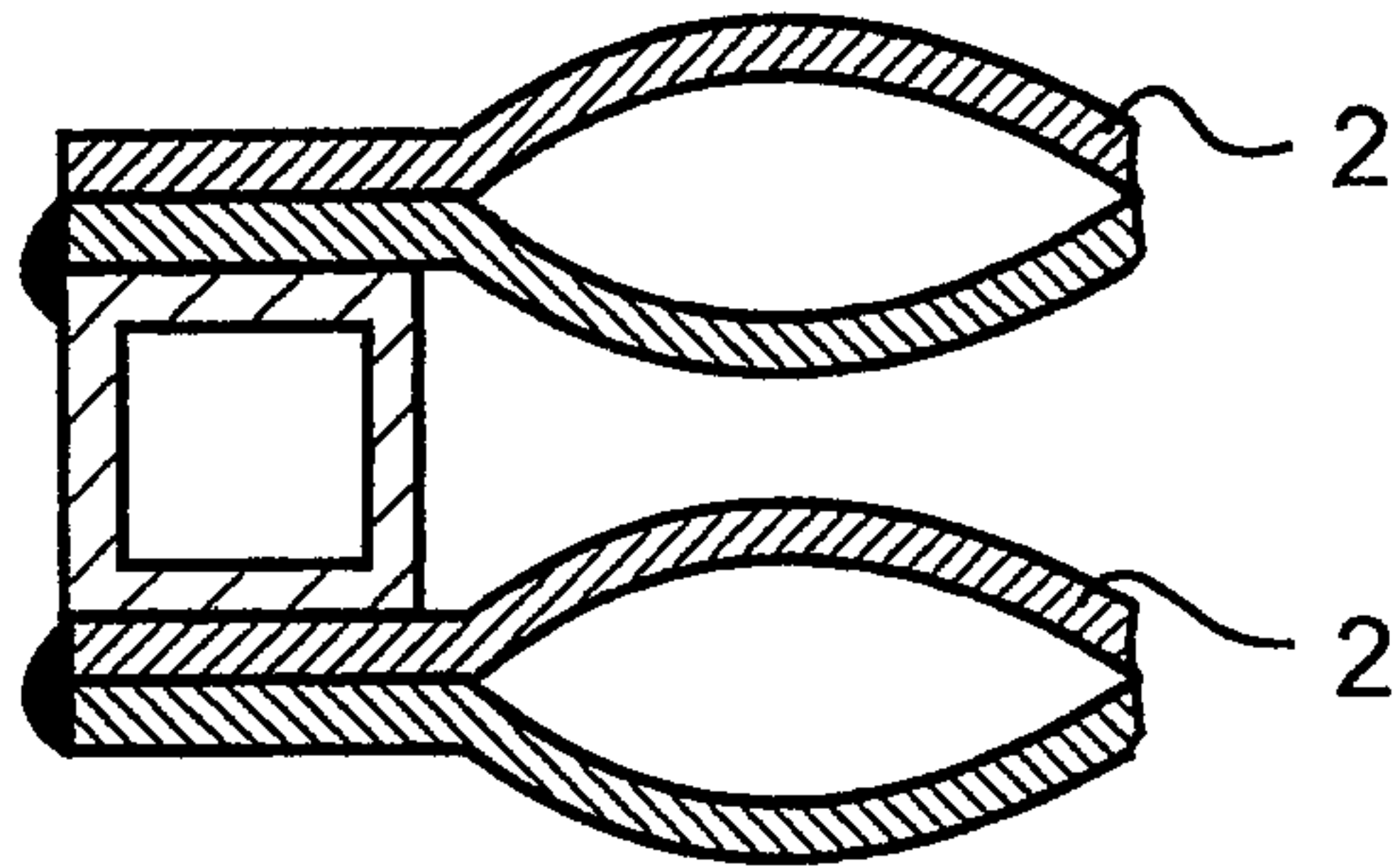


FIG.5G

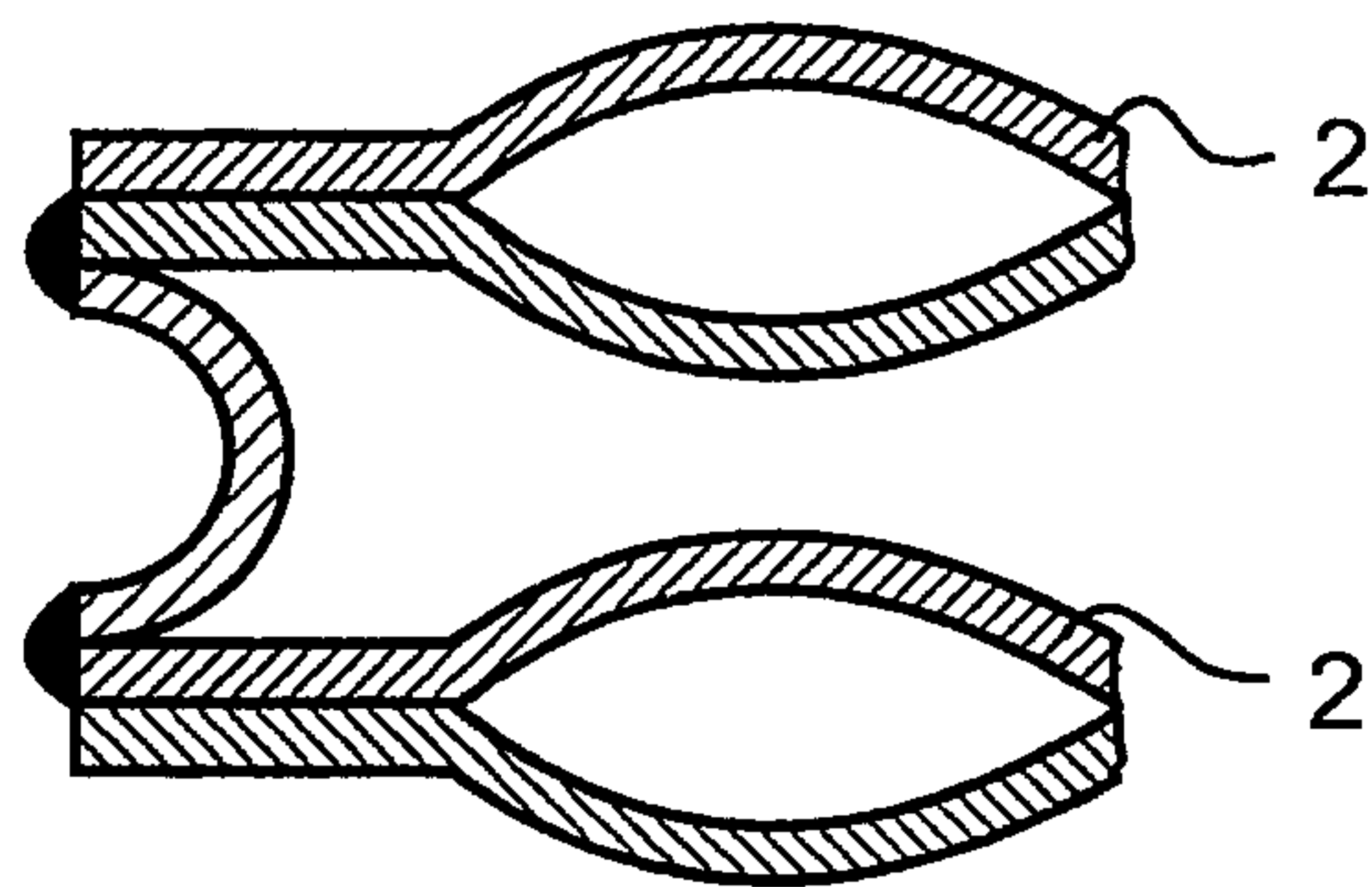


FIG.5H

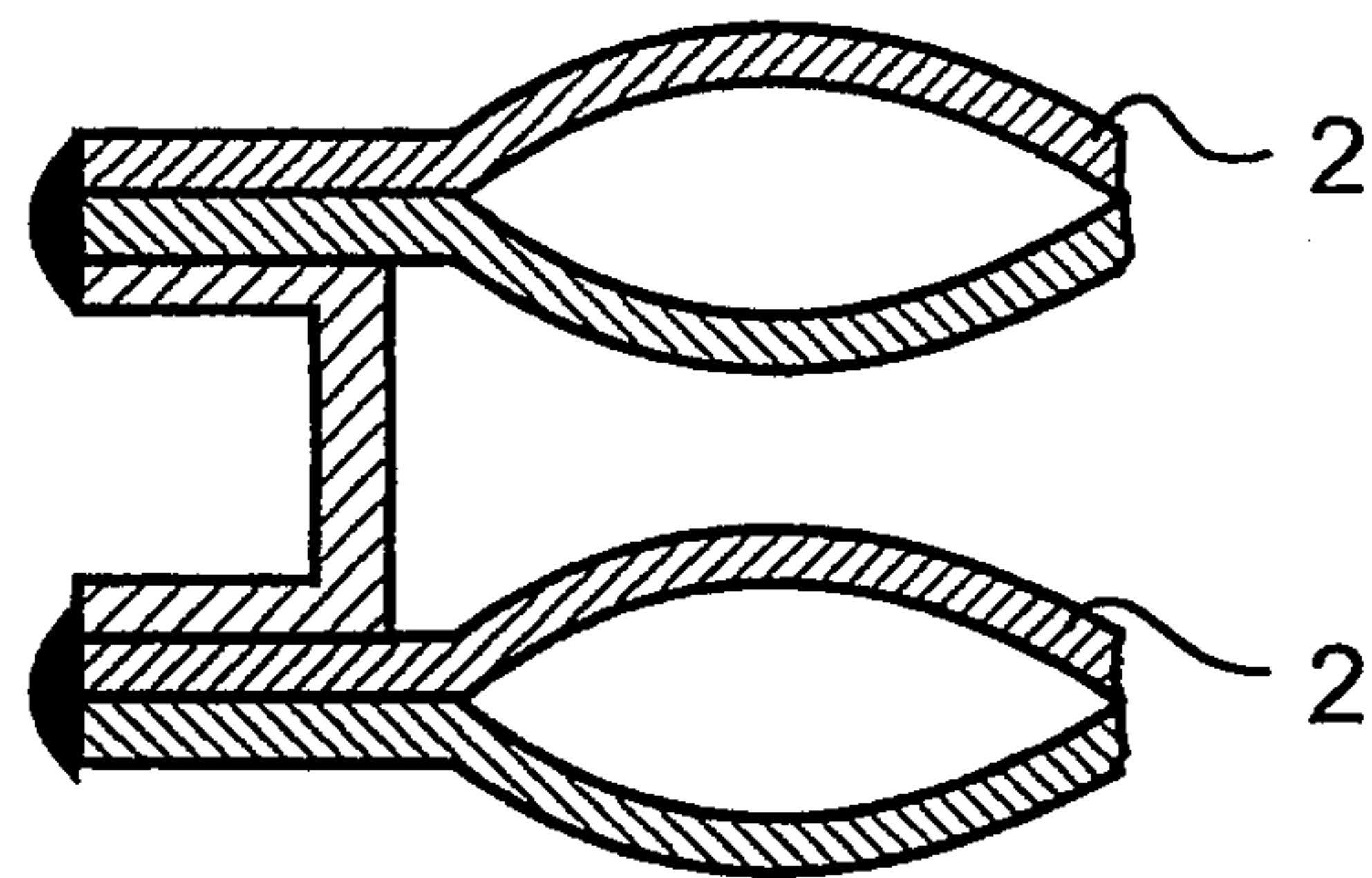


FIG.5I

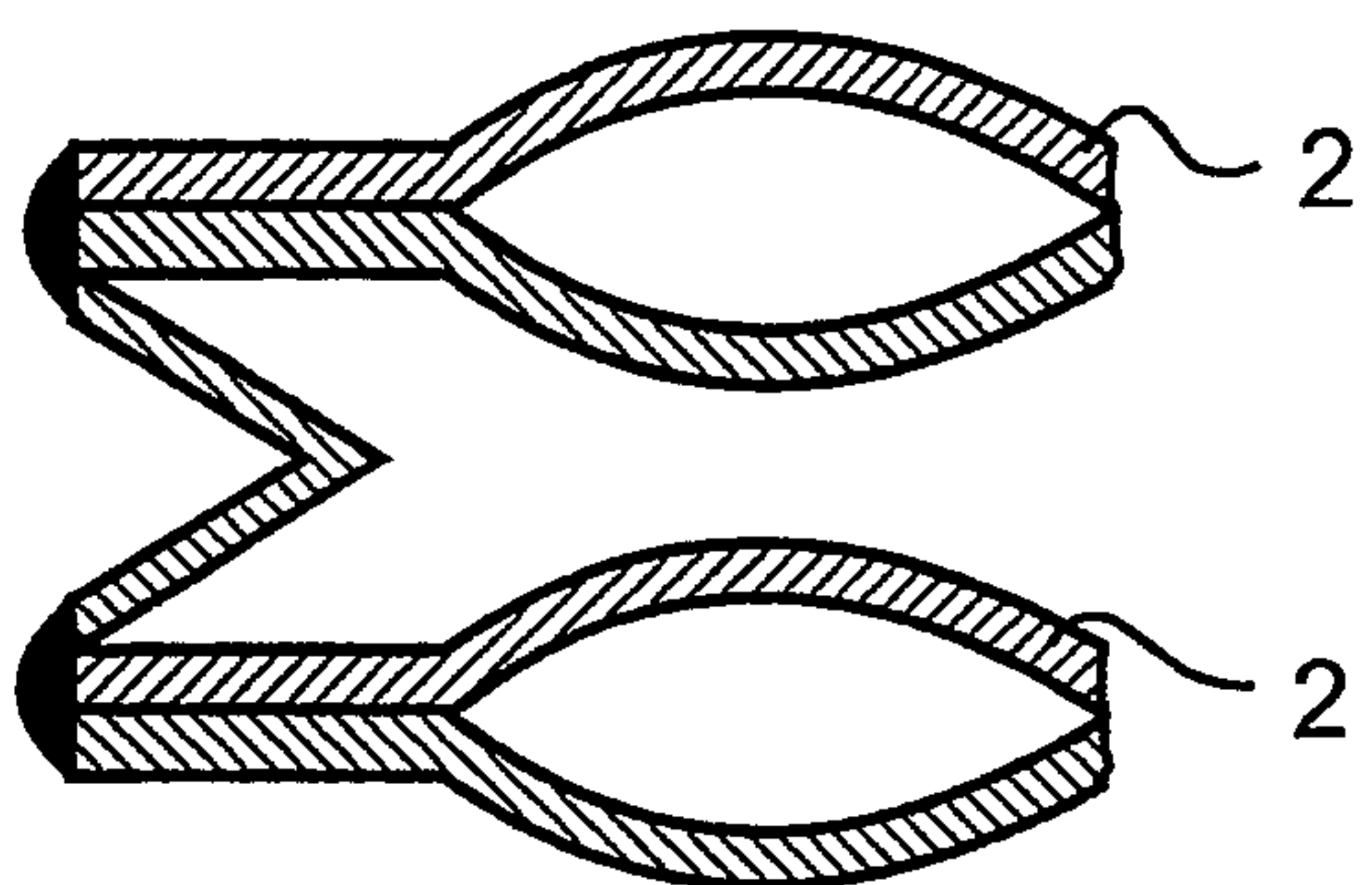


FIG.6

