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(73) Patenthaver: **Beco Invest B.V., Fortweg 3, 3992 LX Houten, Holland**

(72) Opfinder: **Emminger, Franz, Steinerweg 2, 2410 Hainburg, Østrig**
FLUCH, Silvia, Markt 8, 7121 Weiden/See, Østrig

(74) Fuldmægtig i Danmark: **Murgitroyd & Company, Mannerheimvägen 12 B 5th floor, FI-00100 Helsinki, Finland**

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Photobioreactor and method for cultivating microalgae

The field of the present invention is that of photobioreactors for cultivating phototrophic microorganisms such as microalgae, for example.

Phototrophic microorganisms such as microalgae are cultivated above all on account of their valuable constituents, which are required in, for example, the production of medicinal preparations, foodstuffs and animal feed, food supplements and cosmetics. These constituents include, for example, unsaturated fatty acids (e.g. omega-3 and omega-6 fatty acids), antioxidants such as astaxanthin und lutein, and chlorophyll. The composition of the constituents is dependent upon the cultivated type of phototrophic microorganisms. Predominantly, a pure culture of phototrophic microorganisms is used in order to be able to guarantee a certain quality or minimum concentration of the desired constituents.

Normally the microorganisms that conduct photosynthesis under the action of light (e.g. sunlight) are cultivated in the nutrient-containing culture medium in a photobioreactor, and subsequently concentrated and processed. The constituents for further processing can be extracted from the biomass obtained or the biomass itself can be used, for example, as animal feed or fertilizer.

A known prior art design of photobioreactors for the cultivating of phototrophic microorganisms is the “vertical tubular reactor”, in which upright, parallel, substantially transparent tubes (sometimes also referred to as columns) are connected in series and the culture medium with the phototrophic microorganisms flows through them, usually in a meandering manner. A photobioreactor of this design is known from US 2014/0242681 A1, for example.

In general, the tubes of a photobioreactor are prone to fouling over time, especially during continuous operation. In this case, residues from cultivating (for example, from the remains of dead microorganisms) often accumulate on the inside of the tubes. On the one hand, this can reduce the light yield (as these residues typically absorb light) and, on the other hand, pose a constant risk in terms of contamination of the culture medium with undesirable microorganisms that find a suitable breeding ground in the residues. Reduced light yield or contamination can in turn significantly reduce the yield from the cultivation. Furthermore, especially for sensitive sectors such as the production of medicinal preparations or food supplements, it can be of great importance for product safety to prevent contamination of the culture with undesirable (and sometimes even toxic) microorganisms as far as possible.

WO 2009/051478 A2 relates to a photobioreactor with a cleaning system. A cleaning tool (e.g. a cylindrical sponge, cf. also Figs. 2-5 of the document) can be pumped back and forth between stations to clean the reactor tube inner walls (cf. p. 12, 2nd paragraph). In the document, the tubes of the photobioreactor are disclosed as connected via U-shaped connecting pieces (cf. Fig. 1, reference sign 5, of the document) and not as gassed.

WO 2015/179888 A1 discloses a reactor of the vertical type. This reactor consists of at least one reactor element, which is formed from at least two upright, connected tubes or chambers, wherein the individual reactor elements have inlet and outlet openings on the underside on the outermost tubes or chambers in each case, wherein the inlet opening is assigned in each case one against the direction of gravity, that is, an ascending branch, and the outlet opening is assigned one in the direction of gravity, that is, a descending branch, in that all the connections in the lower region, in particular the inlet opening, the outlet opening and the introduction inlet, are flushed with the reaction medium. It can be gleaned from Fig. 1 and Fig. 3 of the document that the tubes or chambers in the reactor element “are connected in series” (cf. also p. 14, line 19, of the document), i.e. that never more than two tubes or chambers in the reactor element are disclosed as directly connected to one another. According to one configuration, the reactor element is closed on the upper side with a closing element, wherein the closing element is formed to be removable in order to be able to clean the system (p. 16, 1st paragraph, of the document).

The prior art alleges to have found a further approach to solving the problem outlined above in the “disposable” photobioreactor. In this case, the reactor components such as tubes, for example, are produced from comparatively inexpensive plastic material that is replaced after only a short operation.

Thus, US 2011/0027875 A1 relates to an inexpensive, vertical photobioreactor for production use. According to the depicted embodiments of the document, this photobioreactor has substantially vertically oriented, parallel, transparent columns or tubes connected to one another by lower and upper U-shaped connecting pieces, so that culture medium with microalgae can flow in a meandering manner through the photobioreactor during operation in a closed circuit. The tubes or columns (or the culture medium therein) are gassed with carbon dioxide, which is known to be converted to oxygen by the microalgae. The lower and upper U-shaped connecting pieces can each be connected to a “gas manifold” (cf. Fig. 1, which reproduces the lower detail of Fig. 1 of said document). A flexible polyethylene having low density (“flexible LDP bag material”) is suggested as the material for the columns or tubes. According to paragraphs [0087]-[0090], if the microalgae culture is in an unfavourable state, this material is discarded, the U-shaped connecting pieces are separated from the gas manifold and cleaned in a dishwasher, for example.

This approach to cleaning photobioreactors or keeping photobioreactors clean in the prior art is associated with many disadvantages, amongst other things it requires high manual outlay (especially for large production plants) and long standing times, which diminish the yield of the photobioreactor over time. Furthermore, the high consumption of material (usually plastic) has a negative impact on the overall ecological balance of photobioreactor operation.

It is an object of the present invention to simplify the cleaning or keeping-clean of a photobioreactor for the cultivating of phototrophic microorganisms. This can increase the service life or yield of the photobioreactor and reduce the operating costs.

The present invention makes available a photobioreactor for cultivating phototrophic microorganisms, with a reactor element that has a multiplicity of riser and downcomer tubes for liquid culture medium, which contains the microorganisms, and a manifold. The riser and downcomer tubes are in each case connected to the manifold in a liquid-permeable manner at their upper end. At least one of the riser and one of the downcomer tubes are additionally connected (or attached) to one another in a liquid-permeable manner by a connecting piece. The photobioreactor furthermore has a device for introducing gas into at least one riser tube. According to the invention, the photobioreactor is designed in such a way that, in the operating state, both culture medium and, above the culture medium, a gas space for receiving gas bubbles rising from the culture medium are present in the manifold, wherein an interface between the culture medium and the gas space is arranged in the manifold. This achieves the stated object.

Accordingly, the invention also makes available a method for cultivating phototrophic microorganisms. This comprises exposing a photobioreactor, wherein the photobioreactor is provided with a reactor element that has a multiplicity of riser and downcomer tubes for liquid culture medium, which contains the microorganisms, and a manifold, wherein the riser and downcomer tubes are each connected to the manifold in a liquid-permeable manner at their upper end, wherein at least one of the riser and one of the downcomer tubes are additionally connected to one another in a liquid-permeable manner by a connecting piece, and wherein the photobioreactor contains liquid culture medium, with the microorganisms, in the riser and downcomer tubes, which medium is at least partially gassed. Both liquid culture medium with the microorganisms and, above the culture medium, a gas space, are present in the manifold, wherein an interface between the culture medium and the gas space is formed in the manifold, and the gas space receives gas bubbles rising from the culture medium. This also achieves the stated object.

It has been found, during the development of the present invention, that it is precisely the internal surfaces of a photobioreactor which are in contact with the interface between the culture medium and the gas space (or the "interface space" in the immediate vicinity of the interface) which are susceptible to fouling, with more and more impurities usually accumulating with the operating time. In the region of the interface (which often varies slightly in height over the operating time), foam formation and drying of residues of the phototrophic microorganisms can occur again and again. Especially if gassing of the photobioreactor is envisaged, the occurrence of such fouling-prone interfaces (or interface spaces) in the photobioreactor can hardly be avoided. In addition, the gas bubbles rising from the culture medium cause the inner surface of the photobioreactor to be splashed with culture medium and these splashes also dry over time, thus forming impurities. If said interfaces, as shown in Fig. 1 (see in particular the uppermost curved arrows in Fig. 1), are located in areas that are more difficult to access, for cleaning there is often no alternative but to temporarily disassemble the photobioreactor, as disclosed in US 2011/0027875 A1, for example.

The present invention is now based on, amongst other things, the realisation that cleaning the photobioreactor or keeping the photobioreactor clean is made substantially easier by the fact that said interfaces of areas that are more difficult to access are displaced, as it were, into a (more easily accessible) manifold by the design according to the invention or the operation, according to the invention, of the photobioreactor, and are combined there into one interface.

Unexpectedly, it has been found that a meandering flow can nevertheless be maintained in the photobioreactor according to the invention, although in the prior art U-shaped connecting pieces are usually provided at both the upper and lower ends of the riser and downcomer tubes, respectively, to guarantee the meandering flow (cf. e.g. US 2014/0242681 A1 or US 2011/0027875 A1). Therefore, in a preferred embodiment of the method according to the invention, the culture medium flows through the riser and downcomer tubes in a meandering manner. One advantage of the meandering flow is that the maturation of the phototrophic microorganisms proceeds in a more regulated manner, because microorganisms of a similar degree of maturity separate from one another in the culture medium to a lesser extent than would be the case with a more chaotic flow (e.g. if turbulence or different flow paths are present). This also makes it easier to remove microorganisms having a similar degree of maturity together from the photobioreactor together.

It has proven to be particularly advantageous for stabilising the meandering flow if at least two reactor elements are provided in the photobioreactor, wherein a downcomer tube of the first reactor element is connected in a liquid-permeable manner to a riser tube of the second reactor element to one another by a connecting piece.

In a preferred implementation, a meandering flow of the culture medium through the riser and downcomer tubes is achieved in the operating state by the culture medium being gassed more strongly in the riser tube, which is connected to the downcomer tube by the connecting piece, than in the downcomer tube. In this context, one can also speak of a “gaslift effect”. One advantage of this implementation is that pumps (which are usually harmful to the phototrophic microorganisms due to the shear forces they cause) can be at least largely dispensed with during operation. A further advantage is that the inner surfaces of the riser or downcomer tubes are kept cleaner by frequent contact with rising gas bubbles.

Thus, expediently, in the operating state of the photobioreactor, agitation and/or flow of the culture medium is substantially caused by the gas bubbles rising in the culture medium.

In a particularly preferred embodiment, an apparatus for guiding a maintenance device that is movable in the manifold is provided on the manifold. This can be, for example, a guide rail, a guide wire, or a strip with positioning markings that can be read by the maintenance device. In particular, when the apparatus for guiding is magnetic, it can also be attached to the outside of the manifold. The maintenance device can free, i.e. clean or keep clean, the inner surface of the manifold, in particular in the region of the interface, from any dried residues, with the aid of spray nozzles, brushes and/or wiper blades.

In a preferred implementation of the method according to the invention, the inner surface of the manifold is cleaned by the movable maintenance device, preferably at presettable time intervals. Advantageously, this happens during operation, so that losses in yield are avoided as far as possible. In this case, it is expedient if the maintenance device can be flowed around inside the manifold.

The design according to the invention makes it possible to use (higher quality) glass components instead of disposable plastic components, amongst other things also because the risk of glass breakage is reduced if disassembly for cleaning is required less often. Thus, in a preferred embodiment of the photobioreactor, the riser and downcomer tubes and/or the manifold are substantially made of glass. As a result, amongst other things, the longevity or resistance of the photobioreactor is increased, especially when microalgae that require a culture medium with an extreme pH value are cultivated. In addition, over time, glass typically becomes less roughened than the plastic that is normally used, so that the cleaning or keeping-clean is simplified. The glass can be coated, as disclosed in DE 10 2009 029 792 A1 or WO 2011/015653 A2, for example.

According to a further preferred embodiment, an inlet for gassing with the apparatus is provided for the riser tube that is connected to the downcomer tube by the connecting piece, and a further inlet for gassing with the apparatus is provided for the downcomer tube that is connected to the riser tube by the connecting piece. This allows for varying degrees of gassing of the riser and downcomer tubes. In the case of gassing via the same gas conduit, this can be achieved, for example, by providing a gassing inlet of the riser tube with one or more openings (e.g. in the form of membranes or sintered discs), which are altogether more permeable than those of the gassing inlet of the downcomer tube. Alternatively, the riser tube (i.e. the gassing inlet of the riser tube) can be gassed with a pressure A via a first gas conduit, for example, while the downcomer tube (i.e. the gassing inlet of the downcomer tube) is gassed with a pressure B via a second gas conduit, A being greater than B.

It is particularly favourable if at least one of the inlets for gassing is provided in the connecting piece, because this is easier to accomplish in the construction of the photobioreactor. This is because the connecting piece can be made (throughout) of more easily machineable, non-transparent materials such as stainless steel, for example.

The photobioreactor of the present invention is preferably of the “tubular reactor” type, more specifically a “vertical tubular reactor”, or respectively not a “plate reactor” or “flat panel reactor”.

According to the invention, said multiplicity of riser or downcomer tubes of the reactor element, which are connected to the same manifold in a fluid-permeable manner, is at least three (e.g. in the arrangement downcomer tube - riser tube - downcomer tube or riser tube - downcomer tube - riser tube along the manifold). In terms of scalability of the cleaning, it is favourable if said multiplicity is at least four, preferably at least five, more preferably at least ten, even more preferably at least twenty, in particular at least thirty or even at least forty. Advantageously, an alternating arrangement of riser or downcomer tubes along the manifold is selected (that is to say e.g. riser tube - downcomer tube - riser tube - ... - downcomer tube - riser tube or riser tube - downcomer tube - riser tube - ... - downcomer tube - riser tube - downcomer tube, or downcomer tube - riser tube - downcomer tube - ... - riser tube). Expediently, the positioning of inlets or outlets (e.g. at the upper or lower end) in the photobioreactor should of course be selected according to this arrangement in such a way that a dead volume is avoided. It is obvious to the person skilled in the art that by reversing the flow of the culture medium (e.g. by changing the gassing), a riser tube can become a downcomer tube or vice versa. Advantageously, the sum of the flow velocity vectors of the flows of the culture medium which prevail in the manifold (in particular if a meandering flow is guided in the reactor element) results in a flow velocity vector that is substantially parallel to the longitudinal axis of the manifold (a net flow along the longitudinal axis, so to speak, cf. also the horizontal dashed arrows in Fig. 3).

It is favourable if the longitudinal axes of the riser or downcomer tubes, if appropriate independently of one another, are at an angle of more than 5°, preferably of more than 20°, more preferably of more than 40° or even of more than 60°, even more preferably of more than 70° or even of more than 80°, in particular of more than 85° or even of more than 87.5° to the level of the culture medium or to the manifold. It is particularly favourable if the longitudinal axes of the riser or downcomer tubes are substantially normal (or normal) to the level of the culture medium or to the (preferably substantially horizontal) manifold (in other words: if they are oriented vertically). Expediently, the longitudinal axes of the riser and downcomer tubes (especially those which are each connected by a connecting piece) are substantially parallel to one another.

According to the definition according to the invention, the “manifold” has at least three liquid-permeable connections for riser or downcomer tubes. These can be formed, for example, as boreholes, openings or connection extensions (in this case, however, said interface must be located in the interior of the manifold itself (in other words: in the main tube of the manifold) in order to ensure simplified cleaning). It is favourable if the manifold does not have a slope or gradient, along its longitudinal axis, with an angle (in relation to the level of the culture medium) of more than 10°, preferably of more than 5°, more preferably of more than 2.5°, even more preferably of more than 1° or even of more than 0.5°. Particularly preferably, the manifold is oriented (along its longitudinal axis) substantially horizontally or horizontally (i.e. its longitudinal axis is substantially parallel or parallel to the level of the culture medium).

In the context of the invention, the gas space in the manifold (which is located above the culture medium in the manifold) is preferably a gas space that extends along the longitudinal axis of the manifold over at least 10%, preferably at least 20% or even at least 30%, more preferably at least 40% or even at least 50%, even more preferably at least 60% or even at least 70%, in particular at least 80% or even at least 90% of the length of the manifold. It is particularly expedient if said gas space extends over the entire length of the manifold. It goes without saying that “gas” can also be understood to mean a gas mixture.

In order to facilitate the cleaning, the manifold and/or the riser or downcomer tubes expediently, if appropriate independently of one another, do not have a bend, along their longitudinal axis, of more than 90°, preferably of more than 70°, more preferably of more than 50°, even more preferably of more than 30° or even of more than 20°, in particular of more than 10° or even of more than 5°. It is particularly favourable if the manifold and/or the riser or downcomer tubes are substantially straight or straight along their longitudinal axis. Preferably, the manifold and/or the riser or downcomer tubes (where appropriate except for any connection extensions) have a substantially round profile.

For the entire context of the invention, it is the case that a connecting piece preferably connects exactly one of the riser tubes to exactly one of the downcomer tubes in a liquid-permeable manner (or attaches the two to one another in a liquid-permeable manner). Here, it is preferred that at least all but one or two riser tubes of the reactor element and/or at least all but one or two downcomer tubes of the reactor element are each connected in pairs to such a connecting piece in a liquid-permeable manner, in particular at least all but one riser tube of the reactor element and/or at least all but one downcomer tube of the reactor element are each connected in pairs to such a connecting piece in a liquid-permeable manner. In structural terms, it is favourable (in particular for supporting a meandering flow) if a connecting piece connects a riser tube and a downcomer tube, which are adjacent to one another (i.e. attached adjacent to the manifold), to one another in a liquid-permeable manner.

“Operating state” is to be understood herein as a state of the photobioreactor in which living phototrophic microorganisms are cultivated in culture medium in the photobioreactor, wherein the culture medium in the photobioreactor preferably has a flow (in particular substantially caused by the gassing).

The present invention further relates to the following aspects or embodiments thereof:

Embodiment 1. Photobioreactor for the cultivation of phototrophic microorganisms, having a reactor element that has a tube, and having a maintenance device and a drive system that can move the maintenance device in the tube, wherein the photobioreactor is designed in such a way that, in the operating state of the photobioreactor, liquid culture medium with the microorganisms flows at least partially through the tube, characterised in that the photobioreactor is designed in such a way that the maintenance device can be inserted in the tube in the operating state of the photobioreactor and can be moved by the drive system at least against the flow of the culture medium in the tube.

Embodiment 2. Photobioreactor according to embodiment 1, characterised in that the photobioreactor further comprises an apparatus for gassing the culture medium, wherein the photobioreactor is designed in such a way that, in the operating state of the photobioreactor, the maintenance device in the tube is brought into contact with gas bubbles situated in the culture medium.

Embodiment 3. Photobioreactor according to embodiment 1 or 2, characterised in that, in the operating state of the photobioreactor, the maintenance device in the tube for the culture medium can be flowed around and/or flowed through.

Embodiment 4. Photobioreactor according to any one of embodiments 1 to 3, characterised in that the photobioreactor is designed in such a way that, in the operating state, both culture medium and, above the culture medium, a gas space for receiving gas bubbles rising from the culture medium are present in the tube, wherein an interface between the culture medium and the gas space is arranged in the tube, and the maintenance device is set up at least for cleaning inner surface of the tube which is in contact with the gas space.

Embodiment 5. Photobioreactor according to any one of embodiments 1 to 4, characterised in that the maintenance device comprises a spray nozzle for spraying the inner surface of the tube with a cleaning liquid, preferably wherein the maintenance device is set up at least for spraying inner surface of the tube which is in contact with said gas space by means of the spray nozzle.

Embodiment 6. Photobioreactor according to any one of embodiments 1 to 5, characterised in that the maintenance device comprises at least one wiper blade made of an elastic material for wiping the inner surface of the tube, preferably wherein the maintenance device is set up at least for wiping inner surface of the tube which is in contact with said gas space with the wiper blade and/or preferably wherein the maintenance device has a, where appropriate further, spray nozzle that is set up for spraying the wiper blade with a cleaning liquid.

Embodiment 7. Photobioreactor according to embodiment 5 or 6, wherein the spray nozzle is connected to a liquid reservoir outside the tube via a conduit.

Embodiment 8. Photobioreactor according to any one of embodiments 1 to 8, characterised in that the tube is a manifold having at least three connections for the inflow or outflow of culture medium, and the photobioreactor is designed in such a way that the maintenance device can be moved to at least one of the connections in the tube and seal it off.

Embodiment 9. Photobioreactor according to embodiment 8, characterised in that the reactor element further has a multiplicity of riser and downcomer tubes for the liquid culture medium, wherein the riser and downcomer tubes are each attached at their upper end in a liquid-permeable manner to the tube that is formed as a manifold, wherein at least one of the riser and one of the downcomer tubes are additionally connected to one another in a liquid-permeable manner by a connecting piece, and wherein the photobioreactor is designed in such a way that the maintenance device can simultaneously seal off the connection for the downcomer tube and the connection for the riser tube, which are both additionally connected to one another in a liquid-permeable manner by a connecting piece.

Embodiment 10. Photobioreactor according to embodiment 9, characterised in that the maintenance device is set up for cleaning the down pipe, which is sealed off from the tube by the maintenance device, and the riser tube, which is sealed off from the tube by the maintenance device, both of which are connected to one another in a liquid-permeable manner by a connecting piece.

Embodiment 11. Photobioreactor according to any one of embodiments 1 to 10, characterised in that a guide strip is provided on the tube, preferably on the outside thereof, for stabilising and/or positioning the maintenance device in the tube.

Embodiment 12. Photobioreactor according to any one of embodiments 1 to 11, characterised in that the drive system has at least one cable winch, which can drive a cable that is guided in the tube and connected to the maintenance device, the cable winch preferably being equipped with an apparatus for disinfecting the cable.

Embodiment 13. Photobioreactor according to any one of embodiments 1 to 12, characterised in that the maintenance device comprises at least two modules, which are connected to one another by a coupling, preferably wherein the tube consists substantially of glass.

Embodiment 14. Photobioreactor according to any one of embodiments 1 to 13, characterised in that the photobioreactor has a station for the maintenance device, which is set up for cleaning the maintenance device and into which the maintenance device can be moved.

Embodiment 15. Method for cultivating phototrophic microorganisms in a photobioreactor, wherein the photobioreactor is equipped with a reactor element, which has a tube, and with a maintenance device in the tube and a drive system, which moves the maintenance device in the tube, wherein liquid culture medium with the microorganisms flows at least partially through the tube, characterised in that the method comprises the use of the maintenance device in the tube in the operating state of the photobioreactor and the maintenance device is moved by the drive system at least against the flow of the culture medium in the tube, preferably wherein the photobioreactor is further defined according to any one of embodiments 1 to 11.

Embodiment 16. Movable maintenance device for the maintenance of the inner surface of a tube of a photobioreactor for the cultivation of phototrophic microorganisms, characterised in that the maintenance device is suitable for the maintenance of the inner surface of the tube during ongoing operation of the photobioreactor, while liquid culture medium with the microorganisms flows at least partially through the tube, and is set up for being moved by an external drive system, which preferably has a cable winch, at least against the flow of the culture medium in the tube.

Embodiment 17. Movable maintenance device according to embodiment 16, characterised in that the maintenance device has a spray nozzle for spraying the inner surface of the tube with a cleaning liquid and a connection for a conduit with the liquid.

Embodiment 18. Movable maintenance device according to embodiment 16 or 17, characterised in that the maintenance device has at least one wiper blade made of an elastic material for wiping the inner surface of the tube, preferably wherein the maintenance device has a, where appropriate further, spray nozzle that is set up for spraying the wiper blade with a cleaning liquid.

Embodiment 19. Movable maintenance device according to any one of embodiments 16 to 18, characterised in that the maintenance device has at least two modules, which are connected to one another by a coupling.

Embodiment 20. Movable maintenance device according to any one of embodiments 16 to 19, characterised in that the maintenance device is further equipped with an apparatus for sealing off connections of the tube.

Embodiment 21. Use of the movable maintenance device according to any one of embodiments 16 to 20 for maintaining the inner surface of a tube of a photobioreactor for cultivating phototrophic microorganisms, wherein the maintenance takes place during ongoing operation of the photobioreactor, wherein liquid culture medium with the microorganisms flows at least partially through the tube.

The invention will be further explained hereinafter with reference to particularly preferred exemplary embodiments, but is not limited thereto, and with reference to drawings. In the drawings, in detail:

Fig. 1 shows a photobioreactor according to the prior art (US 2011/0027875 A1), in which the interfaces between the culture medium and the gas space are located below the upper gas manifold;

Fig. 2 shows a plan view of an implementation of the photobioreactor according to the invention in the operating state;

Fig. 3 shows a plan view of an implementation of the photobioreactor according to the invention with the maintenance device in the operating state;

Fig. 4 is a locally enlarged view of the implementations according to Fig. 2 and Fig. 3;

Fig. 5A shows a plan view of a filled manifold, as can be used for the present invention;

Fig. 5B shows a perspective view of the manifold according to Fig. 5A;

Fig. 6 shows a perspective view of a metal framework, as can be for implementations of reactor elements of the photobioreactor according to the invention;

Fig. 7 shows a perspective view of reactor elements of an embodiment of the photobioreactor according to the invention.

Fig. 2 shows a photobioreactor 1 for the cultivation of phototrophic microorganisms, with two reactor elements 2, each having a multiplicity of vertical, straight riser tubes 3a and downcomer tubes 3b for the culture medium 4 and a horizontal, straight manifold 5. The culture medium 4 is a water-based liquid culture medium enriched with nutrients; it contains the phototrophic microorganisms (usually microalgae). Said tubes consist of glass, with the manifolds 5 being provided with connection extensions 50 (cf. also Fig. 5A and Fig. 5B). The riser tubes 3a and downcomer tubes 3b are each connected in a liquid-permeable manner at their upper end 6 to the connection extensions 50 of the manifold 5 with the aid of the tube connectors 51. The riser tubes 3a and the downcomer tubes 3b are additionally connected to one another in a liquid-permeable manner by means of a U-shaped connecting piece 7 in each case (cf. also Fig. 4).

The photobioreactor 1 further has an apparatus 8 for introducing carbon dioxide (and/or compressed air) into the riser tubes 3a or the downcomer tubes 3b. For the riser tube 3a that is connected to the downcomer tube 3b by means of the connecting piece 7, an inlet 14a is provided for gassing by means of the apparatus 8. For the downcomer tube 3b that is connected to the riser tube 3a by means of the connecting piece 7, a further inlet 14b is provided for gassing by means of the apparatus 8. The carbon dioxide is pumped from a liquid tank into a gas manifold by means of a gas pump. The connections of the gas manifold are connected to an inlet 14a and 14b in each case by hoses. By providing an opening of the inlet 14a which is more permeable than the opening of the inlet 14b, a stronger gassing of the riser tubes 3a compared to the downcomer tubes 3b is made possible. Surprisingly - although the manifold 5, rather than U-shaped connecting pieces 7, is provided at the respective upper end 6 of the riser tubes 3a or downcomer tubes 3b - this results in a meandering flow of the culture medium 4 (upwards in the riser tubes 3a, downwards in the downcomer tubes 3b; cf. also the dashed arrows in Fig. 3). Furthermore, this meandering flow is further stabilised by connecting the two reactor elements 2 to one another in a liquid-permeable manner via a downcomer tube 3b of the first reactor element 2 to a riser tube 3a of the second reactor element 2 by means of a U-shaped connecting piece 7 - that is to say, in simple terms, by providing a “gap” between the two manifolds 5.

The inlet 52a and the outlet 52b can be connected to one another by means of a hose, with the result that cyclical operation of the photobioreactor 1 is made possible. After a certain number of cycles under exposure, the culture medium 4, which now contains a significantly higher concentration of microorganisms, can be removed at the outlet 52b for harvesting (i.e. for concentration and drying of the phototrophic microorganisms), while fresh culture medium 4 with a low initial concentration of phototrophic microorganisms is introduced at the inlet 52a. Of course, continuous cyclical operation is also conceivable, in which the inlet 52a remains connected to the outlet 52b by means of a hose, and fresh culture medium 5 is continuously supplied at an inlet in a first lower connecting piece 7 and the same quantity of denser culture medium 4 is continuously removed at an outlet in a second lower connecting piece 7 that is located directly in front of it, starting from the direction of flow. Of course, a certain minimum length of the culturing line is required for this. Likewise, if the photobioreactor 1 has a certain minimum length, continuous linear operation is also conceivable, in which fresh culture medium 4 with a low initial concentration of phototrophic microorganisms is continuously introduced at the inlet 52a and the same quantity of mature culture medium 4 is continuously removed at the outlet 52b for harvesting. However, inlets can also be provided at other locations in the reactor (e.g. U-bend connecting piece of the first/last riser or downcomer tube, but also in another U-bend connecting piece in the photobioreactor).

The meandering flow of culture medium 4 with the phototrophic microorganisms is so high in the reactor elements 2 that the manifolds 5 are each also approximately half filled with it. Both culture medium 4 and, above the culture medium 4, a gas space 9 for receiving gas bubbles 10 rising from the culture medium 4 are present in the manifold 5, wherein an interface 11 between the culture medium 4 and the gas space 9 is arranged in the manifold 5. Gas pressure equalisation with the environment takes place via the valve 53, which is equipped with a filter system in order to prevent contamination of the culture medium 4.

The impurities on the inner surface of the manifold 5 which associated with the interface 11 between the culture medium 4 and the gas space 9 can be cleaned with relatively little effort, by briefly taking the photobioreactor 1 out of operation, draining the culture medium 4 from the manifold 5, removing the cover plate 54 of the manifold and cleaning the inner surface of the manifold e.g. with a brush that is secured to a telescopic rod.

The implementation of the photobioreactor 1 shown in Fig. 3 allows the inner surface of the manifold 5 to be cleaned or kept clean during operation. In this case, the guide rail 12 for the movable maintenance device 13 is provided on the manifold 5. The maintenance device 13 is equipped with brushes and spray nozzles for the inner surface of the manifold 5. The maintenance device 13 is magnetic, for example, and can be moved by means of a magnet (or cables) that can be displaced in the guide rail 12. The maintenance device 13 can be flowed around and can be used during ongoing operation at presettable time intervals, which significantly reduces the standing times of the photobioreactor 1. The dashed arrows illustrate the flow path in the reactor element 2.

Fig. 7 diagrammatically shows an embodiment of the photobioreactor 1, in which the respective manifold 5 of a reactor element 2 consists of glass sections 56 which are directly connected to one another. In each case, two reactor elements 2 are held by the metal frame 55 shown in Fig. 6.

Patentkrav

1. Fotobioreaktor (1) til dyrkning af fototrofe mikroorganismer, med et reaktorelement (2), der har et multiplum af stig- (3a) og faldrør (3b) til flydende kulturmedium (4), som indeholder mikroorganismerne, og et fordelerrør (5), hvor stig- (3a) og faldrørene (3b) hver især ved deres øverste ende (6) er forbundet væskegennemtrængeligt med fordelerrøret (5), hvor i det mindste et af stig- (3a) og et af faldrørene (3b) yderligere er forbundet væskegennemtrængeligt med hinanden ved hjælp af et forbindelsesstykke (7), hvor fotobioreaktoren (1) endvidere har en indretning (8) til ledning af gas ind i i det mindste et stigrør (3a), kendetegnet ved, at fotobioreaktoren (1) er konstrueret sådan, at der i driftstilstanden i fordelerrøret (5) findes såvel kulturmedium (4) som, oven over kulturmediet (4), et gasrum (9) til optagelse af gasblærer (10), der stiger op fra kulturmediet (4), hvor der i fordelerrøret (5) er anbragt en grænseflade (11) mellem kulturmediet (4) og gasrummet (9).

2. Fotobioreaktor (1) ifølge krav 1, kendetegnet ved, at der er indrettet i det mindste to reaktorelementer (2), hvor et faldrør (3b) i det første reaktorelement (2) og et stigrør (3a) i det andet reaktorelement (2) er forbundet væskegennemtrængeligt med hinanden ved hjælp af et forbindelsesstykke (7).

3. Fotobioreaktor (1) ifølge krav 1 eller 2, kendetegnet ved, at stig- (3a) og faldrørene (3b) og/eller fordelerrøret (5) i det væsentlige består af glas.

4. Fotobioreaktor (1) ifølge et af kravene 1 til 3, kendetegnet ved, at der på fordelerrøret (5) er indrettet en indretning (12) til føring af en vedligeholdelsesanordning (13), der er bevægelig i fordelerrøret (5).

5. Fotobioreaktor (1) ifølge et af kravene 1 til 4, kendetegnet ved, at der til det med faldrøret (3b) ved hjælp af forbindelsesstykket (7) forbundne stigrør (3a) er indrettet et indløb (14a) til begasning med indretningen (8), og at der til det med stigrøret (3a) ved hjælp af forbindelsesstykket (7) forbundne faldrør (3b) er indrettet et yderligere indløb (14b) til begasning med indretningen (8).

6. Fotobioreaktor (1) ifølge krav 5, kendetegnet ved, at i det mindste et af indløbene til begasningen (14a,14b) er indrettet i forbindelsesstykket (7).

7. Fotobioreaktor (1) ifølge krav 5 eller 6, kendetegnet ved, at den er konstrueret sådan, at der i driftstilstanden forårsages en agitation og/eller en strømning af kulturmediet (4) i det væsentlige ved hjælp af de gasblærer (10), der stiger op i kulturmediet (4).

8. Fotobioreaktor (1) ifølge krav 7, kendetegnet ved, at den er konstrueret sådan, at der i driftstilstanden opnås en mæanderformet strømning af kulturmediet (4) gennem stig- (3a) og faldrørene (3b) ved, at kulturmediet (4) begasses stærkere i det stigrør (3a), der ved hjælp af forbindelsesstykket (7) er forbundet med faldrøret (3b), end i faldrøret (3b).

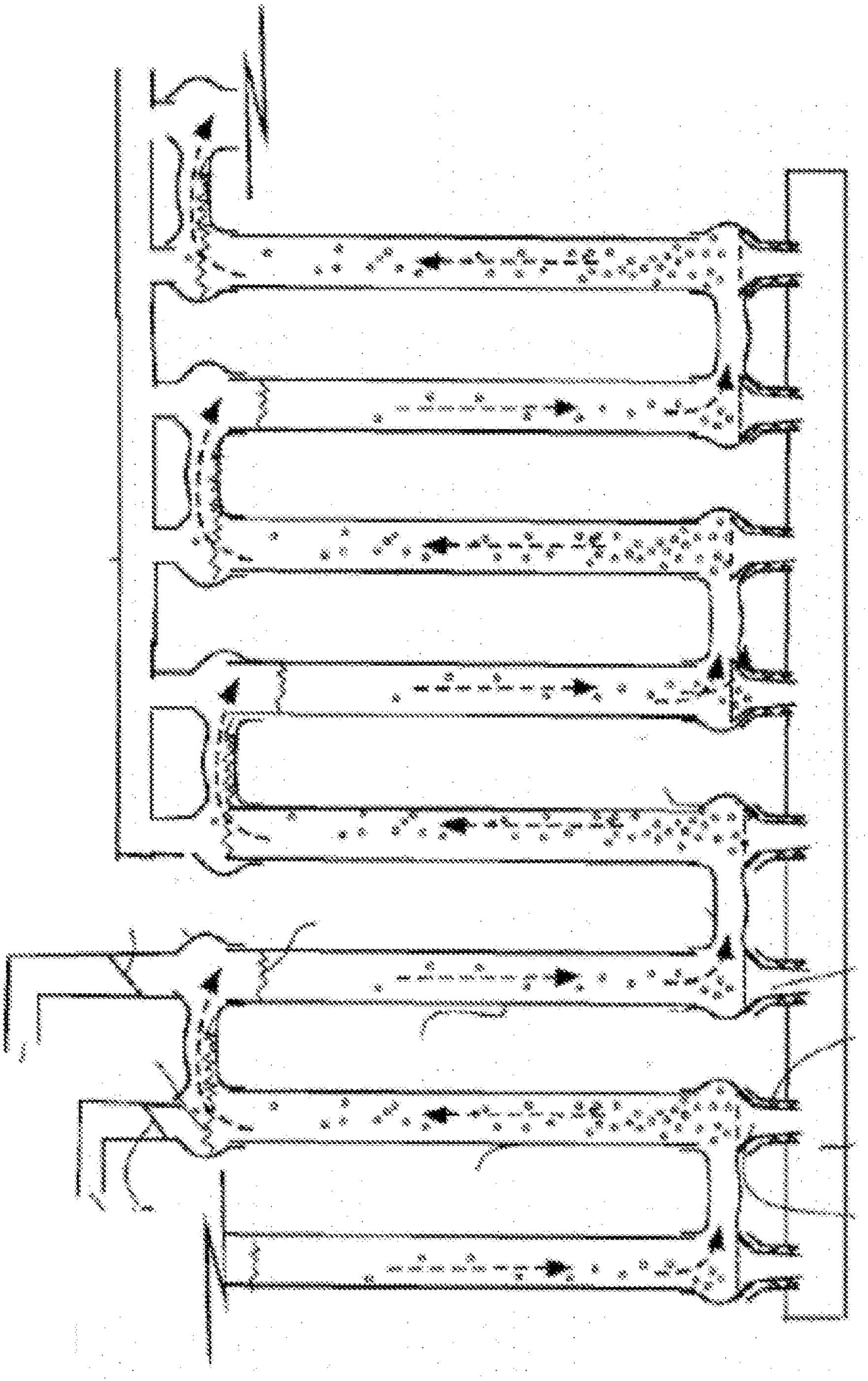
9. Fremgangsmåde til dyrkning af fototrofe mikroorganismer, omfattende belysningen af en fotobioreaktor (1),
hvorved fotobioreaktoren (1) er forsynet med et reaktorelement (2), der har et multiplum af stig- (3a) og faldrør (3b) til flydende kulturmedium (4), som indeholder mikroorganismerne, og et fordelerrør (5), hvorved stig- (3a) og faldrørene (3b) hver især ved deres øverste ende (6) er forbundet væskegennemtrængeligt med fordelerrøret (5), hvorved i det mindste et af stig- (3a) og et af faldrørene (3b) yderligere er forbundet væskegennemtrængeligt med hinanden ved hjælp af et forbindelsesstykke (7),
og hvorved fotobioreaktoren (1) i stig- (3a) og faldrørene (3b) indeholder flydende kulturmedium (4) med mikroorganismerne, hvilket kulturmedium i det mindste delvist begasses,
kendetegnet ved, at der i fordelerrøret (5) findes såvel flydende kulturmedium (4) med mikroorganismerne som, oven over kulturmediet (4), et gasrum (9), hvorved der i fordelerrøret (5) udformes en grænseflade (11) mellem kulturmediet (4) og gasrummet (9), og gasrummet (9) optager gasblærer (10), der stiger op fra kulturmediet (4).

10. Fremgangsmåde ifølge krav 9, kendetegnet ved, at fotobioreaktoren er fotobioreaktoren ifølge et af kravene 1 til 8.

11. Fremgangsmåde ifølge krav 9 eller 10, kendetegnet ved, at kulturmediet (4) strømmer mæanderformet gennem stig- (3a) og faldrørene (3b).

12. Fremgangsmåde ifølge et af kravene 8 til 11, kendetegnet ved, at fordelerrørets (5) indre overflade renses af den bevægelige vedligeholdelsesanordning (13), fortrinsvis i forudindstillelige tidsintervaller.

Fig. 1



Prior art

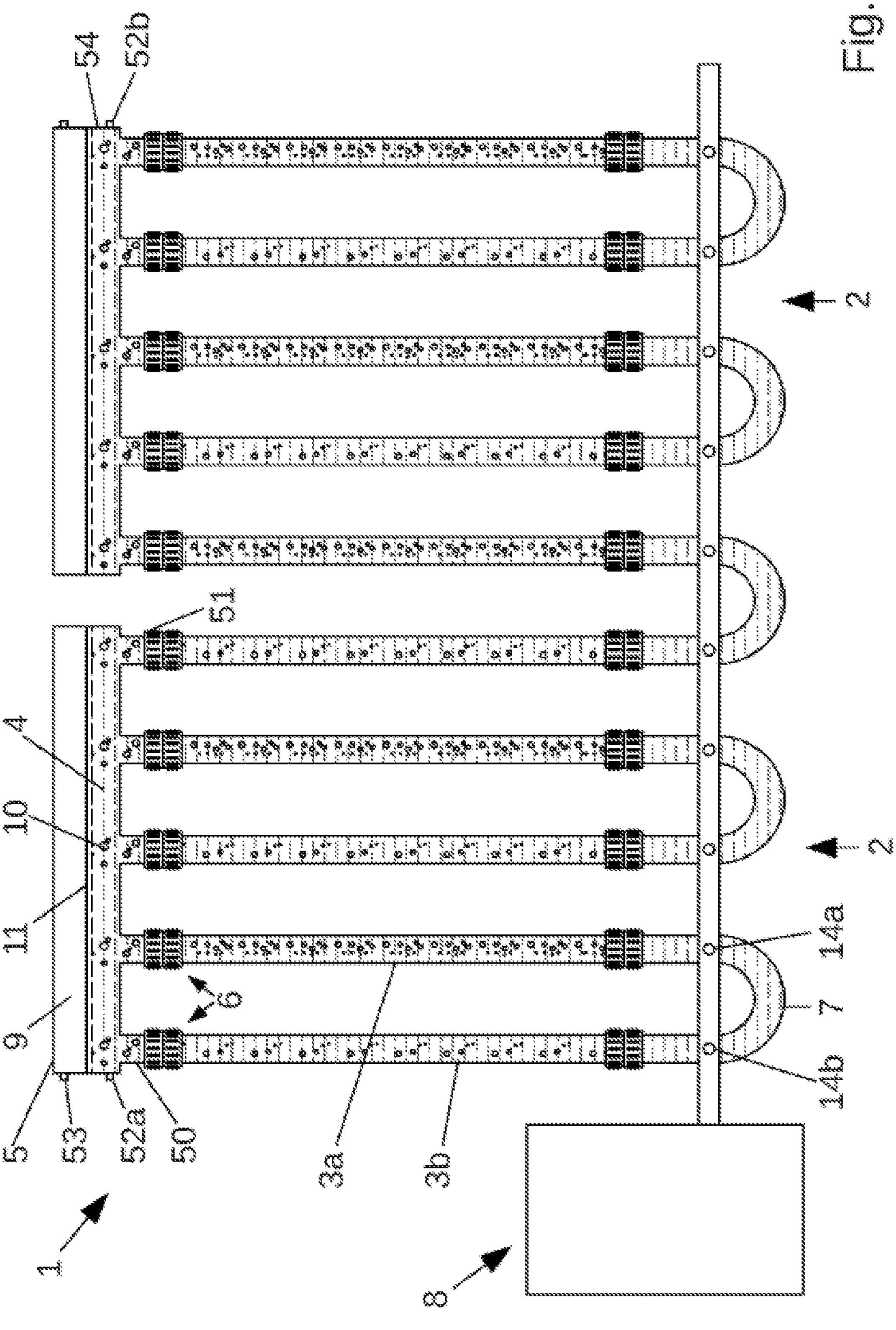


Fig. 2

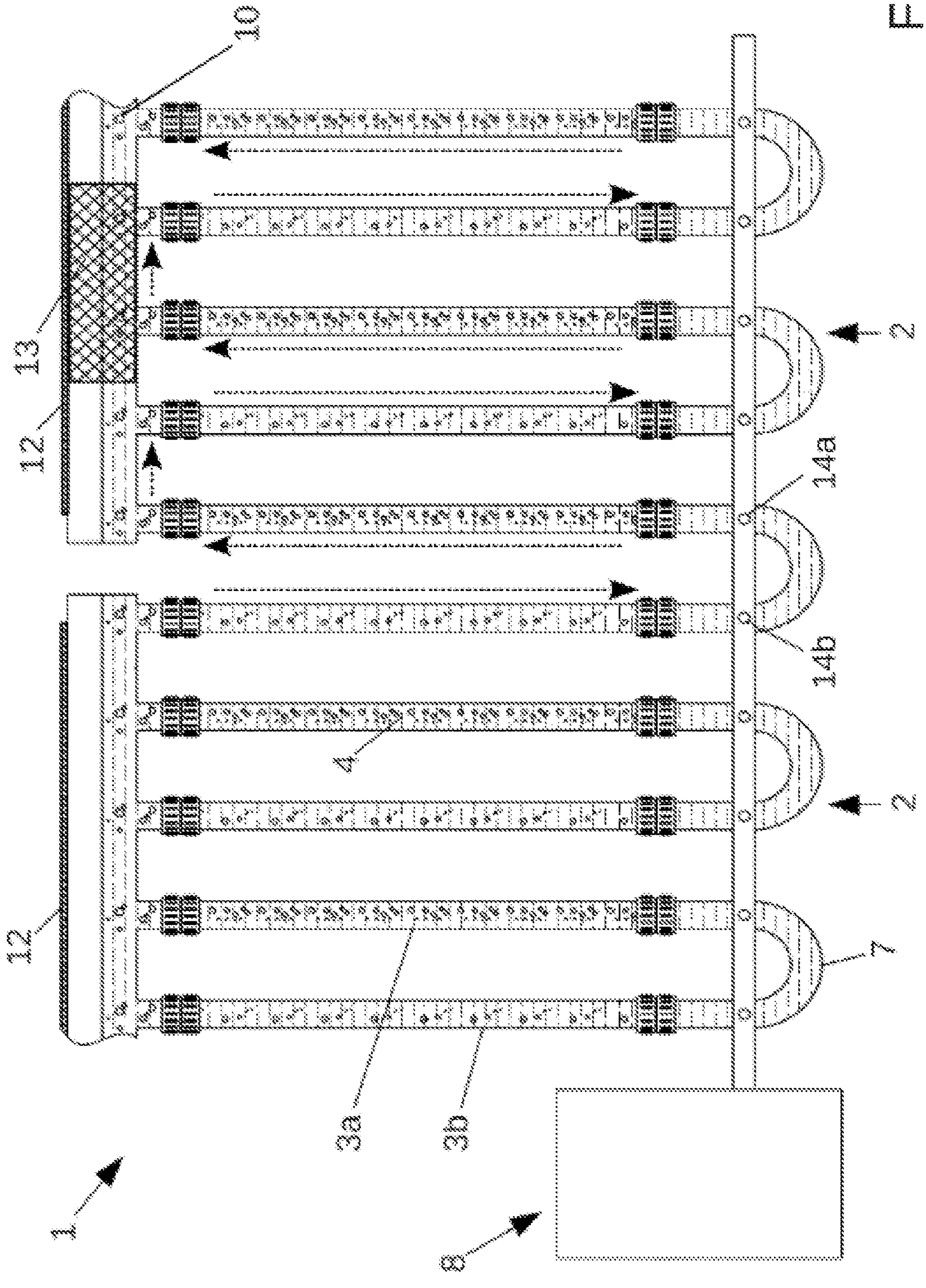


Fig. 3

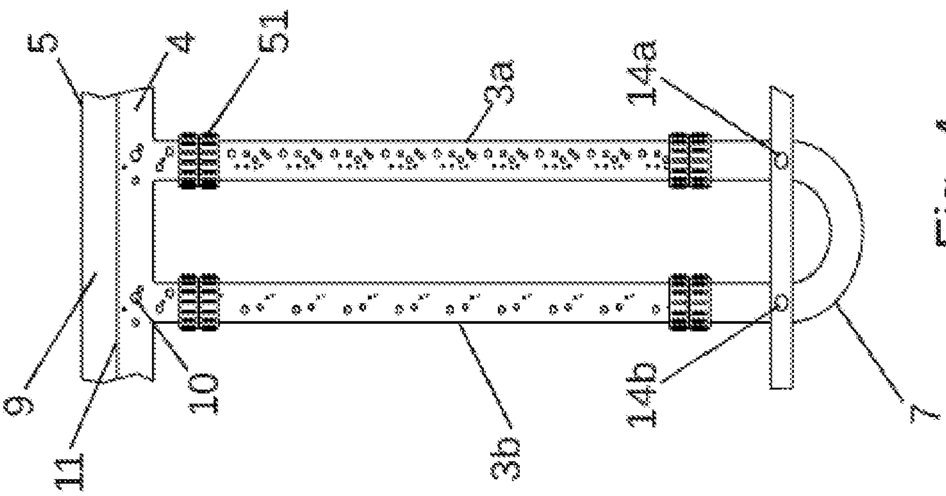


Fig. 4

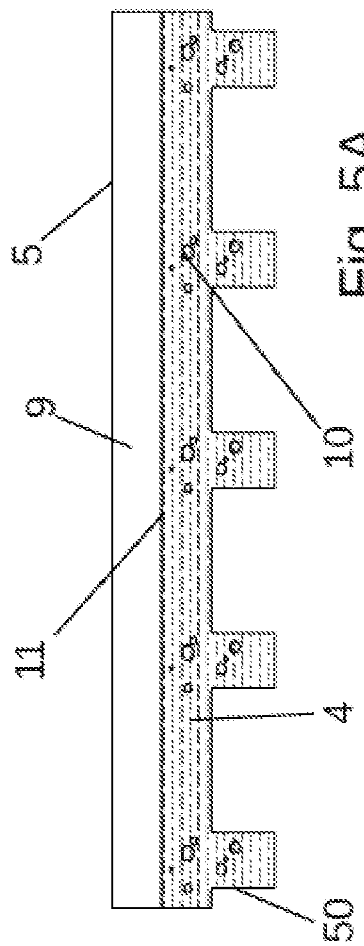


Fig. 5A

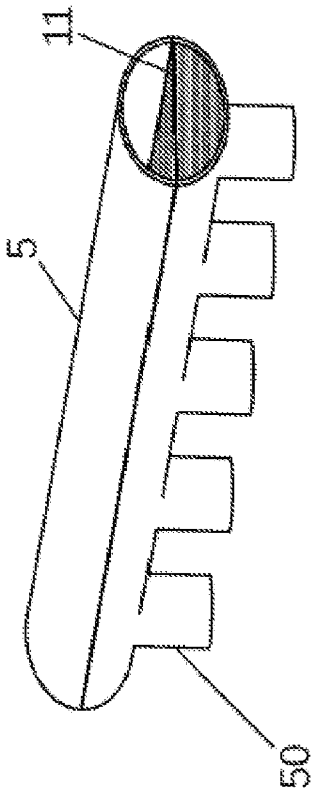


Fig. 5B

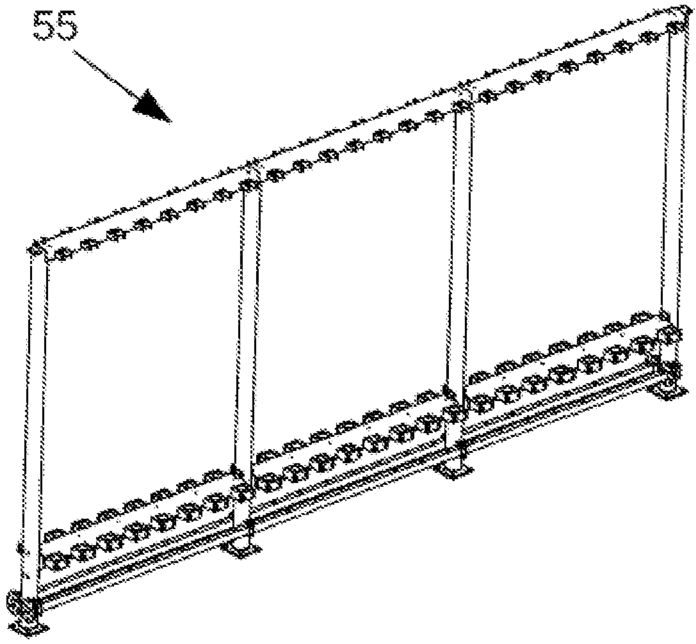


Fig. 6

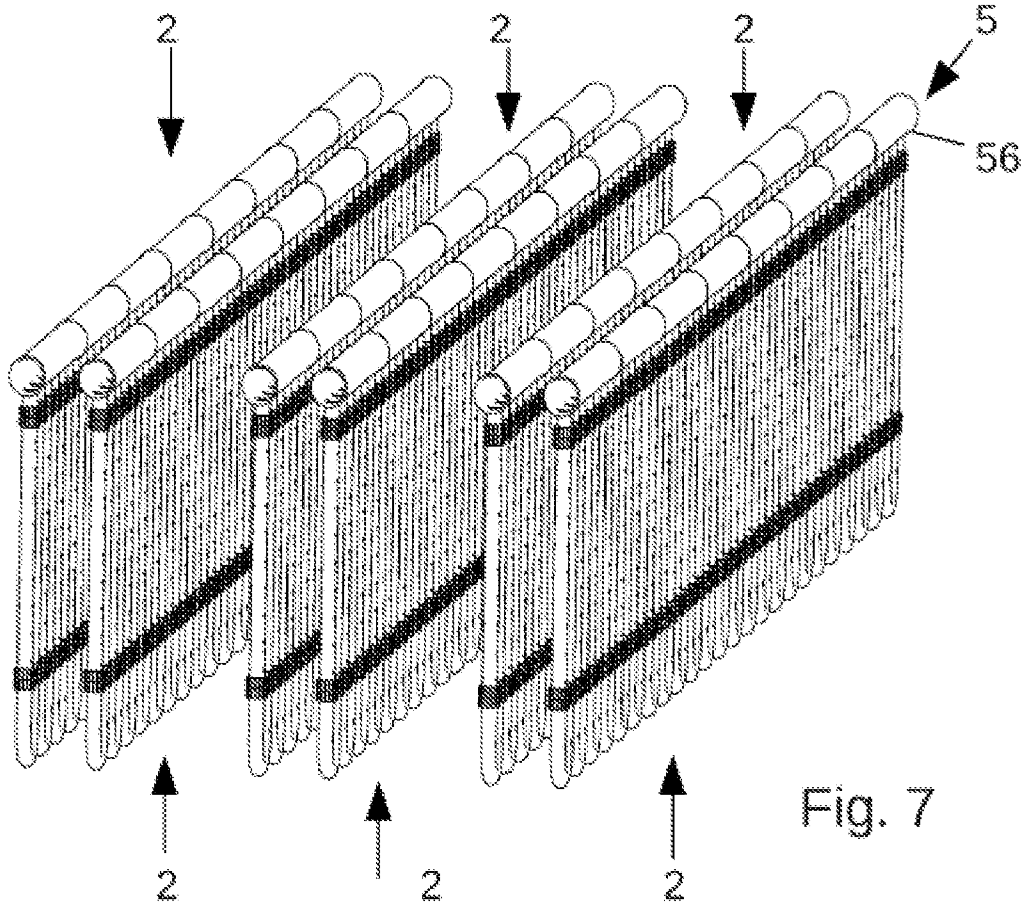


Fig. 7