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(54) **Titre :** BIOREATEURS SUSPENDUS
(54) **Title:** SUSPENDED BIOREACTORS

(57) **Abrégé/Abstract:**

Banks of suspended thin bioreactors for biomass production having substantially transparent chambers suitable for containing biomass in an aqueous suspension are suspended to elevated gothic trusses; each bioreactors is provided with an elongate rigid base portion slightly inclined side wise and flanked by two side walls and a semi-rigid upper cover portion; a sparging means placed in bioreactors length creates turbulence in the aqueous suspension to ensure continual mixing of all the biomass and provide an intermittent exposure of the biomass to a light source. In another embodiment of the invention a water jacket under the bioreactors acts as a low-cost temperature control. Covering gothic trusses with a thin layer of transparent bioreactor chambers creates a greenhouse under which food may be grown.

Suspended bioreactors for biomass production

Abstract

Banks of suspended thin bioreactors for biomass production having substantially transparent chambers suitable for containing biomass in an aqueous suspension are suspended to elevated gothic trusses; each bioreactors is provided with an elongate rigid base portion slightly inclined side wise and flanked by two side walls and a semi-rigid upper cover portion; a sparging means placed in bioreactors length creates turbulence in the aqueous suspension to ensure continual mixing of all the biomass and provide an intermittent exposure of the biomass to a light source. In another embodiment of the invention a water jacket under the bioreactors acts as a low-cost temperature control. Covering gothic trusses with a thin layer of transparent bioreactor chambers creates a greenhouse under which food may be grown

DESCRIPTION

This invention relates to an apparatus for the production of biomass and more particularly to cultivating biomass in a dense bank of suspended bioreactors.

The commercial potential of producing useful products by photosynthesis techniques using simple plant matter, such as algae and seaweed, has been recognized. The ability of simple single cell organisms, such as blue green algae, to utilize sunlight, carbon dioxide and the inorganic constituents of sea water to produce more complex matter played an essential part in the evolutionary process. Many attempts have been made to harness the ability of simple organisms to produce complex materials.

To appreciate the value of attempts made and associated prior art, a short review of recent studies and related publications has revealed the following:

According to Mario R. Tredici: "Outdoors, under full sunlight, the photosynthetic efficiency drops to one tenth-one fifth of the values observed at low irradiances. The major causes for this inefficiency are the light saturation effect (LSE) and photoinhibition, phenomena that strongly limit the growth of microalgae in outdoor culture, although these because of the high cell density, are light-limited. The main problem is that photosynthetic apparatus of phototrophs saturates at low irradiances (typically from 1/20 to 1/10, 100 and 300 of full sunlight) and that, at irradiances above saturation, the absorbed photons are used inefficiently and may cause cell injury. Several strategies to overcome the LSE and photoinhibition have been proposed, based on engineering (light dilution, ultra high cell density culture, high turbulence), physiologic (photoacclimation, nutrient deprivation) or genetic . . . ." (Tredici M. R. (2004) Mass production of microalgae: photobioreactors. In Richmond A (ed.), Handbook of Microalgae Culture. Blackwell Publishing, Oxford (UK), pp 178-214.
Dimanshteyn taught in US Pat. 7,824,904 that photobioreactors generally consist of a container containing a liquid medium that is exposed to a light source.

However, the configuration of the photobioreactor often prevents the light from penetrating more than a few centimeters from the surface of the liquid. This problem reduces the efficiency of the photobioreactor, and was recognized in "Solar Lightning for Growth of Algae in a Photobioreactor" published by the Oak Ridge National Lab and Ohio University: Light delivery and distribution is the principle obstacle to using commercial-scale photobioreactors for algae production. In horizontal cultivator systems, light penetrates the suspension only to 5 cm leaving most of the algae in darkness. The top layer of algae requires only about 1/10th the intensity of full sunlight to maximize growth, so the remaining sunlight is wasted.

As described in Healthy Algae, Fraunhofer Magazine, January 2002, "Algae are a very undemanding life form--they only need water, CO2, nutrients and sunlight. However, providing sufficient sunlight can be a problem in large scale facilities. "As the algae at the surface absorb the light, it does not penetrate to a depth of more than a few millimeters. The organism inside the unit gets no light and cannot grow," explains Walter Troesch, who has been cultivating algae for years. "This is the reason why there are only a few Algae production units dotted around the world. One of the problems with growing algae in any kind of pond is that only in the top 1/4" or so of the pond receives sufficient solar radiation for the algae to grow. In effect, this means that the ability of a pond to grow algae is limited by its surface area, not by its volume."

In summary, as stated by the above Fraunhofer Magazine, “the ability of a pond to grow algae is limited by its surface area, not by its volume." Therefore limitation of prior art will be examined in consideration of the above important findings.

Traditional procedures employed for culturing autotrophic organisms have involved the use of shallow open ponds or open channels exposed to sunlight. Not surprisingly this comparatively crude method has proved impracticable for production of pure high grade products because of such problems as invasion by hostile species (sometimes producing dangerous toxins), other pollution (such as dust), difficulty in the control of such variables as nutrient ratios, temperature and pH, intrinsically low yield because of escape of carbon dioxide to the atmosphere and inefficient use of light to illuminate only the top portion of the biomass.

Somewhat more sophisticated attempts have involved the use of horizontally disposed large diameter transparent plastics tubes for biomass production. The problems of such a system include the low density of biomass in the liquid within the tubes, coating of the pipes by algae due to low velocity flow therethrough thus reducing transparency, overheating in summer weather, high land usage and high energy input to displace large amount of un-necessary diluted water.

U.K. Patent No. 2ll8572 discloses a flat vertical panel, (of area about l square meter) having a pipe of comparatively small diameter wound substantially horizontally against the panel face thereof. Land usage was high and required that for square meter of plant, a square meter of ground area be allocated for its installation. Furthermore, experience showed that the process control problems of manipulating a sufficiently large number of such units for commercial production were enormous. Also, the design of the panels resulted in an inherently unstable construction unable to withstand adverse weather conditions.

U.S. Pat. No. 5,846,816 to Forth ("Forth") discloses a biomass production apparatus including a transparent chamber which has an inverted, triangular cross-section, as is shown in prior art FIG. 1 of Forth. Extending through the chamber is a first conduit which has a plurality of perforations along its length to allow the introduction of gasses into the chamber. Also extending through the chamber are a pair of heat exchange conduits connected to a supply of heat exchange medium.

Although the bioreactor disclosed by Forth promotes the growth of biological matter, it contradicts the above principles set by Tredici, Fraunhofer and National Labs of the need to maximize exposed surface area relative to the volume displaced, also taught by Branson et al. in US Patent 7,176,024, which states that Forth bioreactor "is generally not useful for applications requiring a sterile growth environment. The vents are open to external air which may include airborne contaminants. Such contaminants are especially troublesome for pharmacological applications wherein strict Food and Drug Administration guidelines for avoiding contamination must be met".

In addition, the constant circulation of the liquid required by Forth interferes with the growth of some types of biological matter. For instance, fully differentiated aquatic plants from the lemnaceae or "duckweed" family are fresh-water plants that grow best on the surface of the water. Such surface growing plants typically prefer relatively still water to support and promote optimal growth.

Therefore, it would be advantageous to have a photo-bioreactor system for promoting the growth of plant biological materials in a relatively sterile environment isolated from contaminants.

Consequently, the present invention seeks to provide an improved photobioreactor system that mimics more closely nature's work and more particularly on how leaves are able to optimize the absorption of sunlight and maximize the photosynthesis process.

In nature, and as confirmed by the findings of Fraunhofer light "does not penetrate to a depth of more than a few millimeters", and the same applies to thin leaves that maximize their surface area relative to their volume to maximize absorption of photons from sunlight. In a similar manner, this invention seeks to maximize exposure of thin layers of algal solution to sunlight or to artificial light inside a dense network of thin but elongate panel-shape bioreactors.

Again, as nature teaches us, leaves are strategically positioned on a tree to maximize light absorption; in a similar manner, in this invention, thin transparent elongate bioreactors are suspended at strategic positions to gothic-shape trusses, a shape that generally replicates the elevated contour of trees to minimize the shadow effect. Gothic-shape and gothic trusses are known to be strong, stable and cost-effective structures able to withstand adverse weather conditions.

Therefore, the present invention teaches a bank of improved thin elongate photobioreactors suspended in strategic elevated positions for reduce land usage while maximizing sunlight exposure; furthermore the invention teaches stable gothic-shape trusses to support the disclosed bioreactors, with said trusses being able to withstand adverse weather conditions. The invention also discloses a bank of bioreactors provided with a sparging means that is positioned over an inclined base portion to create a circulation that encourages optimal exposure to light of the entire biomass present in the aqueous suspension. Finally, the invention uses cost-effective transparent materials such as, but not limited to, light but tough fiber reinforced plastics (FRP) that last 15 to 25 years and that can be shaped in conventional production facilities for wide distribution on a substantial commercial scale to saving costs, energy, land usage, water usage and operate efficiently.

Thus, the present invention resides in a collection, cluster or a bank of suspended bioreactors for biomass production comprising:

(a) a bank of suspended substantially transparent thin chambers, each chamber being at least suitable for containing biomass in an aqueous suspension, and having a substantially flat base portion flanked between two side walls and an upper cover portion; said flat base provided with an inclined position created by either inclining the entire length of chambers or by providing an inclined base portion to each chamber.

(b) a repeating pattern of generally gothic-shape trusses positioned at equal distances along the length of said bank, said trusses for supporting said chambers by suspension means in positions that maximize chambers exposure to a light source; and

(c) a sparging means for creating turbulence in the aqueous suspension to ensure continual mixing and prevent settling of the biomass within the chambers;

Four factors affect this invention. The thickness of the aqueous suspension, the relative spatial positioning of each bioreactor within the bank of suspended bioreactors, the amount of light that penetrates the bioreactor chambers and the amount of sparging of air and/or gases provided to move biomass within each suspended chamber.

Therefore, it is the object of this invention to provide a bank of photobioreactors (PBR) with each PBR strategically suspended to a repeating pattern of gothic-shape trusses that are positioned along the longitudinal axis of the bank. Each bank being comprised of independent horizontal rows of photobioreactors.

By providing identical cross-sectional dimensions to all thin photobioreactor chambers, it becomes possible to overlap all PBR segment ends, thus making mounting and sealing of PBR easy against water leakage, using the right sealing tapes and fasteners. PBR panel side edges are configured, to rest over rafters mounted on the gothic-shape trusses on one side and to suspenders, bars or cables on the other side. Cables in turn may be attached directly or indirectly to trusses on one side and to longitudinal bars placed under the PBR chamber edges to distribute loads along the length of the PBR.

Each row of suspended photobioreactors is strategically positioned within the space available under the trusses to expose PBRs upper and lower surfaces to a maximum amount of direct and reflected sunlight, taking in consideration shadow effects imposed by other adjacent PBRs positioned in the bank. Furthermore, to enable cleaning and inspection of chambers of the pond-type, the preferred embodiments of PBRs disclosed in this invention are provided with openable covers. In other embodiments of the invention, PBR are closed and sealed.

As disclosed PBR chambers are transparent on all sides, light penetration to the underside of the chambers is promoted. This may be achieved by covering the ground under each bank of suspended PBR with light reflecting means such as aluminium foil. As an alternative, the ground may be painted white and/or provided with a reflective surface. Alternatively, or in addition, reflecting means such as mirrors may be also positioned at selected locations.

To enhance further growth of the biomass, the present invention teaches that the thin flat chambers suspended in each bank of PBRs be preferably mounted with an inclined orientation or alternatively by configured with an inclined angle. This angle may be adjusted for each PBR depending on its relative position in the bank, to the geographic location of the each PBR bank, to weather conditions, to sun's trajectory and also to the amount and speed of exhaust gases from the sparger, which will be discussed later.

It is preferable to mount the different rows of PBR close to the inner contour of the gothic-shape trusses with PBR's inclination properly oriented so that the largest amount of the aqueous suspension in each chamber be the most exposed to sunlight. The moving forces generated by the sparging gases at the deepest portion of the panels and directed towards the inclined base of the chambers creates a circular motion that exposes intermittently the content of the aqueous suspension to sunlight and to darkness. Alternately, an artificial flickering light may also be used to create a similar effect.

The arrangement of a sparger exiting gases over an inclined base, where maximum amount of the aqueous suspension is located guarantees a deeper absorption of gases in this aqueous suspension. Extra unused gases including the oxygen generated by the plant matter in the aqueous suspension may be removed by a piping system attached on top of the semi-rigid chamber covers via hollow screw pipes positioned at different locations along the length of PBRs. The chambers semi-rigid covers may be made of thin FPR material that can be rolled to reduce space during storage or transport.

In the preferred embodiment of the invention, each suspended PBR semi-rigid cover is provided with a rubber silicon sealing means mounted along the cover contour at selected locations. Covers longitudinal ends overlap each other to provide a sealing effect. Also, covers transversal ends (width) disclosed in this invention are configured to self-seal by wedging themselves in slots provided at chamber's edges. Additionally sealants may increase that effect to provide an air-tight arrangement.

In other embodiments of the invention, the cover back edge portion may roll back inside a chamber and rest over the chamber inclined base portion. In that case, the central portion of the cover assumes a natural curve that extends along the width of the panel to lean against the PBR chambers front edge forcing the semi-rigid cover to keep its bulge upwardly.

One of the advantages of having a cover portion that rolls inwardly over the deeper portion of the chamber is to enable the back edge to maintain a portion of the sparging flexible tube of the invention deep down under the aqueous suspension, preventing it to float. Another advantage is that the surrounding aqueous solution acts as a water seal. Yet another advantage is to enhance the circular motion of aqueous suspension caused by the sparger. Finally, the bulging of the cover encourages light penetration into the aqueous suspension. However, this arrangement presents some limitation as it allowing rain, snow or particulate such dust to accumulate over the cover.

In yet another embodiment of the invention, the semi-rigid cover takes on the shape of the natural curve stated before, with edges pressing via seals against the chamber back and front recessed edges to provide air-tight sealing. This arrangement also suffers from the same limitations presented earlier. However, given its simplicity and low-cost manufacturing method, it may be applied when low-cost becomes a primary concern.

The sparging rate within the thin inclined chambers is set at a suitable level to ensure that continual mixing of substantially all of the aqueous suspension is achieved and so that the biomass is exposed to light during sparging without unduly stressing the biomass.

Positioning rows of PBR along horizontal planes in a bank of suspended PBRs as taught by the present invention reduces the need for pumping aqueous solutions to a minimum. Also the level of pressure in the sparging tube is also minimal. These saving are primarily gained by the minimal height differential between the PBR entry point and its exit. This energy saving is essential for both a continuous production cycle and a batch production cycle.

It will be appreciated that the present invention may be used to produce biomass of various types and forms or products derived from the biomass. The term "biomass" as used herein includes all organisms capable of photosynthetic growth such as plant cells and microorganisms (including algae and euglena) in unicellular or multicellular form that are capable of growth in a liquid phase. The term may also include organisms modified artificially or by gene manipulation. The suspended bioreactors of the present invention are particularly suited for cultivation of algae or photosynthetic bacteria. For example, the suspended bioreactors may be used as photobioreactors for the production of algal biomass. In this respect, algae of various types (eg. Chlorella, Spirolina, Dunaliella etc), which have particular and diverse growth requirements may be cultivated in the suspended bioreactors.

The disclosed bank of suspended PBRs of the invention is suitable for use for both aerobic and anaerobic biomass production processes. Gases such as carbon dioxide or air may be used, for example for Spirulina and Chlorella production, while air/oxygen mixtures or oxygen alone may be employed for certain processes such as yeast growth. Anaerobic processes may be carried out, such as the cultivation of Rhodopseudomonas Palustris using as nutrient high BOD (biological oxygen demand) carbohydrate waste, a reaction which produces carbon dioxide. Alternative processes include the growth of Norcadia, Candida and other Pseudomonas organisms for degradation of hydrocarbons to carbon dioxide.

According to one embodiment of the invention, two independent rows of suspended PBRs or, two banks of suspended PBRs, may be joined in series, the first being used for an anaerobic reaction, such as the growth of Rhodopseudomonas Palustris or Acidophila which produces CO.sub.2, while the second bank of suspended PBRs utilizes the CO.sub.2 in the cultivation of CO.sub.2 - utilize, oxygen-producing algae such as Chlorella or Spirulina.

The suspended PBR chambers may be formed as two separate pieces of substantially transparent material such as fiber reinforced plastics (FRP); a first piece comprising an integral base portion with side walls and a second piece comprising of a cover means. All intersections of parts are preferably formed as rounded edges.

Each PBR may comprise one or more light conduction means to promote effective distribution of light in the bioreactor. Due to the advantageous inclined orientation of the PBR, a single or two lines of light conduction means, such as, but not limited to, an LED cord may be mounted within the bioreactor or preferably external to the bioreactor against the transparent side wall where the aqueous suspension accumulates the most. The sparging force within PBRs causes circulation of the aqueous suspension and thus brings the algal content intermittently in close proximity to the light source and then away from it.

Positioning a jacketing means over the gothic-shape trusses to cover a bank of suspended PBR with a transparent material, as done for greenhouses, insulates the bank of PBRs against undesirable weather conditions. This enables to externally heat or cool the entire bank of PBRs. Preferably the jacketing means seals the entire bank. For example the jacketing means may comprise a transparent flexible polyethylene or polyvinyl chloride film. Hot or cold air can be circulated in-between the external surfaces of each of the chambers in the bank of suspended PBRs by one or more pump means inside the jacketing means.

In one embodiment of the invention, chambers are provided with a low-cost temperature control system by circulating a fluid in a parallel compartment positioned under the chambers base portion. This is achieved by adding a parallel transparent wall under the chamber base portion.

It is known that to complete a full biomass production cycle, it is useful that the suspended bioreactors in a bank may be brought in fluid communication with a separate container, acting either as a dark phase area, as a settling system or simply as a reservoir.

Like in any turn-key system, a bank of suspended PBR may be used on a batch production cycle basis wherein a single culture of biomass can be grown in any one or all of the PBR chambers at any one time, or using all rows in the bank to complete a continuous production cycle with a steady feed of essential nutrients and of aqueous suspension into the PBR system and continuously discharging the aqueous suspension that contains the cultured biomass from the PBR system.

In a large commercial production, banks of suspended PBRs are preferably operated in a continuous production manner and new nutrients are continuously fed into the PBR chambers with biomass continuously discharged. In such systems, banks of suspended PBRs may be connected to other banks in series with different banks providing a continuous feed of new reactants. In this manner, a continuous flow of reacting materials may flow from one bank to the next. The resulting cultured biomass may then be continuously discharged from the last of the series PBR banks.

Another manner to prevent settling of the biomass during the algal propagation phase is to provide a gentle rocking motion to all chambers in an entire bank of PBRs. Because PBR chambers of the invention are suspended on one side and because the weight of PBR chambers on one side of the bank can be counter-balanced with the weight of chambers on the other side, a low energy-consuming drive means can be used to provide a rocking motion to virtually agitate the entire bank. This can be achieved by generating a slight back-and-forth tilt motion on an elongate shaft rotating a series of slightly-offset idlers that support symmetrically positioned suspension cables that support the PBR chambers which contain relatively small amount of aqueous solution. The amount of energy needed to create such a gentle rocking motion that replicates the movement of waves is minimal. This energy needed requires only to offset the rotational resistance of a rotating shaft rotating slightly offset ball-bearings that carry the lower weight portion of the inclined PBR chambers.

It is also an objective of this invention to provide a bioreactor system that also acts as a roofing tile for building structures such as greenhouses, warehouses and roofed structures of the like. Growing food in a greenhouse which roof is configured to farm micro-algae is very cost-effective and environmentally sustainable. In such double-function buildings, some clear space between the aqueous suspension needs to be provided to guarantee that enough sunlight penetrates the greenhouse. Such an action, in turn, is of benefit to algae farmers who use the disclosed transparent PBRs of the invention. Any light source from either inside or outside the greenhouse is beneficial.

The present invention will now be described in more detail by way of example with reference to the accompanying drawings wherein:

FIG. 1 is a perspective view of a prior art deep prism shape bioreactor.

FIG. 2 is a side cross sectional view of a preferred asymmetrical bioreactor chamber

FIG. 3 is a side cross sectional view of a preferred symmetrical bioreactor;

FIG. 4 is a side cross sectional view of an asymmetrical bioreactor with an inner cover;

FIG 5 is a perspective view of FIG. 4

FIG. 6 is a side cross sectional view of a symmetrical bioreactor with an inner cover;

FIG. 7 is a simplified side view of a bank of suspended bioreactors

FIG. 8 is a perspective view of a bank of suspended bioreactors in accordance with a preferred embodiment of the invention

FIG. 9 is a perspective view of a bank of suspended bioreactor chambers covered by a jacket

FIG. 10, 100 and 300 is a side view of a combination greenhouse, roof-type bioreactor and suspended pond without showing trusses

FIG. 11 is a cross sectional view of a roof-type bioreactor

FIG. 12 is detail view of FIG. 11

The bank of suspended bioreactors as shown in FIGS. 7, 8 and 9 and generally indicated by the numeral 100 and 300 comprises a collection of individual transparent bioreactors 10 suspended by suspension means 30 to generally arcuate trusses 50 and preferably of gothic shape, maximizing elevation and minimizing overall footprint.

As shown in FIGS. 2, 3, 4, 5 and 6 each bioreactor 10, 100 and 300 comprises of a chamber 24 defined by an elongate generally flat base portion 22 flanked between integral side walls 11 and 13 that extend upwardly. Chamber 24 is configured to contain an aqueous suspension of biomass and is covered by a semi-rigid cover 14 configured to arch or bulge when mounted in position and forced to lean or wedge against side walls 11 and 13 to create an air-tight fit.

Bioreactor 10 also comprises a sparging means 20 for creating turbulence in the aqueous suspension to ensure continual mixing and prevent settling of the biomass within chamber 24.

In the preferred embodiment of the invention, chamber 24 is intentionally inclined in one direction so that the sparging tube 20 may be always covered by a layer of aqueous suspension despite the repulsion effect caused by the exiting gases from the sparging tube 20. Such effects force the aqueous suspension to adopt a circular motion that enhances gas absorption, creates continuous agitation of the aqueous suspension which in turn ensures continual mixing to prevent settling of the biomass within chambers and more importantly exposes, at least intermittently, the biomass within the aqueous suspension to be exposed to a light source such as sunlight or to artificial light 16 preferably mounted within the chamber 24 as shown in FIGS. 4 and 5.

To illustrate the reason for bioreactor 10 to adopt an asymmetrical shape as shown in FIGS. 2, 4 and 5, an example is given. For example, a symmetrical container with equal 30 mm high sidewalls when inclined may hold a liquid around 30 mm deep. Whereas, an asymmetrical container having one sidewall of 60 mm high and the other of 0 mm high, when inclined will hold a liquid around 60 mm deep.

Said example illustrates well how more wetted surface area and volume may be exposed to light by adopting a bioreactor 10 that has an inclined base portion 22 and an associated sparger 20 that continuously spreads the aqueous volume over more surface area, like waves washing a shore. Inclination of the base portion 22 of chambers 24 may be achieved by either inclining a symmetrical bioreactor 10 such as shown in FIG. 3 and 6, or preferably by adopting an inclined base portion 22 as shown in FIGS. 2, 4 and 5.

As revealed by the numerous studies made by researchers such as Mario Tredici, Dimanshteyn and Fraunhofer that were quoted earlier, it is essential that bioreactors 10 maximize their exposed surface area relative to their volume. These studies also imply that an enormous amount of water is being displaced for achieving very little results. Similarly, questions regarding land usage, bioreactors footprint, water consumption and amounts of energy used for each bioreactor system must be addressed.

Therefore, like thin leaves, bioreactors 10 of the present invention are provided with large surface areas and shallow profiles, ranging in average between 20mm to 30 mm thick. When using inclined bioreactor chambers 10 of the invention, this average height remains the same when averaging an inclination that varies between 60 mm deep to 0 mm shallow. Adopting thinner bioreactors 10 also means displacing less water, using lees artificial light when needed, less land, less maintenance and less operation costs per volume of biomass produced and therefore achieving a more efficient system.

To further mimic nature, the invention discloses multiple bioreactors 10 that are suspended in strategic positions, like leaves suspended in a tree. While conical shapes come in mind, for commercial applications, only gothic shape trusses 50 withstand loads without additional need of bracing. Gothic trusses 50 minimize costs and when combined with thin bioreactors 10, 100 and 300 to meet all criteria discussed above. Gothic structures have been erected for thousands of years and have been proven to be the most cost-effective structures in every sense. Such stable structures 50 as the disclosed by the invention are able to be elevated in sufficient heights as to reduce land usage and support 2.5 to 4 square meter of bioreactor surface on 1 square meter of land; this solution further includes all the pumping and operating systems that may be lodged under banks of suspended PBRs 100 and 300.

In addition to the benefits indicated above, when combining pond bioreactors 10 to roof–type bioreactors 200, a greenhouse 300 (FIG. 10) takes place under which food can be grown.

Because forces are oriented towards the center of gravity of the system, the system is inherently stable and able to withstand strong winds and other weather conditions.

As shown in FIGS. 7, 8, 9 and 10 in the bank of the suspended bioreactors 100 and 300, bioreactors 10 are suspended to cables 30 and therefore can be collectively moved by moving those cables 30 to adopt a slight rocking motion that generates waves, a very similar movement found in oceans. To achieve this, a low energy-consuming drive means (not shown) may be used to provide a rocking motion. This can be achieved by rotating an elongate shaft 34 rotating slightly-offset pulleys or idlers 32 that support symmetrically positioned suspension cables 30 that in turn support chambers 10. The amount of energy needed to create a gentle rocking motion that replicates the movement of waves is minimal. This energy needs only to offset the rotational resistance of a slowly rotating shaft 34 that rotates slightly offset ball-bearings that carry a medium weight.

The sparging means 20 of the invention may be made of a conventional semi-rigid PVC pipe or preferably by a flexible flat tube 20 that can be pierced rapidly and cost-effectively by the needle of a sewing machine (without threading).

As shown in FIGS. 4, 5, 11 and 12, this invention also discloses a low-cost temperature control system provided by circulating a fluid in a parallel compartment created under chamber 10 base portion, in between the two bottom surfaces 22 and 26. As shown in detail A illustrated in FIG. 12, base portion wall 22 is configured with two undulated steps, a first landing step for receiving a flat span of transparent sheet 26 that creates a space between surfaces 22 and 26 for circulating a hot or cold fluid. Again, base portion 22 ondulates to form another flat portion as shown in FIGS. 11 and 12 when the cover 14 is intended to be sealed with a rigid outer sheet 60; or alternately, base portion 22 continues to define sidewalls 11 and 13 as shown in FIGS. 2, 3, 4, 5 and 6 when the cover 14 is removable and semi-rigid and is intended to be positioned inside the chamber.

It will be appreciated that there will be further variations which will be apparent to those skilled in the art from the teaching of the above, such variations are deemed to be within the scope of the invention herein disclosed.

I claim:

1. Suspended bioreactors for biomass production comprising:
(a) a bank of substantially transparent elongate rows of chambers, each chamber being at least suitable for containing an aqueous suspension of biomass and media, and having a substantially flat base portion flanked between two side walls and a cover portion;

(b) a repeating pattern of generally gothic-shape trusses positioned at equal interval locations, said trusses for supporting said chambers by suspension means at locations best exposing chambers to a light source; and

(c) a sparging means for creating turbulence in the aqueous suspension to ensure continual mixing and prevent settling of the biomass within chambers.

2. Suspended bioreactors according to claim 1 wherein said suspended chambers are inclined, said inclination provided by inclining entire chambers or by providing an inclined base portion to each chamber, said inclination being adjustable.

3. Suspended bioreactors according to claim 1 wherein said suspended chambers are moved by a rocking motion.

4. Suspended bioreactors according to claim 1 wherein said cover portion is removable.

5. Suspended bioreactors according to claim 1 wherein said chamber flat portion is lined with a thin transparent disposable plastic film or a thin plastic bag that integrates a sparging means; therby avoiding the need for cleaning chambers.

6. Suspended bioreactors according to claim 1 wherein said sparging means is a conduit placed at the lowest position within chambers and extending through the length of the chambers, the conduit being perforated and connected to a gas source such that in operation the passage of gas out of the conduit and into the chamber causes turbulence of the chamber contents.

7. Suspended bioreactors according to claim 1 wherein said sparging means is a flat flexible tube pierced with holes by a machine such as, but not limited to, a sewing machine.

8. Suspended bioreactors according to claim 1 wherein said chambers further include a low-cost temperature control system provided by circulating a fluid in a parallel compartment created under said chambers base portion.

9. Suspended bioreactors according to claim 1 further including one or more light conduction means which promote effective distribution of light within chambers.

10. Suspended bioreactors according to claim 1 wherein aqueous suspension contents of multiple bioreactor chambers come into fluid communication with

a separate container through which the aqueous suspension is diverted prior to its return to same or dissimilar suspended bioreactors.

11. Suspended bioreactors according to claim 1, wherein said cover means is sealed to sidewalls.

12. Suspended bioreactors according to claim 1, wherein the cover means is removable and is of an gothic shape.

13. Suspended bioreactors according to claim 12, wherein the middle portion of the cover means is elevated relative to the junction between the cover means and the side walls for enabling gas to be vented from the chamber.

14. Suspended bioreactors according to claim 1, wherein jacketing gothic trusses with an outer cover creates a greenhouse.

15. Suspended bioreactors for biomass production comprising:

(a) multiple substantially transparent elongate rows of arcuate chambers, each chamber being at least suitable for containing biomass in a liquid phase, and having a transparent arcuate base portion flanked between two side walls and a transparent arcuate sealed cover portion;

(b) a repeating pattern of generally gothic-shape trusses positioned at interval locations, said trusses outer contour for supporting said chambers to expose them to a light source;

(c) a sparging means for creating turbulence in the aqueous suspension to ensure continual mixing and prevent settling of the biomass within the chambers;

said transparent cover portions and associated chambers collectively defining an external roof cover for a greenhouse.

16. Suspended bioreactors according to claims 1 and 15, wherein biomass in a aqueous
suspension contained in rows of external roof-type bioreactors enter in fluid communication with biomass in suspended bioreactors chambers to enhance biomass production.

17. Suspended bioreactors according to claim 1, wherein the ground over which bioreactors are suspended is covered by a reflective material such as paint, aluminum foil, reflective minerals and reflective materials of the like.

Application number / numéro de demande: 2755419

Figures: 3, 4, 5, 8, 9

Pages:

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Documents reçu avec cette demande ne pouvant être balayés
(Commander les documents originaux dans la section de préparation des dossiers au 10ème étage)

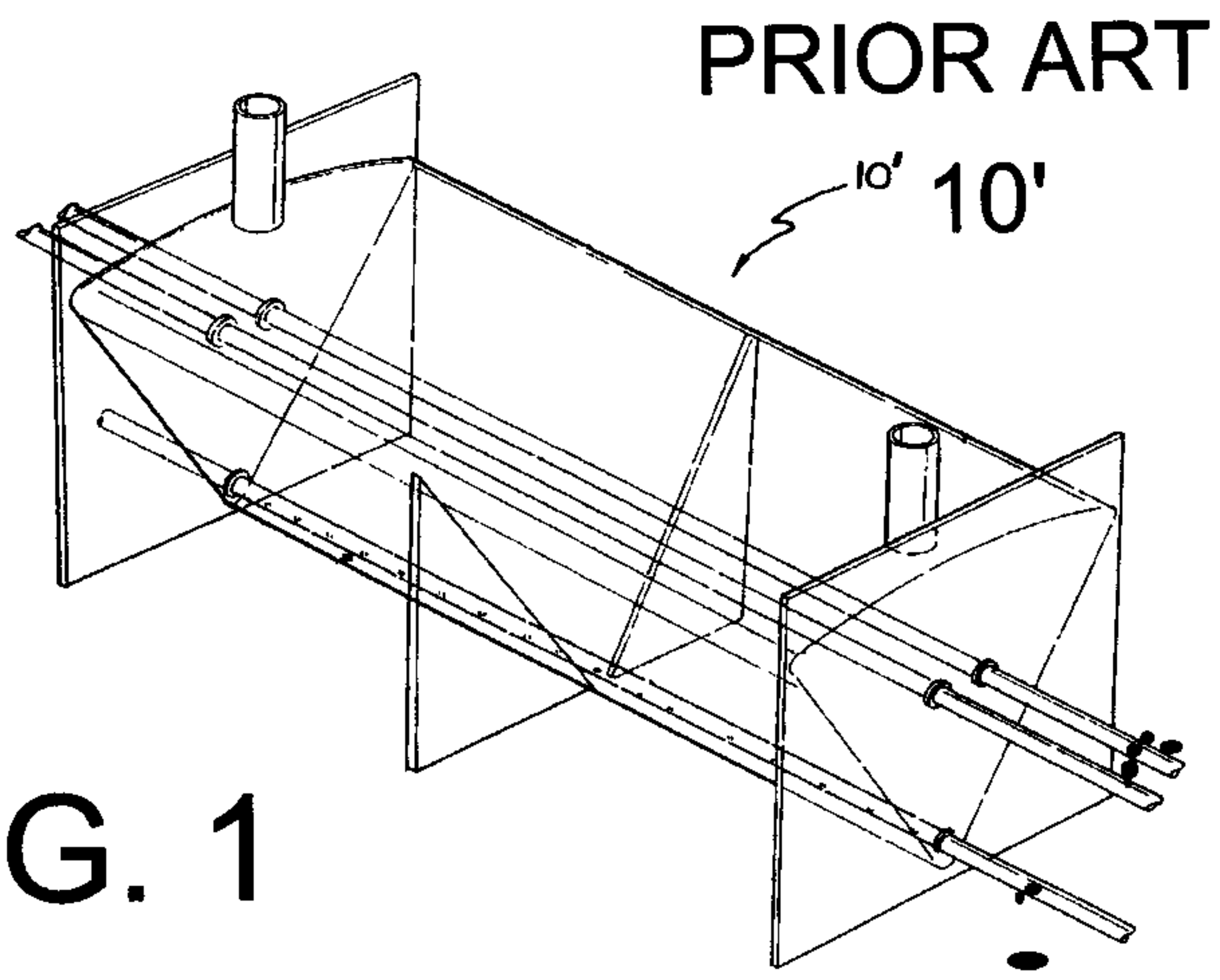


FIG. 1

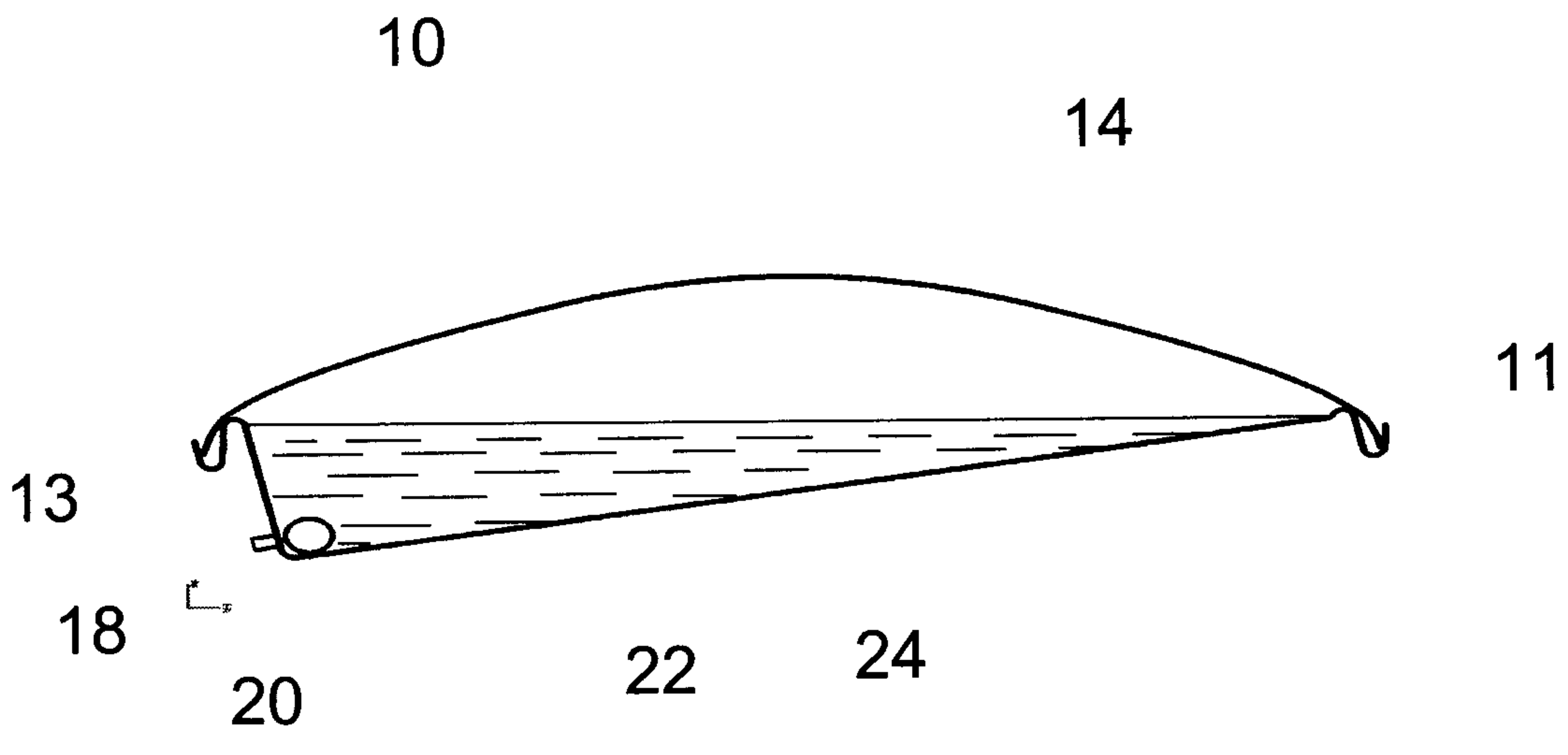
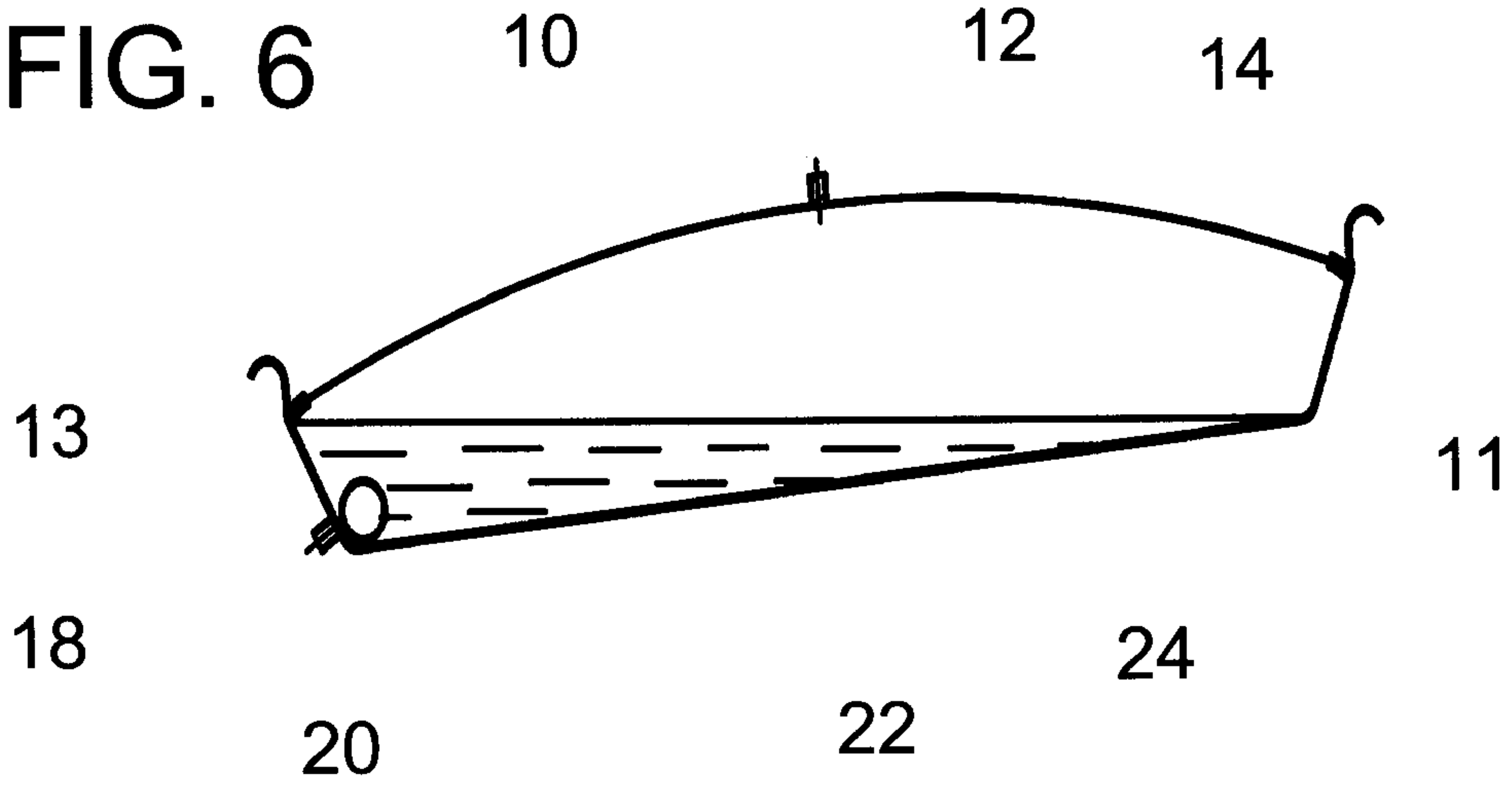


FIG. 2

FIG. 6



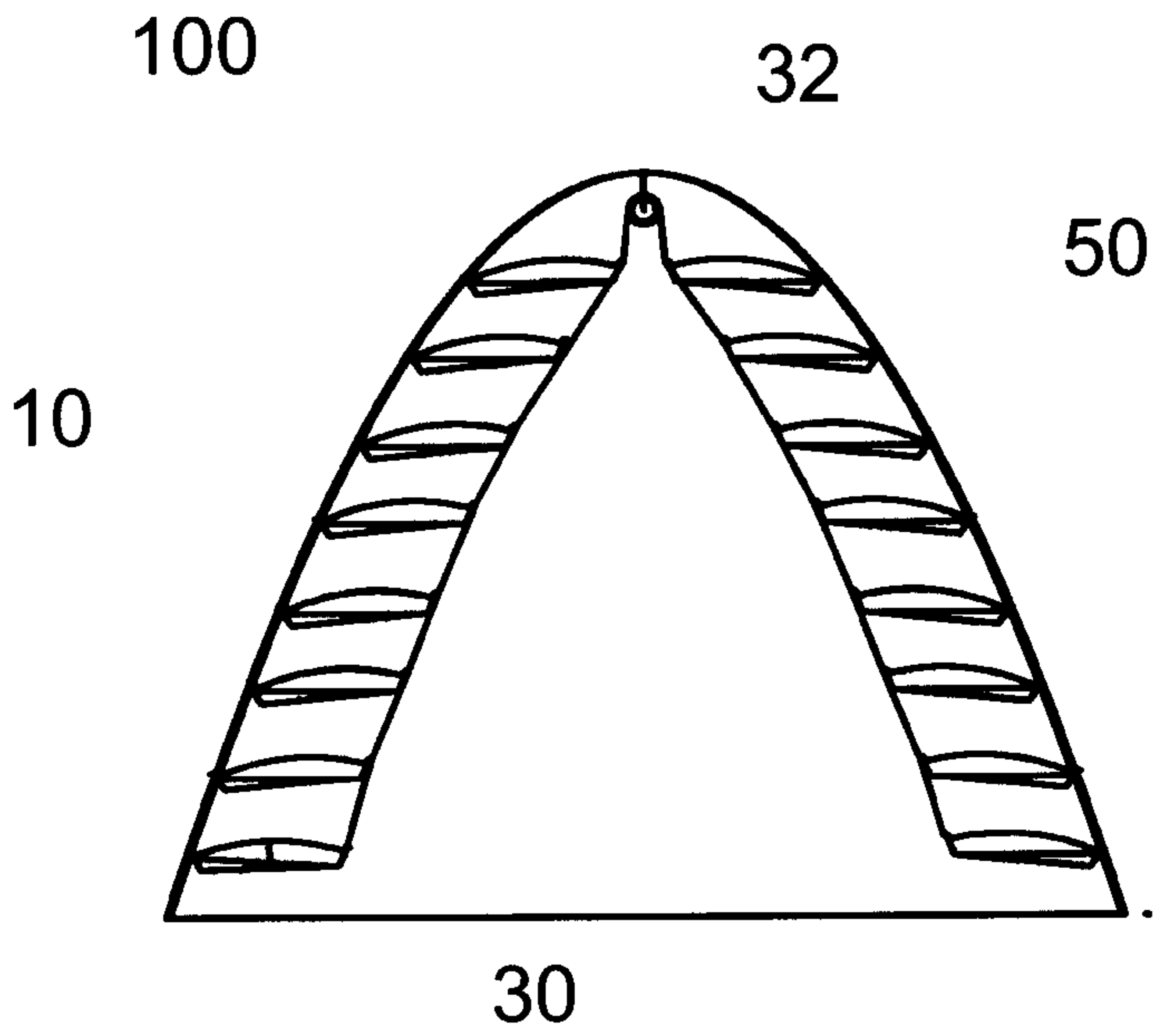
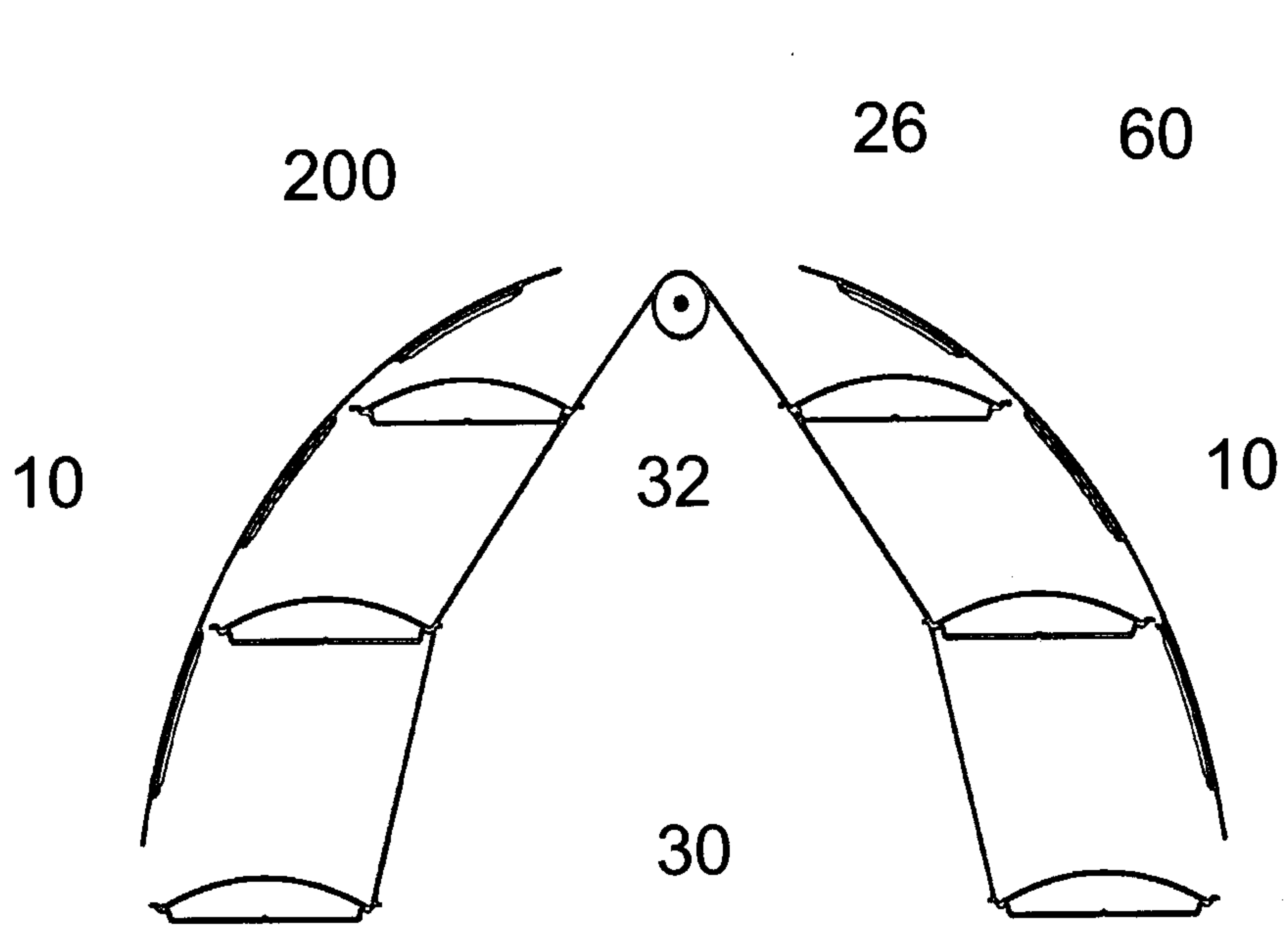


FIG. 7

FIG. 8



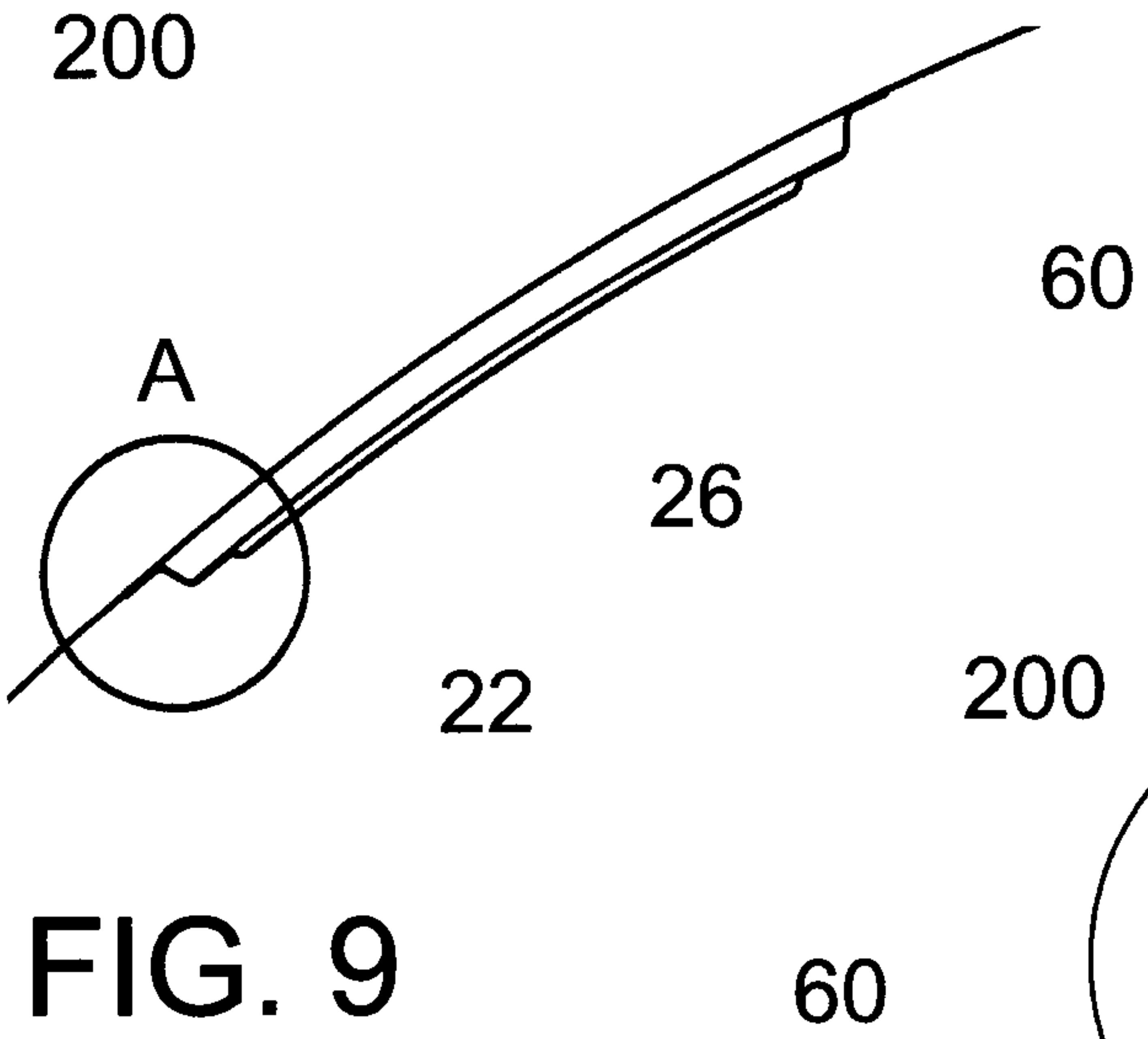


FIG. 9

FIG. 10