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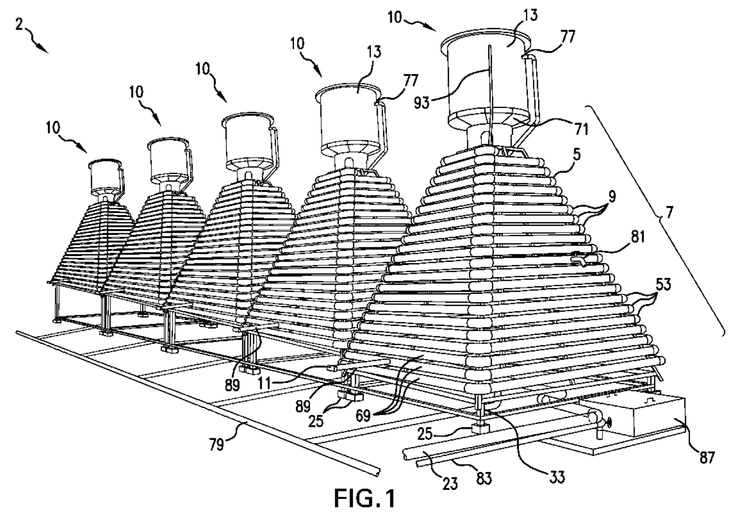

FIG.1

(57) Abstract: A gravity flow photobioreactor core (10) comprised of a support means (3); a tube (5) that continuously runs and curls with declination about a vertical axis to form a stack (7) of levels (9) and having an inlet sparge (11); a gas exchange tank (13) and a central feed pipe (15) with a sparge (17). A gravity flow photobioreactor farm comprised of a bottom tank (19); a pump (21); a plurality of bioreactor cores (10) connected in series at decreasing elevations and a return pipe (23).

WO 2011/022349 A1

GRAVITY FLOW TUBULAR PHOTOBIOREACTOR AND PHOTOBIOREACTOR FARM

CROSS-REFERENCE TO RELATED APPLICATIONS

[Para 1] This application claims priority from U.S. Provisional Application Ser. No. 61/274,449, filed on August 17, 2009. The entirety of that provisional application is incorporated herein by reference.

TECHNICAL FIELD

[Para 2] This invention pertains generally to bioreactors and more particularly to tubular-type photobioreactors.

BACKGROUND ART

[Para 3] The world has entered an era of climate shifts for which there is evidence that this attributable to carbon dioxide from the burning of fossil fuels. Concomitantly, the world-wide supply of fossil fuels is being exhausted. In addition, nitrogen oxides ($NO_{x)}$ are being admitted into the air at levels for which there is evidence that this is causing health abnormalities and shortening life spans. This in turn is imposing a financial burden on the healthcare and insurance system.

[Para 1] Governments around the world are responding by regulations that limit the emission of carbon dioxide and nitrogen oxide and/or by imposing financial penalties on the emission of carbon dioxide and nitrogen oxide. Socially conscious activists and governments are promoting environmentally friendly technology that is going by the colloquial phrase “green technology,” including photobioreactors.

[Para 2] Australian patent publication number 2006100045 is known in the art of photobioreactors. This patent publication relates to a photobioreactor for the cultivation and harvesting of a blue-green algae solution. The photobioreactor design of the invention consists of the following components. A vertical coil of transparent or semi-transparent tubing joined at top and bottom via a tube or tank so as to provide a system through which a solution of blue-green algae, water, nutrients and gas can circulate. The coil may be made into shape other than a cylinder, such as a cone, oval cylinder, cuboid, tetrahedron, pyramid or a flat horizontal coil shape. A tap at the base of the photobioreactor to allow the solution to be drained off and harvested or cleaning of the photobioreactor. A gas inlet (11) into the tubing, connected at the base of the coil, above the tap so that gas rises up through the solution in the tubular coil, causing it to circulate. A gas outlet at the uppermost point of the photobioreactor. This invention has the disadvantage of being inefficient, building up oxygen that retards algae growth, not having a significant sequestration capability and not teaching a multireactor system that is mechanically simple and energy efficient.

[Para 3] Japanese patent publication number 9121835 is also known in the art. This patent publication provides a tubular-type photobioreactor designed with a light transmissive tube installed spirally and spacedly on the side of a conical body to effect greater light receiving area despite small installation area. The photobioreactor is designed to culture for example fine algae. This invention has the disadvantage building up oxygen that retards algae growth, not having a significant sequestration capability and not teaching a multireactor system that is mechanically simple and energy efficient.

[Para 4] World Intellectual Property Organization patent publication WO 9928018 (A1) relates to a method and device for reducing the concentration of ingredients in a gas and in a liquid. According to the inventive method, the liquid is first guided through a washing unit. A gas containing ingredients is guided into the washing unit and comes in contact with the liquid in the washing unit such that the liquid absorbs ingredients in an optionally converted form from the gas. Afterwards, the gas whose ingredients have been reduced is removed from the washing unit. The liquid enriched with ingredients is at least partially guided from the washing unit to a conversion device containing microalgae in which the ingredients are at least partially absorbed by the migroalgae by means of photosynthetic activation, and the microalgae are at least partially separated from the liquid after they have absorbed ingredients. This invention has the disadvantage utilizing a prewashing unit, not having a significant sequestration capability and not teaching a multireactor system that is mechanically simple and energy efficient..

[Para 5] Accordingly, there exists a need for a bioreactor with enhanced oxygen exchange that does not employ sprayers, is mechanically simple and energy efficient.

[Para 6] There is a need for a bioreactor that significantly sequesters carbon dioxide.

[Para 7] There is a need for a bioreactor that significantly sequesters nitrogen oxides.

[Para 8] There is a need for a bioreactor that quickly produces significant quantities of algae or other microorganism that is usable as a feedstock for the production of biofuel and biomass.

[Para 9] There is a need for a multi-bioreactor system that does not require a pre-washing unit.

[Para 10] There is a need for a multi-bioreactor system that moves material in a manner that is mechanically simple and energy efficient.

[Para 11] The present invention satisfies these needs, as well as others, and generally overcomes the presently known deficiencies in the art.

SUMMARRY OF THE INVENTION

[Para 12] The present invention is directed to, inter alia, a bioreactor for growing a microorganism (especially algae,) a series of bioreactor cores that are joined together in a farm, a method for the sequestration of carbon dioxide, a method for the sequestration of nitrogen oxides, a method for the collection of oxygen and method for the production of a biofuel feedstock.

[Para 13] An object of the present invention is a bioreactor with enhanced oxygen exchange that does not employ a sprayer, is mechanically simple and energy efficient.

[Para 14] Another object of the present invention is a bioreactor and muti-bioreactor system that significantly sequesters carbon dioxide.

[Para 15] Another object of the present invention is a bioreactor and muti-bioreactor system that significantly sequesters nitrogen oxides.

[Para 16] Another object of the present invention is a muti-bioreactor system that does not require a pre-washing unit.

[Para 17] Another object of the present invention is a bioreactor and muti-bioreactor system that moves material in a manner that is mechanically simple and energy efficient.

[Para 18] Another object of the present invention is a muti-bioreactor system that employs gravity to move material/slurry so as to reduce the utilization of pumps, motors and compressed air to do the same. Concomitant objects of the invention are a bioreactor and a multi-bioreactor system that consumes less energy, is less expensive and less subject to breaking with the incursion of downtime and repair cost.

[Para 19] Another object of the present invention is to collect diatomic oxygen for use in aiding combustion.

[Para 20] Another object of the present invention is to produce a feedstock for biofuel and biomass.

[Para 21] One aspect present invention is a bioreactor. The bioreactor has a support means having vertical height. Mounted to this support means is a tube that at a minimum partially pass light through itself. This tube starts at an upper position, continuously runs and curls with declination about a vertical axis to form a stack of levels. Each level encompassing about 360 degrees around the vertical axis. The radial distance between the tube and the vertical axis indexes within the stack so as to enhance the tube's exposure to light emanating from above the stack relative to the tube being vertically aligned at a constant radial distance from the axis within the stack. The tube ends in lower position. There is a sparge for introducing a froth of gas, usually carbon dioxide and/or nitrogen oxides, into the tube. Above the tube and mounted to the support means is a gas exchange tank. This tank empties by gravity into the upper end of the tube. This gas exchange tank has a slurry entry inlet and an outlet for the elimination of gas.

[Para 22] There is a bottom tank that is reservoir for a microorganism, for example algae, nutrients and water. A pump is connected to the bottom tank and to a central feed pipe. The central feed pipe runs from the pump to the slurry entry inlet of the gas exchange tank. The central feed pipe has a sparge for introducing a froth of gas into the central feed pipe. There is a return pipe that runs from the lower end of the tube to the bottom tank. The bioreactor is a closed system where the entry and release of fluid and gas is controlled.

[Para 23] Another aspect of the present invention is a support means for the bioreactor as just described. The support means has an upper frame; a lower frame and vertical supports that run from the lower frame to the upper frame. A plurality of cables depend from the upper frame and attach to the tube so as to support the tube in the stack. There is a column onto which is mounted the gas exchange tank in a position generally above the stack.

[Para 24] Another aspect of the present invention is a bioreactor farm comprised of a successive series of bioreactor cores on a surface. There is a first bioreactor core along the lines of that which was just described. There is a bottom tank. and a pump where the inlet side of the pump is in fluid communication with the bottom tank. The outlet side of the pump is in fluid communication with the central feed pipe of the first bioreactor core. There is a subseries of bioreactor cores where the lower opening of the tube of preceding bioreactor core is in fluid communication with the central feed pipe of succeeding bioreactor core. These bioreactor cores rest on the surface such that succeeding bioreactor cores decrease in elevation relative to the preceding bioreactor core. Accordingly, the fluid fill level of a gas exchange tank in a succeeding bioreactor core is generally lower than the bottom of the gas exchange tank of a preceding bioreactor. There is a final bioreactor core. A return pipe runs from the lower opening of the tube of the final bioreactor to the bottom tank. The bioreactor farm is a closed system where the entry and release of fluid and gas is controlled.

[Para 25] Another aspect of the present invention is method for sequestration of carbon dioxide. The method is comprised of steps. The steps are to provide a bioreactor farm as just described; introduce into the bioreactor cores of the farm a mixture of a microorganism that metabolizes carbon dioxide, nutrients and water; introduce carbon dioxide into the sparge for introducing a gas in communication with the tube of at least one bioreactor core and actuation of the pump (21).

[Para 26] Another aspect of the present invention is method for sequestration of nitrogen oxides. The method is comprised of steps. The steps are to provide a bioreactor farm as just described; introduce into the bioreactor cores of the farm a mixture of a microorganism that metabolizes nitrogen oxides, nutrients and water; introduce nitrogen oxides into the sparge for introducing a gas in communication with the tube of at least one bioreactor core and actuation of the pump (21).

[Para 27] The previously described versions of the present invention has many advantages which include low energy consumption, durability arising from utilization of gravity to move material, a high removal of oxygen which impedes the growth of algae, fast and abundant algae growth, the sequestration of nitrogen oxides, the sequestration of carbon dioxide and the production of a feedstock for biofuel.

BRIEF DESCRIPTION OF THE DRAWINGS

[Para 28] These and other features, aspects and advantages of the present invention will become better understood with reference to the following description, appended claims and accompanying drawings where:

[Para 29] Fig. 1 is a perspective view of a bioreactor farm according to the present invention;

[Para 30] Fig. 2 is a perspective view of a bioreactor according to the present invention;

[Para 31] Fig. 3 is a perspective view of a gas exchange tank (13) and center feed pipe according to the present invention;

[Para 32] Fig. 4 is a side plan view of a support means for a bioreactor according to the present invention;

[Para 33] Fig. 5 is an enlarged view of a diagonal support and arms of the support means of Fig. 4;

[Para 34] Fig. 6 is a diagrammatic view of a bioreactor according to the present invention;

[Para 35] Fig. 7 is a perspective view of a support means for a plurality of bioreactors in a farm according to the present invention;

[Para 36] Fig. 8 is a top plan view of a cage of the support means of Fig. 7;

[Para 37] Fig. 9 is a perspective view of a column and gas exchange tank engaging an upper support of the support means of Fig. 7;

[Para 38] Fig. 10 is a perspective view of a column and gas exchange tank (13), along with vertical support ribs, engaging an upper support of the support means of Fig. 7;

[Para 39] Fig. 11A is a perspective view of a gas elimination outlet and manifold in connection with a gas exchange tank and Fig. 11B is a perspective view of a center feed pipe in connection with a gas exchange tank and

[Para 40] Fig. 12 is a diagrammatic view of a bioreactor farm according to the present invention.

DESCRIPTION OF EMBODIMENTS

[Para 41] The present invention is described more fully in the following disclosure. In this disclosure, there is a discussion of embodiments of the invention and references to the accompanying drawings in which embodiments of the invention are shown. These specific embodiments are provided so that this invention will be understood by those skilled in the art. This invention is not limited to the specific embodiments set forth herein below and in the drawings. The invention is embodied in many different forms and should be construed as such with reference to the appended claims.

[Para 42] The invention pertains, inter alia, to a bioreactor for growing a microorganism, especially algae, a bioreactor farm of joined bioreactor cores (10), a method for the sequestration of carbon dioxide, a method for the sequestration of nitrogen oxides, a method for the collection of oxygen and method for the production of a biofuel feedstock.

[Para 43] Referring to Fig. 2, in general terms and for an overview, the major components and assemblies of a bioreactor (1) are a support means (3); a tube (5) that continuously runs and curls with declination about a vertical axis to form a stack (7) of levels (9) and has a inlet/sparge (11) for an effluent; a gas exchange tank (13); a central feed pipe (15) which optionally has a sparge (17); a settling tank (19); a pump (21) and a return pipe (23). In the discussion that follows, each of these major components and assemblies is discussed, along with other structures and components in the embodiments of this invention. Thereafter, there is a discussion on the methods and the use of the invention.

[Para 44] Referring to Figs. 4 and 7, the support means (3) is characterized by having vertical height. The vertical height of the support means (3) is usually up to about 25 feet. The support means (3) provides support, inter alia, for the tube (5) and for a gas exchange tank (13). The support means (3) in turn rests and/or is supported by a base means (25) (discussed below) which interfaces with a surface. The support means (3) is preferably an open air-like structure without panels and walls such that light can substantially pass through it. This facilitates the tube (5) being exposed to light from all directions and loosely referred to as 360° exposure.

[Para 45] One structure for the support means (3) is a Christmas tree-like structure (not illustrated.) This structure has a central support column, typically made of metal, around which numerous branches are attached in layers. The numerous branches circle the column in layers with the shortest branches being on top and the longest branches being on the bottom. The structure is that of a large cone or a Christmas tree. This structure can be set in a square or rectangular base to keep the support steady.

[Para 46] Referring to Figs. 2 and 4, another structure for the support means (3) is a truncated pyramid or truncated tetrahedron like structure. This structure is comprised of a lower square-like frame (27) having vertices and an upper square-like frame (29) having vertices (31). The upper square-like frame 29 is smaller than the lower square-like frame (29). The term "square-like" implies that frame approximates a parallelogram and need not have precisely four sides, straight sides, equal length sides and/or 90 degree angles. The suffix "-like" as used herein has this meaning of generally approximating a shape. The upper square-like frame (29) and lower square-like frame (27) are approximately centered on a vertical axis. There are four main diagonal support members (33) that are each attached to vertices (31) of the upper square-like frame (29) and the lower square-like frame (27) so as to form a configuration that has a truncated pyramid-like shape. Optionally, there can be intermediate diagonal support members (35) that are each attached the upper square-like frame (29) and lower square-like frame (27); vertical support members (37) that run from a base means (25) (discussed below) or surface to a main diagonal support member (33) and horizontal support members (39). The support members (33, 35, 37 and 39) can be angle iron, steel I-beam, metal bars, pipes or greenhouse frame and can be welded together and/or joined with brackets and screws.

[Para 47] Referring to Figs. 4 and 5, there is a flat bar strip (41) mounted along the main diagonals with a plurality of bends that bend back on themselves to form shelves for supporting the tube (5) in the levels (9) of the stack (7). Preferably, the shelves are on an angle so that the tube (5) can be straddled between the shelve and the main diagonal support (33).

[Para 48] Referring to Fig. 7, another physical structure, and a most preferred physical structure is a comprised of a upper frame (43), typically a square or a rectangle, that encompasses a bioreactor (1) or a series of bioreactor cores (10) in a bioreactor farm (2) (discussed below.) The shape is not critical and other shapes can be deployed. Optionally, there is a lower frame (45) complimentary to the upper frame (43). There are vertical supports (47) that run from lower frame (45) or base means (25) to the upper frame (43) to support the upper frame (43) at a position above the tube (5).

[Para 49] Continuing to refer to Fig. 7, there is plurality of cables (49) that drop or depend from the upper frame (43) to support the tube (5). Thus, this structure provides "top support" for the tube (5). Referring to Figs. 9 and 10, there is a column (51) to support a a gas exchange tank (13). This column is typically positioned in the center of the bioreactor (1) or bioreactor core (10). Where the bioreactor (1) or bioreactor core (10) is a pyramid-like in shape, the column (51) is in the center of the pyramid. The column (51) is sufficiently strong to support a gas exchange tank (13) having a weight of 8,000 pounds. There may be depending cables (49) from the upper frame (43) to gas exchange tank (13) to stabilize the gas exchange tank (13). Notwithstanding, the weight of the a gas exchange tank (13) is borne by the columns (51) and is off the upper frame (43). There may be a plate extending between the column (51) and the tube (5) to stabilize the tube (5).

[Para 50] Referring to Figs. 7 and 9, the column (51) and frames (43 and 45) are typically made from I-beams or greenhouse frame which are welded and/or joined with brackets and screws. The cables (49) are typically steel cable. There can be precision drilled holes in the I-beams by which to fasten precisely measured cables that drop down to attach to stainless bands around each elbow (53) (discussed below.) The stainless steel bands have eyes hook for attaching to the cables. In this structure there is no need for an underneath support structure for the pipes (discussed below.) Referring to Fig. 10, 1i a preferred embodiment, there are vertical ribs (55) that extend from the column (51) to support the upper frame (43). This reduces the strength of the material and construction required for the upper frame (43).

[Para 51] Referring to Figs. 8 and 9, in a more preferred embodiment, there is a cage (55) that is capable of receiving the gas exchange tank (13) that extends between the column (51) and the upper frame (43) so as to provide vertical support to the upper frame (43). The cage (55) is comprised of vertical support members (59), horizontal support members (63); which can be on diagonal with respect to the upper frame (43) and a circular inset

(61). The horizontal support members (63) run from the upper frame (43) to the circular inset (61). The vertical support members (59) run from the column (51) and the circular inset (61). More preferably, cables (49) depend from the horizontal support members (63) which are on diagonal and positioned above the elbow tubes of a truncated pyramid shaped tube (5).

[Para 52] Referring to Figs.1 and 2, the base means (25) is the ground, a surface, a slab, a plurality of pads or a plurality of pylons.

[Para 53] Referring to Figs. 2 and 6, the tube (5) is an elongated conduit having a upper opening (65) and lower opening (67). At a minimum, the tube (5) partially passes light there through. More preferably, the tube (5) is substantially transparent and most preferably, it is transparent. The tube (5) has flexible or rigid walls and preferably the tube (5) is annular and with rigid walls. The internal diameter of the tube (5) ranges from about one inch to about twelve inches. Preferably, the tube (5) has an internal diameter between about 3 inches to about 5 inches. Most preferably, the internal diameter of the tube (5) is about 4 inches. The wall thickness is sufficiently great to withstand the pressure of the system's fluid contents. The material of the tube (5) is non-toxic to microorganisms, especially algae. Preferred materials are transparent plastics. More preferred materials are polyvinyl chloride (PVC), acrylic and polycarbonate. A most preferred material is polycarbonate.

[Para 54] Continuing to referring to Figs. 2 and 6, the tube (5) spirals, curls and bends with declination around a vertical axis to form a stack (7) of levels (9). At about a minimum, the declination is such that tube (5) loses approximately two (2) inches in elevation with each level (9). This enables a desired downward flow of liquid under the force of gravity. More preferably, the slope of declination lowers each level between about 4 inches to about 8 inches. Most preferably, the slope of declination lowers each level about 6 inches.

[Para 55] Continuing to refer to Figs. 2 and 6, preferably, the levels (9) are in substantially parallel planes. The spacing of the tube (5) from each other in the vertical direction in going from level (9) to level (9) is preferably such that the tube (5) can be efficiently exposed to sunlight and is not so great so as to waste space. More preferably, the spacing between levels is between about one inch to about three inches with two inches most preferred.

[Para 56] Continuing to refer to Figs. 2 and 6, in preferred embodiments, as the tube (5) spirals, curls, bends and runs downward, it gets sequentially larger in encompassed surface area. More preferably, the tube (5) in a particular level (9) indexes out from the vertical axis by the diameter of the tube relative to the above level (9) so that the tube (5) is not in vertical alignment in going from level to level (9). This maximize exposure of the tube (5) to sunlight.

[Para 57] In more preferred embodiments, the levels (9) of tube (5) in the stack (7) are parallelogram-like or square-like in shape. Parrallogram-like means that frame approximates a parallelogram and need not have precisely four sides, straight sides, equal length sides and/or 90 degree angles. Accordingly, the stack (7) has a pyramid or tetrahedron like shape. In these embodiment, the tube (5) can be constructed from a kit comprised of straight lengths (69) and approximately 90° elbow tubes (53). The elbow tubes (53) are made from a material that is non-toxic to microorganisms, especially algae, and preferably, from poly vinyl chloride (PVC), acrylic or polycarbonate. A most preferred material is PVC. A fluid tight attachment of the straight lengths (69) to elbow tubes (53) can be achieved by dipping the end of a straight length of tube (5) in an adhesive material and then placing the elbow tube (53) on the end.

[Para 58] Preferably, the levels (9) of the tube (5) in the stack (7) encompass an area ranging from about four (4) square feet at the top level to about 625 square feet at the bottom level. More preferably, the levels encompassing an area ranging from between about 9 square feet to about 169 square feet. Most preferably, the bottom level encompasses a surface area of about 100 square feet. Preferably, the stack (7) has a vertical height between of about seven feet to about eleven feet with nine feet most preferred.

[Para 59] Referring to Figs. 1, 2 and 6, there is a sparge or effluent inlet (11) for introducing a gas in communication with the tube (5) in the stack (7). The function of the sparge or effluent inlet (11) is to introduce carbon dioxide, nitrogen oxides and other gasses and liquids into the bioreactor to be metabolized by the microorganism, especially algae, that is resident in the bioreactor. The bubbles of the so introduce carbon dioxide, nitrogen oxides and other gasses are buoyant and travel upwards and counter current to a slurry in the tube (5) which is flowing by gravity downward. Typically, this sparge or effluent inlet (11) is at a lower position within the stack and most preferably, it is positioned at the second lowest level (9). The lower the position in the stack for the sparge or effluent inlet, the greater the residency time of carbon dioxide and nitrogen oxides in the tube (5). A fifteen minute residency time is achievable.

[Para 60] In a preferred embodiment, the sparge (11) introduces the carbon dioxide, nitrogen oxide and/or other gasses as a robust froth of microbubbles having significant surface area to facilitate the gas dissolving in a slurry in the tube (5). In a more preferred embodiment, the sparge has sintered stainless steel or air stone porous element and in a most preferred embodiment, the porous element is sintered stainless steel. Preferably, the porous element has a wide pore size so as to facilitate the entry of gas a low pressure between about six to about ten pounds per square inch.

[Para 61] Referring to Fig. 3, the gas exchange tank (13) is closed vessel with defined inlets and outlets. Thus, pressure can build up in the gas exchange tank (13). The gas exchange tank (13) has a capacity of at least about 350 gallons and preferably between 375 to 400 gallons. Preferably the gas exchange tank (13) has a height between about four feet to about six feet with five feet most preferred. This provides about 1,200 pounds of gravity induced hydraulic force to push slurry into the next bioreactor core (10) of a bioreactor farm (2) (discussed below.) The gas exchange tank (13) is mounted to and supported by the support means (3) at a position that is generally above the stack (7).

[Para 62] Continuing to refer to Fig. 3, the gas exchange tank (13) has a bottom (71) and this bottom (71) can be flat, conical or other shape. A conical bottom is preferred to impede the settling of algae or other microorganism. Referring to Figs. 6 and 12, at the bottom portion of the gas exchange tank (13) is an outlet along with piping to connect it to the upper opening (65) of the tube (5). During operation of the bioreactor (1) or bioreactor core (10), slurry flows from the gas exchange tank (13) to the tube (5).

[Para 63] Continuing to refer to Fig. 3, the gas exchange tank (13) has a slurry entry inlet (73). From this slurry entry inlet (73) there is piping to connect to a central feed pipe (15) (discussed below.) During operation of the bioreactor (1) or bioreactor core (10) slurry flows up the central feed pipe (15) and into the gas exchange tank (13). Optionally, the gas exchange tank (13) can have a fluid fill level (75). This is a level in the gas exchange tank (13) at which fluid does generally rise above during the operation of the bioreactor (1). In a preferred embodiment, slurry entry inlet (73) is above the fluid fill level (75) or off of the top of the gas exchange tank (13). A slurry entry inlet (73) on the side of the side of the gas exchange tank (13) is referred so as not to increase to overall height of the bioreactor (1).

[Para 64] Accordingly, during operation of the bioreactor (1), as slurry exits the slurry entry inlet (73), it splashes down into a reservoir of slurry in the bottom of the gas exchange tank (13). This splashing creates a froth and otherwise enhances the release of gas, especially diatomic oxygen, from the slurry. In a most preferred embodiment, slurry pulsates (that is, the flow rate ebbs up and down) to increase the splashing and hence the freeing of gas for discharge out of the gas exchange tank (13).

[Para 65] Referring to Figs. 1 and 11, the gas exchange tank (13) has an outlet for the elimination of gas. Typically, this outlet for the elimination of gas is positioned above the fluid fill level (75) along a wall or top of the gas exchange tank (13). During operation of the bioreactor (1), gas, especially diatomic oxygen, flows out of the gas exchange tank (13) through outlet for the elimination of gas (77). The outflow is driven by pressure that builds up in the gas exchange tank (13). In a preferred embodiment of a bioreactor (1) or bioreactor farm (discussed below) having a series of bioreactor cores (10), there is a manifold (79) which connects to outlet for the elimination of gas (77) from the bioreactor (1) or bioreactor core (10) in a farm (2) such that oxygen is collected. The manifold (79) has a nozzle and the oxygen can be potted or ported to be used as a combustion enhancer or for other uses.

[Para 66] Referring to Figs. 3 and 11, the central feed pipe (15) is an elongated conduit that is a fluid communication between the outlet side of a pump (21) (discussed below) and the slurry entry inlet (73) of the gas exchange tank (13). Typically, the central feed pipe (15) has vertical riser section and runs in the center of the stack (7) along its vertical axis. In a preferred embodiment, a sparge 11 for introducing a gas is in communication with the central feed pipe (15). During operation of the bioreactor (1) or bioreactor farm (2), slurry recycles and becomes rich in dissolved diatomic oxygen. This dissolved oxygen impedes the growth of algae and is a desirable product. The sparge (11) facilitates liberation of the dissolved oxygen. A gas, usually air, is injected into the central feed pipe (15) through this sparge (11) so as to generate bubbles. These bubbles are believed to be nucleation centers for the release of dissolved form the slurry for ultimate recovery by way of the gas exchange tank (13).

[Para 67] In a preferred embodiment, the sparge (11) introduces a robust froth of microbubbles in the central feed pipe (15) having significant surface area to facilitate release of dissolved diatomic oxygen. In a more preferred embodiment, the sparge has porous element made from sintered stainless steel or air stone and preferably from sintered stainless steel. Typically, an air compressor provides the air (or other gas) which enter through sparge (11) and travels up the central feed pipe (15) so as to break oxygen molecules from the slurry as it enters the gas exchange tank (13). Preferably, the air compressor is a rotary screw air compressor for this is an efficient air compressor.

[Para 68] Referring to Figs. 6 and 12, the pump (21) has an inlet side and an outlet side with the inlet side in fluid communication with the settling tank (19) (discussed below) and the outlet side with the central feed pipe (15). Preferably, the pump generates a pulsing fluid flow so as to enhancing splashing in the gas exchange tank (13) as discussed above. In the embodiments of this invention that are a bioreactor farm (2), there is no significant back up of slurry flow so that this pulsing slurry flow translates to each bioreactor core (10) in a bioreactor farm (2). Most preferably, the pump (21) is a diaphragm pump which pulses fluid. This type of pump (21) is more restricted than impeller type pump (21) and results in greater residency time of carbon dioxide and nitrogen oxides in the tube (5); namely, a fifteen minute residency time is achievable.

[Para 69] Referring to Fig. 6, there can be a nutrient tank (91) for nutrients in fluid communication through a pipe (93) with the gas exchange tank (13) of a bioreactor (1) or first bioreactor core (10) of a bioreactor farm (2).

[Para 70] Continue to refer to Figs. 6 and 12, there is a settling tank (19). This settling tank (19) serves the functions of being a receiving and mixing tank for an inoculation of algae, nutrients and water and a reservoir for recovering slurry exiting a bioreactor (1) or bioreactor farm (2). A return pipe (23) makes a fluid communication between the lower opening (67) of the tube (5) of a bioreactor (1) or the lower opening (67) of the tube (5) of the final bioreactor core (10) of a bioreactor farm (2). This closes the system and entry in or out of the system is controlled as described above. Thus alien microorganism is impeded from entering the bioreactor (1) or bioreactor farm (2).

[Para 71] Referring to Figs. 1 and 2, optionally, the tube (5) of a bioreactor (1) has one or more means for accessing fluid for analysis. One structure of the means for accessing fluid for analysis is an outlet valve (81) through which liquid samples are taken. Another structure is a port that is fluid tight for the mounting and insertion of probes into the tube (5) for the continuous measurement of a parameter.

[Para 72] Referring to Fig. 6 and 12, optionally and preferably, there is means for harvesting (95) in communication with the tube (5), return pipe

(23) or settling tank (19) for harvesting microorganism; especially algae. Preferably, the drain (83) is in fluid communication with the return pipe (23). Structures for the means for harvesting (95) are a tap, valve, quick release, Y-connector, T-connector, shunt and combinations of the foregoing.

[Para 73] Referring to Figs. 1 and 7, optionally and preferably, there is a greenhouse frame (85) for supporting a greenhouse structure so as to enclose a bioreactor (1) or bioreactor farm (2) during winter and/or periods of inclement weather.

[Para 74] Referring to Figs. 1 and 7, optionally and preferably, there is an all weather enclosure box (87) with electronics. The enclosure box (87) houses electronics that connect to sensors as well as to a central processor for a bioreactor (1) or bioreactor core (10). In a bioreactor farm (2) each bioreactor core (10) optionally and preferably is automated and it works in tandem with other bioreactor cores (10). This automated feature increases the reliability of operation of each bioreactor core (10) and the combined harvesting cycle of the bioreactor farm (2).

[Para 75] Referring to Figs. 1 and 12, depicted is a bioreactor farm having a plurality bioreactor cores (10). Preferably, there are between about three to about ten bioreactor cores (10) in the bioreactor farm (2) and most preferably there are five. The bioreactor cores (10) are conjoined or connected together in a successive series of bioreactor cores (10). The conjoined in series is accomplished by a pipe extending from the lower opening (67) of the tube (5) of preceding bioreactor core (10) making a fluid communication with the central feed pipe (15) of a succeeding bioreactor core (10). Slurry exits a preceding bioreactor core (10) with sufficient hydraulic force to climb the central feed pipe (15) of a succeeding bioreactor core (10) and enter the gas exchange tank (13) of that bioreactor core (10).

[Para 76] Referring to Fig. 11A, there is an illustration of a gas elimination outlet (77) and manifold (79) in connection with a gas exchange tank (13) and Fig. 11B is a perspective view of a center feed pipe (15) in connection with a gas exchange tank (13).

[Para 77] Optionally, there can be secondary piping and valves in connection with the main center feeds (15) and tube (5) so that a bioreactor core (10) in bioreactor farm (2) can be isolated for cleaning where the pump is operated at high capacity to flush out the bioreactor core (10) and farm (2).

[Para 78] Continue to refer to Fig. 12, the bioreactor farm (2) has a settling tank (19). There is a pump (21) having an inlet and an outlet side with the inlet side in fluid communication with the settling tank (19) and the outlet side in fluid communication with the central feed pipe (15) of a first bioreactor core (10).

[Para 79] Referring to Figs. 1 and 2, the first bioreactor core (10) of a bioreactor farm (2) is mount on legs (89) or suspended by cables (49) at a given elevation and has a gas exchange tank (13). In the series, each subsequent bioreactor core (10) is at lower elevation. The difference in elevation should be sufficiently great that the fluid level (75) in the gas exchange tank (13) of a subsequent bioreactor core (10) is below the fluid in the gas exchange tank of a preceding bioreactor (10). The elevation of a succeeding bioreactor core (10) decreases relative to preceding bioreactor core (10) by between about 0.5 feet to about 6 feet and most preferably, there is an about one foot difference or decline in elevation. This facilitates slurry exiting a preceding bioreactor core (10), climbing the central feed pipe (15) of a succeeding bioreactor core (10) and entering the gas exchange tank (13) of that bioreactor core (10).

[Para 80] Continuing to refer to Fig. 12, off of the lower opening (67) of the tube (5) of the final bioreactor core (10), a return pipe (23) is in fluid communication with a settling tank (19). Thus, there is closed system with controlled entry and exit of material from the system. Thus alien microorganism is impeded from entering the bioreactor farm (2).

[Para 81] The bioreactor farm (2) can have the same optional equipment as described above for a bioreactor.

INDUSTRIAL APPLICABILITY

[Para 82] The method of operating a bioreactor (1) and/or bioreactor farm (2) is a multi-step process. Water is introduced into the settling tank (19). During the operation of the bioreactor (1) extra water may be needed. A microorganism is introduced into the settling tank (19). Less preferably, the microorganism strain could be introduced through the tube (5) or in to the gas exchange tank (13).

[Para 83] The microorganism can be a natural microorganism or genetically engineered microorganism. Preferably, the microorganism is algae. Strains of algae have been identified as suitable for metabolizing carbon dioxide and/or nitrogen oxides and/or for the production of combustible oil extraction. Some of these strains have the characteristic of high lipid content, high protein content and/or high starch content. Examples of such strains are found as members of the following algae genera: *Anabaena, Botryococcus, Chlorella, Dunaliella, Euglena, Haematococcus, Nannochloris, Nannochloropsis, Neochloris, Nostoc, Phaeodactylum, Prymnesium, Scenedesmus, Spirulina, Synecoccus* and *Tetraselmis*. Among these, the presently preferred strains for lipid extraction are found as members of the following genera: *Botryococcus, Chlorella, Dunaliella, Nannochloris, Nannochloropsis, Neochloris, Nostoc, Phaeodactylum, Prymnesium, Scenedesmu,* and *Tetraselmis*. Suitable bacteria may include *Alcanivorax* and *Cycloclastiscus*.

[Para 84] Nutrients are introduced into the settling tank (19). Preferably, the nutrients are animal manure, microbially digested cow manure, treated sewage and fertilizer. More preferred nutrients are animal manure and fertilizer. The bioreactor (1) and bioreactor farm (2) are vehicles for disposing of manure and sewage.

[Para 85] The pump (21) is actuated so as pump material from the settling tank (19) to the gas exchange tank (13) along with the introduction of gas into the central feed pipe (15) through the sparge (11). From the a gas exchange tank (13), the slurry flows under the force of gravity through the tube (5) that makes up the stack (7). Accordingly, the tube (5) that makes up the stack becomes loaded with an aqueous mixture of microorganism (usually algae) and nutrients. Thereafter, it either flows through the return pipe (23) to the settling tank (19) or into the next reactor (__) in a series bioreactors in bioreactor farm (2) unit it exits the final bioreactor (1) and is brought back to the settling tank (19) via the return pipe (23).

[Para 86] Gaseous Carbon dioxide, gaseous nitrogen oxides, an effluent containing carbon dioxide and/or an effluent containing nitrogen oxides and/or other pullatants are introduce into the sparge or inlet (11) in communication with the tube (5). Carbon dioxide is regarded as a substance required for efficient growth of algae. In one embodiment, carbon dioxide is supplied to the system from tanks where this commercially available substance is held, normally in solid form, known as dry ice. It is believed that nitrogen oxide dissolves in the slurry and is taken up and metabolized by the microorganism which may be an algae. Thus, carbon dioxide and nitrogen oxides are sequestered. Nitrogen oxides are metabolized by certain strains of microorganisms into biomass. Likewise, other pollutants oxides are metabolized by certain strains of microorganisms into biomass.

[Para 87] In accordance with the preferred method of operating a bioreactor (1) or a bioreactor core (10) of bioreactor farm (2), carbon dioxide is pumped from its storage tank to adjust the alkalinity of the content of the tube (5) to between about pH 6.0 to pH 7.5 and preferably, pH 6.5. The amount of nutrients added to the bioreactor (1) or series of bioreactor cores (10) in a bioreactor farm (2) can be adjusted from time-to-time to obtain a desired ratio of elements in the contents of the tube (5) that makes up the stack (7) In one embodiment of this method, it is a goal that during the operation of the bioreactor (1) or series of bioreactor cores (10) in a bioreactor farm (2) to reach a level where the ratio of carbon, to nitrogen to phosphorous is about 106:16:1 (106 C, 16 N and 1 P).

[Para 88] In an alternative embodiment of the present invention, the bioreactor or bioreactor farm is harvested through a means for harvesting (95) in communication with the settling tank (19) to generate feedstock rich in microorganism (usually algae) to be used as a feedstock for making biofuel and biomass. The means for harvesting has structures such as a pipe, a tap, a T-connector, a valve and/or a quick release. The harvested slurry can be dewatered and pressed to produce raw combustible oil and biomass. The algae are normally harvested from the bioreactor (1) or series of bioreactor cores (10) in a bioreactor farm (2) when the mass of live algae becomes approximately thirty percent (30%) of the total weight in the tube (5).

[Para 89] The previously described versions of the present invention have many advantages. One advantage is the sequestration of carbon dioxide and nitrogen oxides from industry waste and converting it to algae mass/biomass. This is considered to have a significant beneficial effect for the environment and is an important advantage of the present invention. Another advantage is the collection of oxygen which is usable for the enhancement of combustion. Another advantage of the present invention is that it is employs gravity to move material so as to energy efficient, not require extensive use of pumps and mechanical and thereby be less prone to breaking with concomitant down time and repair costs. Another advantage is that the bioreactor is easy to assemble from kits of frame parts, straight lengths of tube (5), elbows and other components.

EXAMPLES

[Para 90] The following examples further describe and demonstrate embodiments within the scope of the present invention. The examples are given solely for the purpose of illustration and are not to be construed as limitations or restrictions of the present invention, as persons skilled in the art will quickly realize many variations thereof are possible that are all within the spirit and scope of the invention.

Example 1

[Para 91] Example 2 is an example of a bioreactor (1) . Overall, the bioreactor has a truncated pyramid like shape. At the bottom, there is an approximately ten feet by ten feet by 10 feet (10’ X 10’) square base that comprises 100 square feet. The bioreactor (1) is approximately nine feet seven inches (9’ 7”) high. There is an approximate two feet by two feet (2’ X 2’) square shape on top.

Example 2

[Para 92] Example 2 is and example of a bioreactor farm having five bioreactor cores (10). The bioreactor cores (10) have over about 3,300 feet of four inch (4”) clear polycarbonate tube (5). Each bioreactor (1) occupied 950 square feet. It is estimated that 45 bioreactor cores (10) could be placed on one acre.

Example 3

[Para 93] Example 3 is an example of a the residency time of carbon dioxide in a bioreactor (1). Carbon dioxide was introduced into the tube (5) of a bioreactor and there was residency time of over 10 minutes.

[Para 94] Although the present invention has been described in considerable detail with reference to certain preferred versions thereof, other versions are possible with substituted, varied and/or modified materials and steps are employed. For example, a kit of frame parts, straight lengths of tube (5), elbows and other components to assemble a bioreactor. These other versions do not depart from the invention. Therefore, the spirit and scope of the appended claims should not be limited to the description of the preferred versions contained herein.

What is claimed is:

[Claim 1] A bioreactor comprised of:

a) a support means (3) having vertical height;
b) an tube (5) characterized by having lengths which at a minimum partially pass light there through that is mounted on the support means (3) and further characterized by:
    i) an upper opening (65),
    ii) continuously runs and curls with declination about a vertical axis to form a stack (7) of levels (9) with each level (9) encompassing about 360 degrees around the vertical axis where the radial distance between the tube (5) and the vertical axis indexes within the stack (7) so as to enhance the tube's exposure to light emanating from above the stack (7) relative to the tube (5) being vertically aligned at a constant radial distance from the axis within the stack (7);
    iii) an inlet (11) in communication with the tube (5) and
    iv) a lower opening (67);
c) a gas exchange tank (13) that has a mounting to the support means (3) at a position that is generally above the stack (7), is in fluid communication with the upper opening (65) of the tube (5), has a slurry entry inlet (73) and has an outlet for the elimination of gas (77);
d) a settling tank (19);
e) a pump (21) having an inlet and an outlet side with the inlet side in fluid communication with the settling tank (19);
f) a central feed pipe (15) in fluid communication with the outlet side of the pump (21) and the slurry entry inlet (73) of the gas exchange tank;
g) a sparge (17) in communication with the central feed pipe (15) for introducing a gas and
h) a return pipe (23) in fluid communication with the lower opening (67) of the tube (5) and in fluid communication with the settling tank (19).

[Claim 2] The bioreactor of claim 1 where the inlet (11) in communication with the tube (5) is a sparge.

[Claim 3] The bioreactor of claim 1 where the inlet (11) in communication with the tube (5) is positioned at a lower level in the stack (7).

[Claim 4] The bioreactor of claim 1 having a means for harvesting (95).

[Claim 5] The bioreactor of claim 1 where the gas exchange tank (13) has a fluid fill level (75), the slurry entry inlet (73) is above the fluid fill level (75) and the pump (21) is capable of producing a pulsating pulse of fluid from its outlet side.

[Claim 6] The bioreactor of claim 1 where the tube (5) continuously runs and bends with declination about the vertical axis to form a stack (7) of a plurality of levels (9) that are closely spaced in substantially parallel planes with each level having approximately straight lengths and approximately 90° bends to form a square-like configuration around the vertical axis where in a direction from top to bottom the radial distance between the tube (5) and the vertical axis within the stack (7) increases by about the diameter of the tube (5) so as to enhance the tube's exposure to light emanating from above the stack (7) relative to the tube (5) being vertically aligned at a constant radial distance from the axis within the stack (7).

[Claim 7] The bioreactor of claim 6 where the support means (3) is comprised of:

a) a upper square-like frame (29) having vertices (31);
b) a lower square-like frame (27) having vertices (31) which is larger than the upper square-like frame (29);
c) four main diagonal support members (33) that are each attached to vertices (31) of the upper square-like frame (29) and lower square-like

frame (27) so as to form a configuration that has a truncated pyramid-like shape and

d) flat bar strip (41) mounted along the main diagonals with a plurality of bends that bend back on themselves to form shelves for supporting the tube (5) in the levels (9) of the stack (7).

[Claim 8] The bioreactor of claim 6 where the support means (3) is comprised of:

a) an upper frame (43);
b) a lower frame (45);
c) vertical supports (47) that run from the lower frame (45) to the upper frame (43);
d) a plurality of cables (49) that depend from the upper frame (43) and attach to the tube (5) so as to support the tube (5) in the stack (7) and
e) a column (51) onto which is mounted the gas exchange tank (13) in a position generally above the stack (7).

[Claim 9] The bioreactor of claim 8 where the support means (3) has a cage (55) that receives the gas exchange tank (13) that extends between the column (51) and the upper frame (43) so as to provide vertical support to the upper frame (43).

[Claim 10] A conjoinable bioreactor core (10) comprised of:

a) a support means (3) having vertical height;
b) an tube (5) characterized by having lengths which at a minimum partially pass light there through that is mounted on the support means (3) and further characterized by:
   i) an upper opening (65),
   ii) continuously runs and curls with declination about a vertical axis to form a stack (7) of levels (9) with each level (9) encompassing about 360 degrees around the vertical axis where the radial distance between the tube (5) and the vertical axis indexes within

the stack (7) so as to enhance the tube's exposure to light emanating from above the stack (7) relative to the tube (5) being vertically aligned at a constant radial distance from the axis within the stack (7);

iii) an inlet (11) in communication with the tube (5) and

iv) a lower opening (67);

c) a gas exchange tank (13) that has a mounting to the support means (3) at a position that is generally above the stack (7), is in fluid communication with the upper opening (65) of the tube (5), has a slurry entry inlet (73) and has an outlet for the elimination of gas (77) and

d) a central feed pipe (15) in fluid communication with the slurry entry inlet (73) of the gas exchange tank (13),

where the bioreactor core (10) is a part of a bioreactor farm (2) comprised of a successive series of bioreactor cores (10) on a surface where the elevation of a succeeding bioreactor core (10) decreases relative to the elevation of the preceding bioreactor core (10).

[Claim 11] A bioreactor farm comprised of a successive series of bioreactor cores (10) on a surface comprised of:

a) a first bioreactor core (10) as claimed in claim 10 where the bioreactor core (10) is at an elevation above the surface;

b) a settling tank (19);

c) a pump (21) having an inlet and an outlet side with the inlet side in fluid communication with the settling tank (19) and the outlet side in fluid communication with the central feed pipe (15) of the first bioreactor core (10);

d) a subseries of n_1 bioreactors as claimed in claim 10 where:

i) the lower opening (67) of the tube (5) of preceding bioreactor core (10) is in fluid communication with the central feed pipe (15) of succeeding bioreactor core (10),

ii) the elevation of a succeeding bioreactor core (10) decreases relative to the elevation of the preceding bioreactor core (10) and

iii) n_1 is an integer that is 0 or more;

e) a final bioreactor core (10) as claimed in claim 10 where the central feed pipe (15) is in fluid communication with the lower opening (67) of the tube (5) in the preceding reactor and

f) a return pipe (23) in fluid communication with the lower opening (67) of the tube (5) of the final bioreactor core (10) and in fluid communication with the settling tank (19).

[Claim 12] The bioreactor farm of claim 11 where n_1 is about 3.

[Claim 13] The bioreactor farm of claim 11 where:

a) the gas exchange tank (13) has a bottom (71) and a fluid fill level (75) and

b) the elevation of a succeeding bioreactor core (10) decreases relative to the elevation of the preceding bioreactor core (10) such that the fluid fill level (75) of a gas exchange tank (13) in a succeeding bioreactor core (10) is generally lower than the bottom (19) of the gas exchange tank (13) of a preceding bioreactor.

[Claim 14] The bioreactor farm of claim 11 where the elevation of a succeeding bioreactor core (10) decreases relative to preceding bioreactor core (10) by about 1 feet.

[Claim 15] The bioreactor farm of claim 11 where at least one bioreactor core (10) has a sparge for the inlet (11) in communication with the tube (5).

[Claim 16] The bioreactor farm of claim 11 where the inlet (11) in communication with the tube (5) is positioned at a lower level in the stack (7).

[Claim 17] The bioreactor farm of claim 11 where at least one bioreactor core (10) has a sparge (17) in communication with the central feed pipe (15) for introducing a gas.

[Claim 18] The bioreactor farm of claim 11 having a means for harvesting (95).

[Claim 19] The bioreactor farm of claim 11 having a manifold (79) in fluid communication with the outlets for the elimination of gas (77) for at least two bioreactor cores (10) and the manifold (79) having an outlet.

[Claim 20] The bioreactor farm of claim 11 where:

a) at least one bioreactor core (10) has a gas exchange tank (13) that has fluid fill level (75) and the slurry entry inlet (73) is at a position above the fluid fill level (75) and
b) the pump (21) is capable of producing a pulsating pulse of fluid from its outlet side.

[Claim 21] The bioreactor farm of claim 11 where at least one bioreactor core (10) has a tube (5) that continuously runs and bends with declination about the vertical axis to form a stack (7) of a plurality of levels (9) that are closely spaced in substantially parallel planes with each level having approximately straight lengths and approximately 90° bends to form a square-like configuration around the vertical axis where in a direction from top to bottom the radial distance between the tube (5) and the vertical axis within the stack (7) increases by about the diameter of the tube (5) so as to enhance the tube's exposure to light from a light source that is above the stack (7) relative to the tube (5) being vertically aligned at a constant radial distance from the axis within the stack (7).

[Claim 22] The bioreactor farm of claim 21 where at least one bioreactor core (10) having the tube (5) of claim 21 has a support means (3) that is comprised of:

a) a upper square-like frame (29) having vertices (31);
b) a lower square-like frame (27) having vertices (31) which is larger than the upper square-like frame (29) ;
c) four main diagonal support members (33) that are each attached to vertices (31) of the upper square-like frame (29) and lower square-like frame (27) so as to form a configuration that has a truncated pyramid-like shape and
d) flat bar strip (41) mounted along the main diagonals with a plurality of bends that bend back on themselves to form shelves for supporting the tube (5) in the levels (9) of the stack (7).

[Claim 23] The bioreactor farm of claim 22 where at least one bioreactor core (10) having the tube (5) of claim 21 has a support means (3) that is comprised of:

a) an upper frame (43);
b) a lower frame (45);
c) vertical supports (47) that run from the lower frame (45) to the upper frame (43);
d) a plurality of cables (49) that depend from the upper frame (43) and attach to the tube (5) so as to support the tube (5) in the stack (7) and
e) a column (51) onto which is mounted the gas exchange tank (13) in a position generally above the stack (7).

[Claim 24] The bioreactor farm of claim 23 where at least one bioreactor core (10) having the support means (3) of claim 23 has a cage (55) that receives the gas exchange tank (13) that extends between the column (51) and the upper frame (43) so as to provide vertical support to the upper frame (43).

[Claim 25] A method for sequestration of carbon dioxide comprised of the steps of:

a) providing a bioreactor farm of claim 11;
b) introducing into the bioreactor cores (10) a mixture of a microorganism that metabolizes carbon dioxide, nutrients and water;
c) introducing carbon dioxide into the inlet (11) in communication with the tube (5) of at least one bioreactor core (10) and
d) actuating the pump (21).

[Claim 26] The method for sequestration of carbon dioxide of claim 20 where the microorganism is algae.

[Claim 27] A method for sequestration of nitrogen oxides comprised of the steps of:

a) providing a bioreactor farm of claim 11;
b) introducing into the bioreactor cores (10) a mixture of a microorganism that metabolizes nitrogen oxides, nutrients and water;
c) introducing nitrogen oxides into the inlet (11) in communication with the tube (5) of at least one bioreactor core (10) and
e) actuating the pump (21).

[Claim 28] The method for sequestration of nitrogen oxides of claim 27 where the microorganism is algae.

[Claim 29] A method for the collection of oxygen comprised of the steps of:

a) providing a bioreactor farm of claim 19;
b) introducing into the bioreactor cores (10) a mixture of a microorganism that metabolism carbon dioxide into oxygen, nutrients and water;
c) introducing carbon dioxide into the inlet (11) in communication with the tube (5) of at least one bioreactor core (10) and
f) actuating the pump (21).

[Claim 30] The method for the collection of oxygen of claim 29 where the microorganism is algae.

[Claim 31] A method for production of a biofuel feedstock comprised of the steps of:

a) providing a bioreactor farm of claim 18;
b) introducing into the bioreactor cores (10) a mixture of a microorganism that metabolizes carbon dioxide, nutrients and water;
c) introducing carbon dioxide into the inlet (11) in communication with the tube (5) of at least one bioreactor;
d) actuating the pump (21) and
e) draining fluid containing the microorganism

[Claim 32] The method for producing a biofuel feedstock of claim 31 where the microorganism is an oil laden algae.

[Claim 33] A conjoinable bioreactor core (10) comprised of:

a) a support means (3) having vertical height;
b) a rigid and annular tube (5) and having lengths which substantially pass light there through that is mounted on the support means (3) and further characterized by:
    i) an upper opening (65),
    ii) continuously runs and bends with declination about a vertical axis to form a stack (7) of a plurality of levels (9) that are in substantially parallel planes having approximately straight lengths and approximately 90° bends to form a square-like configuration around the vertical axis that are vertically closely spaced with a slope of declination lowering each level and in a direction from top to bottom the radial distance between the tube (5) and the vertical axis within the stack (7) increases by about the diameter of the tube (5) so as to form a configuration that has the general shape of

a truncated pyramid whereby, there is an enhancement of the tube's exposure to light from a light source emanating from the above the stack (7) relative to the tube (5) being vertically aligned at a constant radial distance from the axis within the stack

iii) a sparge (11) for introducing a gas in communication with the tube (5) and is positioned at about the second lowest level (9) of the stack (7) and

iv) a lower opening (67);

c) a gas exchange tank (13) that has a mounting to the support means (3) at a position that is generally above the stack (7), is in fluid communication with the upper opening (65) of the tube (5), has a fluid fill level (75) and a slurry entry inlet (73) above the fluid fill level (75) and an outlet for the elimination of gas (77);

d) a central feed pipe (15) in fluid communication with the outlet side of the pump (21) and the slurry entry inlet (73) of the gas exchange tank (13) and

e) a sparge (17) in communication with the central feed pipe (15) for introducing a gas.

[Claim 34] The conjoinable bioreactor core (10) of claim 34 where the diameter of the tube (5) is between about 3 inches to about 5 inches.

[Claim 35] The conjoinable bioreactor core (10) of claim 34 where the stack (7) has a vertical height of about 10 feet.

[Claim 36] The conjoinable bioreactor core (10) of claim 34 where the levels (9) encompass an area ranging from between about 9 square feet to about 169 square feet.

[Claim 37] The conjoinable bioreactor core (10) of claim 34 where levels (9) are vertically spaced apart about 1 inch to about 3 inches.

[Claim 38] The conjoinable bioreactor core (10) of claim 34 where the slope of declination lowers each level (9) between about 4 inches to about 8 inches.

[Claim 39] The conjoinable bioreactor core (10) of claim 34 where the gas exchange tank (13) has a capacity of at least about 350 gallons

[Claim 40] The conjoinable bioreactor core (10) of claim 34 where the support means (3) is comprised of:

a) a upper square-like frame (29) having vertices (31);
b) a lower square-like frame (27) having vertices (31) which is larger than the upper square-like frame (29) ;
c) four main diagonal support members (33) that are each attached to vertices (31) of the upper square-like frame (29) and lower square-like frame (27) so as to form a configuration that has a truncated pyramid-like shape and
d) flat bar strip (41) mounted along the main diagonals with a plurality of bends that bend back on themselves to form shelves for supporting the tube (5) in the levels (9) of the stack (7).

[Claim 41] The conjoinable bioreactor core (10) of claim 34 where the support means (3) is comprised of:

a) an upper frame (43);
b) a lower frame (45);
c) vertical supports (47) that run from the lower frame (45) to the upper frame (43);
d) a plurality of cables (49) that depend from the upper frame (43) and attach to the tube (5) so as to support the tube (5) in the stack (7) and
e) a column (51) onto which is mounted the gas exchange tank (13) in a position generally above the stack (7).

[Claim 42] The conjoinable bioreactor core (10) of claim 41 where the support means (3) has a cage (55) that receives the gas exchange tank (13) that extends between the column (51) and the upper frame (43) so as to provide vertical support to the upper frame (43).

[Claim 43] A bioreactor farm comprised of a successive series of bioreactor cores (10) on a surface comprised of:

a) a first bioreactor core (10) as claimed in claim 33 where the reactor core is at an elevation above the surface;
b) a settling tank (19);
c) a pump (21) having an inlet and an outlet side with the inlet side in fluid communication with the settling tank (19) and the outlet side in fluid communication with the central feed pipe (15) of the first bioreactor core (10);
d) a subseries of n_1 bioreactors as claimed in claim 33 where:
    i) the lower opening (67) of the tube (5) of preceding bioreactor core (10) is in fluid communication with the central feed pipe (15) of succeeding bioreactor core (10),
    ii) the elevation of a succeeding bioreactor core (10) decreases relative to the elevation of the preceding bioreactor core (10) such that the fluid fill level (75) of a gas exchange tank (13) in a succeeding bioreactor core (10) is generally lower than the bottom (19) of the gas exchange tank (13) of a preceding bioreactor and
    iii) n_1 is an integer that is 0 or more;
e) a final bioreactor core (10) as claimed in claim 33 where:
    i) the central feed pipe (15) is in fluid communication with the lower opening (67) of the tube (5) in the preceding reactor and
    ii) the elevation of the bioreactor core (10) is lower than the preceding bioreactor core (10) such that the fluid fill level in the gas exchange tank (13) is generally lower than the bottom of the gas exchange tank of a preceding bioreactor and

f) a return pipe (23) in fluid communication with the lower opening (67) of the tube (5) of the final bioreactor core (10) and in fluid communication with the settling tank (19).

[Claim 44] The bioreactor farm of claim 43 where n_1 is about 3.

[Claim 45] The bioreactor farm of claim 43 where the elevation of a succeeding bioreactor core (10) decreases relative to preceding bioreactor core (10) by between about 0.5 feet to about 6 feet.

[Claim 46] The bioreactor farm of claim 43 where the elevation of a succeeding bioreactor core (10) decreases relative to preceding bioreactor core (10) by between about 1 feet.

[Claim 47] The bioreactor farm of claim 43 having a means for harvesting (95).

[Claim 48] The bioreactor farm of claim 43 having a manifold (79) in fluid communication with the outlets for the elimination of gas (77) for at least two bioreactor cores (10) and the manifold (79) having an outlet.

[Claim 49] The bioreactor farm of claim 43 the pump (21) is capable of producing a pulsating pulse of fluid from its outlet side.

[Claim 50] The bioreactor farm of claim 43 where at least one bioreactor core (10) has a support means (3) that is comprised of:

a) a upper square-like frame (29) having vertices (31);
b) a lower square-like frame (27) having vertices (31) which is larger than the upper square-like frame (29) ;
c) four main diagonal support members (33) that are each attached to vertices (31) of the upper square-like frame (29) and lower square-like

frame (27) so as to form a configuration that has a truncated pyramid-like shape and

d) flat bar strip (41) mounted along the main diagonals with a plurality of bends that bend back on themselves to form shelves for supporting the tube (5) in the levels (9) of the stack (7).

[Claim 51] The bioreactor farm of claim 43 where at least one bioreactor core (10) has a support means (3) that is comprised of:

a) an upper frame (43);
b) a lower frame (45);
c) vertical supports (47) that run from the lower frame (45) to the upper frame (43);
d) a plurality of cables (49) that depend from the upper frame (43) and attach to the tube (5) so as to support the tube (5) in the stack (7) and
e) a column (51) onto which is mounted the gas exchange tank (13) in a position generally above the stack (7).

[Claim 52] The bioreactor farm of claim 51 where the at least one bioreactor core having the frame means of claim 1 has a cage (55) that receives the gas exchange tank (13) that extends between the column (51) and the upper frame (43) so as to provide vertical support to the upper frame (43).

[Claim 53] The bioreactor farm of claim 43 having a frame for a greenhouse enclosure.

[Claim 54] A method for sequestration of carbon dioxide comprised of the steps of:

a) providing a bioreactor farm of claim 43;
b) introducing into the bioreactor cores (10) a mixture of a microorganism that metabolizes carbon dioxide, nutrients and water;

c) introducing carbon dioxide into the sparge (11) for introducing a gas in communication with the tube (5) of at least one bioreactor core (10) and

g) actuating the pump (21).

[Claim 55] The method for sequestration of carbon dioxide of claim 55 where the microorganism is algae.

[Claim 56] A method for sequestration of nitrogen oxides comprised of the steps of:

a) providing a bioreactor farm of claim 43;

b) introducing into the bioreactor cores (10) a mixture of a microorganism that metabolizes nitrogen oxides, nutrients and water;

c) introducing nitrogen oxides into the sparge (11) for introducing a gas in communication with the tube (5) of at least one bioreactor core (10) and

h) actuating the pump (21).

[Claim 57] The method for sequestration of nitrogen oxides of claim 57 where the microorganism is algae.

[Claim 58] A method for the collection of oxygen comprised of the steps of:

a) providing a bioreactor farm of claim 48;

b) introducing into the bioreactor cores (10) a mixture of a microorganism that metabolism carbon dioxide into oxygen, nutrients and water;

c) introducing carbon dioxide into the sparge (11) for introducing a gas in communication with the tube (5) of at least one bioreactor core (10) and

d) actuating the pump (21).

[Claim 59] The method for the collection of oxygen of claim 60 where the microorganism is algae.

[Claim 60] A method for production of a biofuel feedstock comprised of the steps of:

a) providing a bioreactor farm of claim 47;
b) introducing into the bioreactor cores (10) a mixture of a microorganism that metabolizes carbon dioxide, nutrients and water;
c) introducing carbon dioxice into the sparge (11) for introducing a gas in communication with the tube (5) of at least one bioreactor;
d) actuating the pump (21) and
e) draining fluid containing the microrganism

[Claim 61] The method for producing a biofuel feedstock of claim 61 where the microorganism is an oil laden algae.

[Claim 62] A support for a bioreactor having a tube (5) that runs and bends to form a stack (7) of square-like levels (9) with an overall truncated pyramid-like shape and a header tank centered about the truncated pyramid-like shaped stack (7) comprised of:

a) An upper frame (43);
b) a lower frame (45);
c) a plurality of vertical supports (47) that run from the lower frame (45) to the upper frame (43);
d) a plurality of cables (49) that depend from upper frame (43) such that lower ends of the depending cables (49) are engagable to the tube (5) so as to support the tube (5) in the stack (7) and
e) a column (51) positioned to engage a header tank (13) and
f) a cage (55) that is capable of receiving a header tank (13) that extends between the column (51) and the upper frame (43) so as to provide vertical support to the upper frame (43).

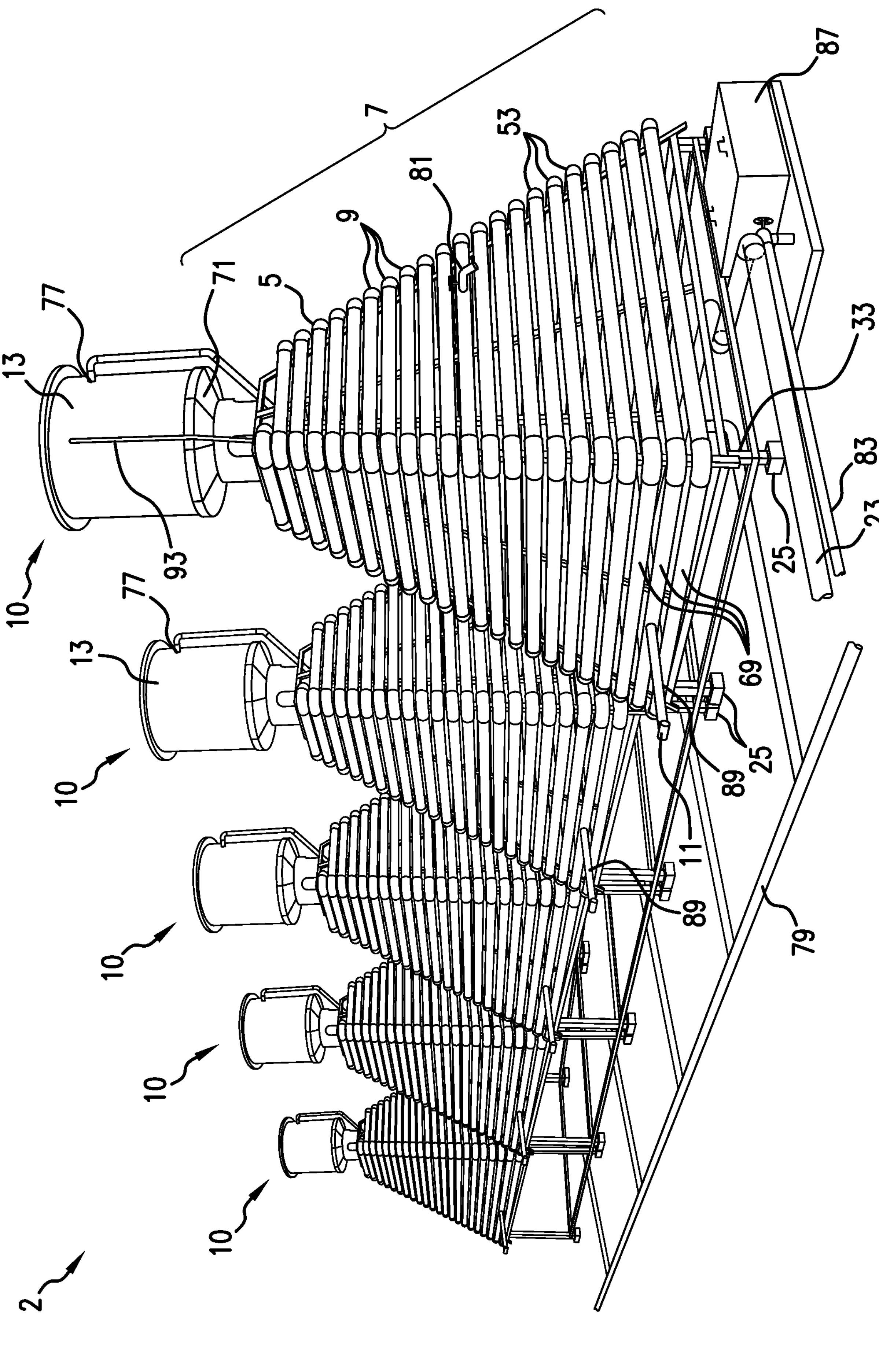

FIG.1

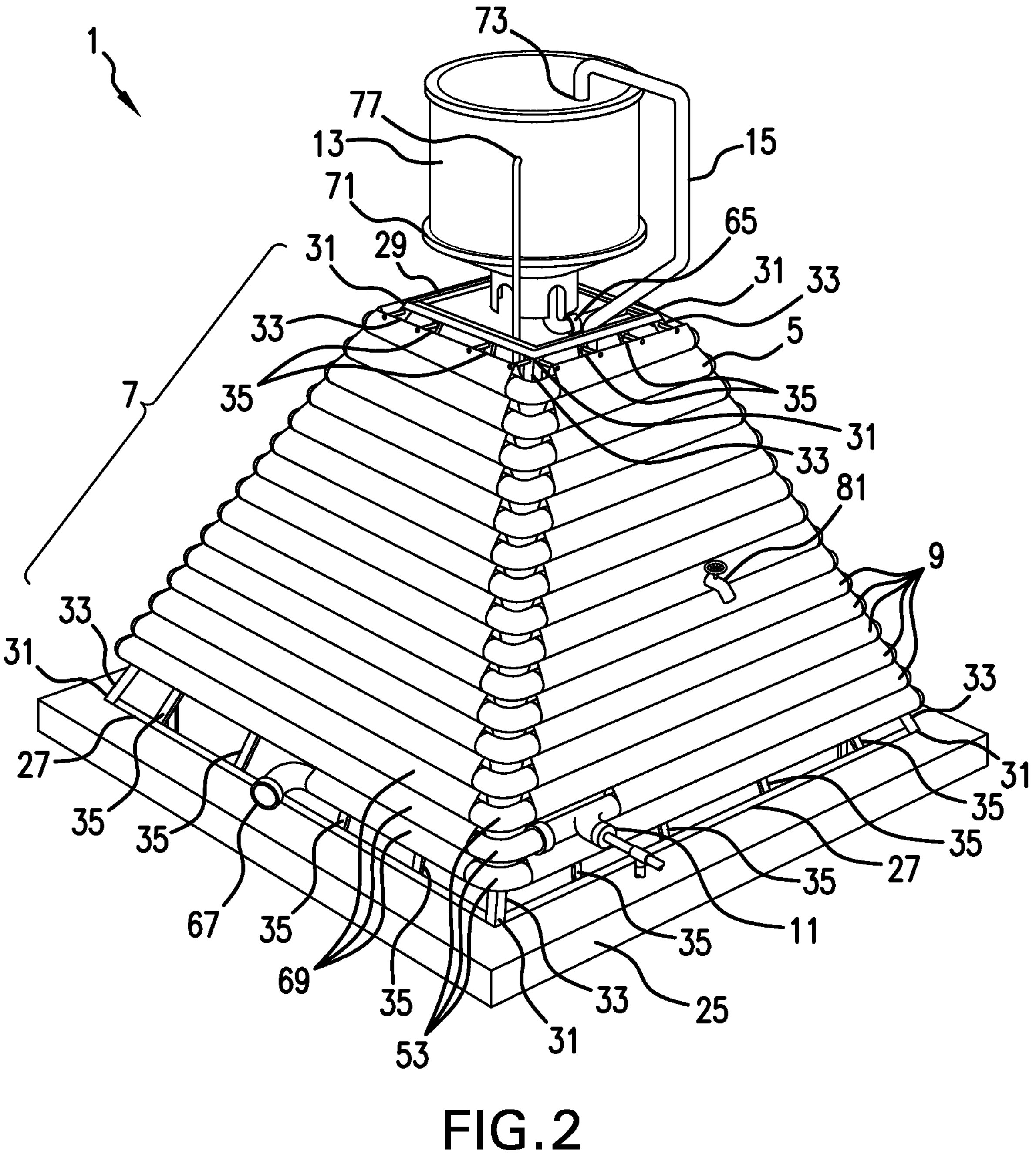

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FIG.2

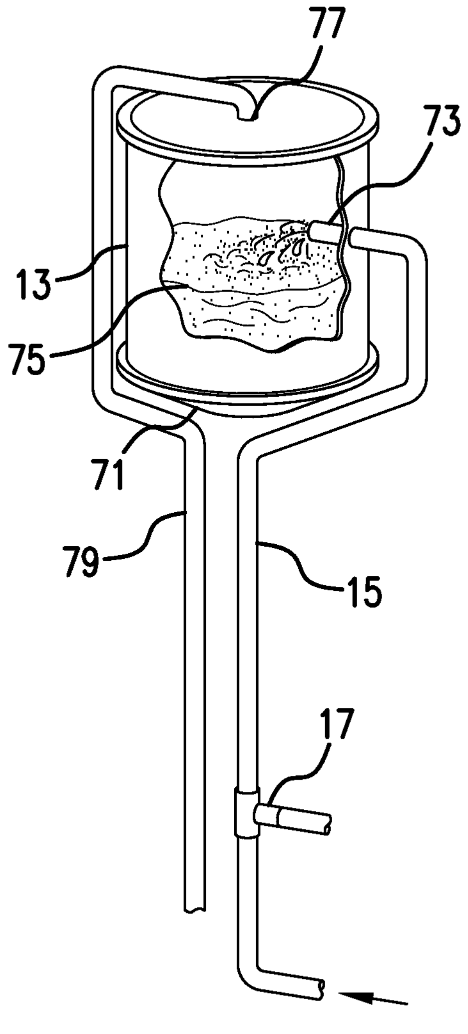


FIG.3

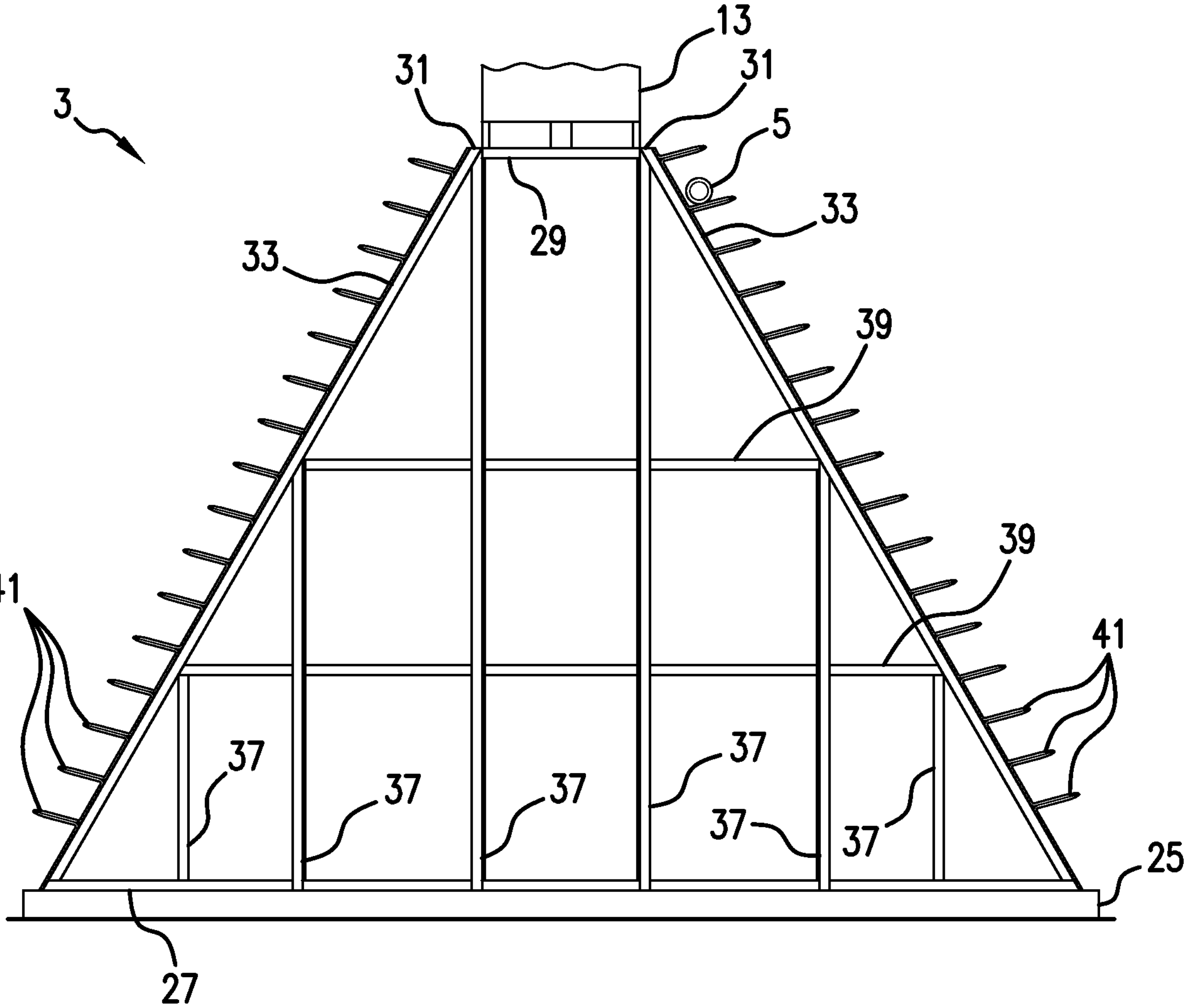


FIG.4

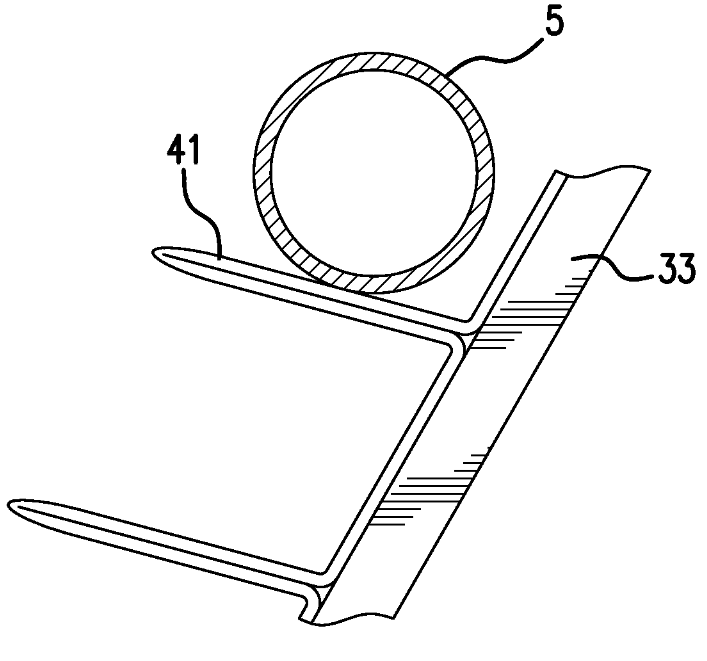
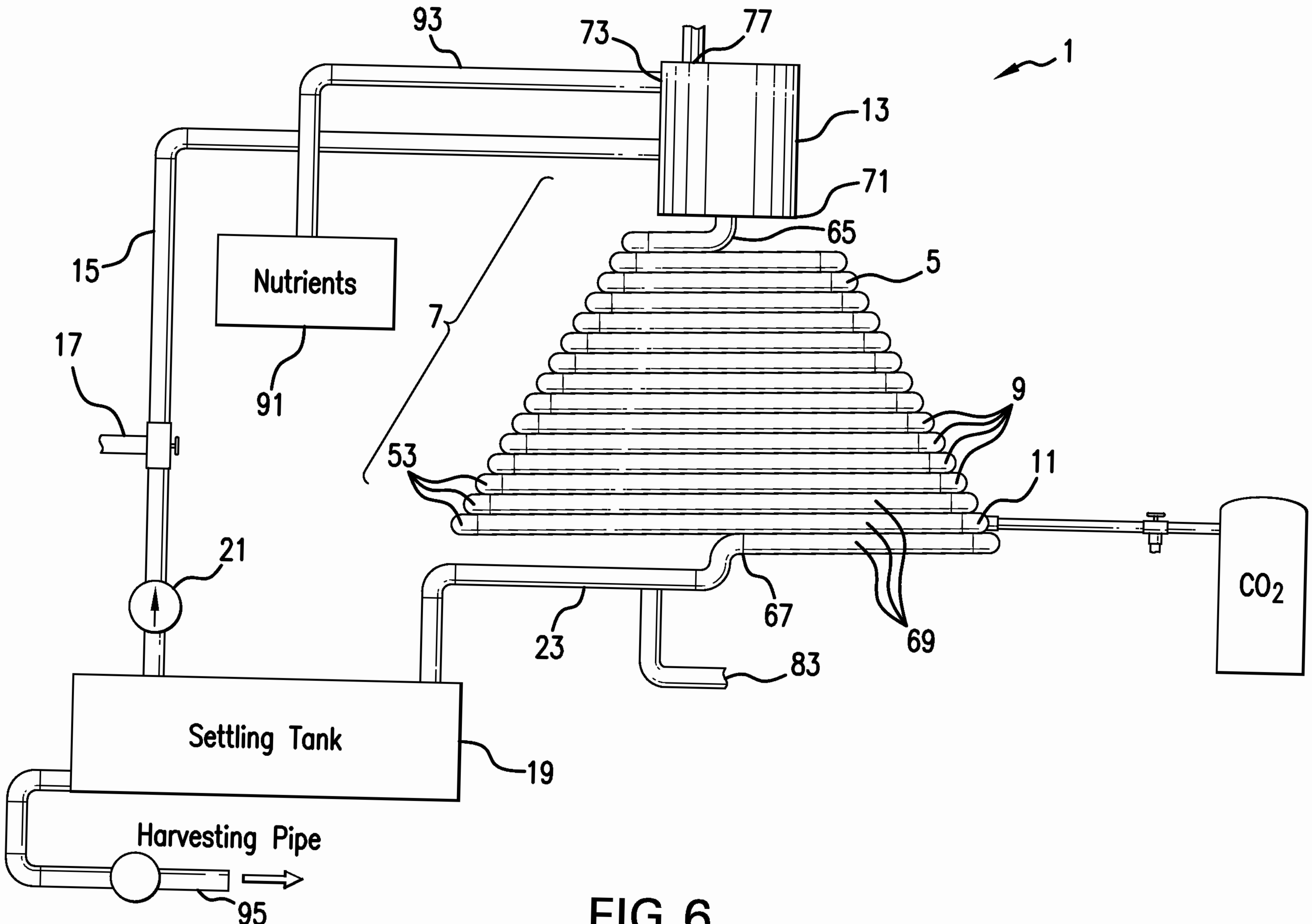


FIG.5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Nutrients
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CO$_2$
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Settling Tank
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Harvesting Pipe
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FIG.6

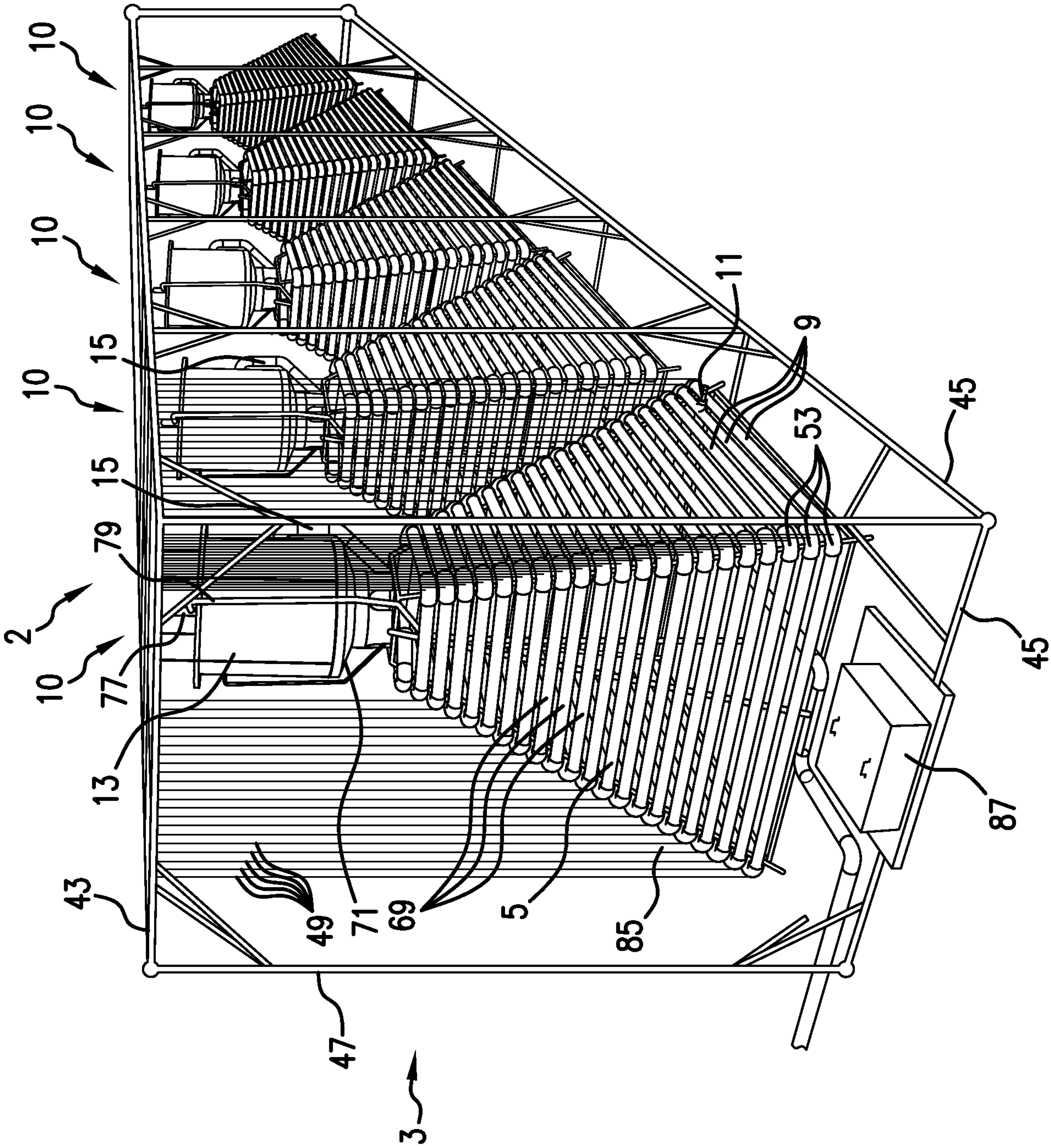


FIG. 7

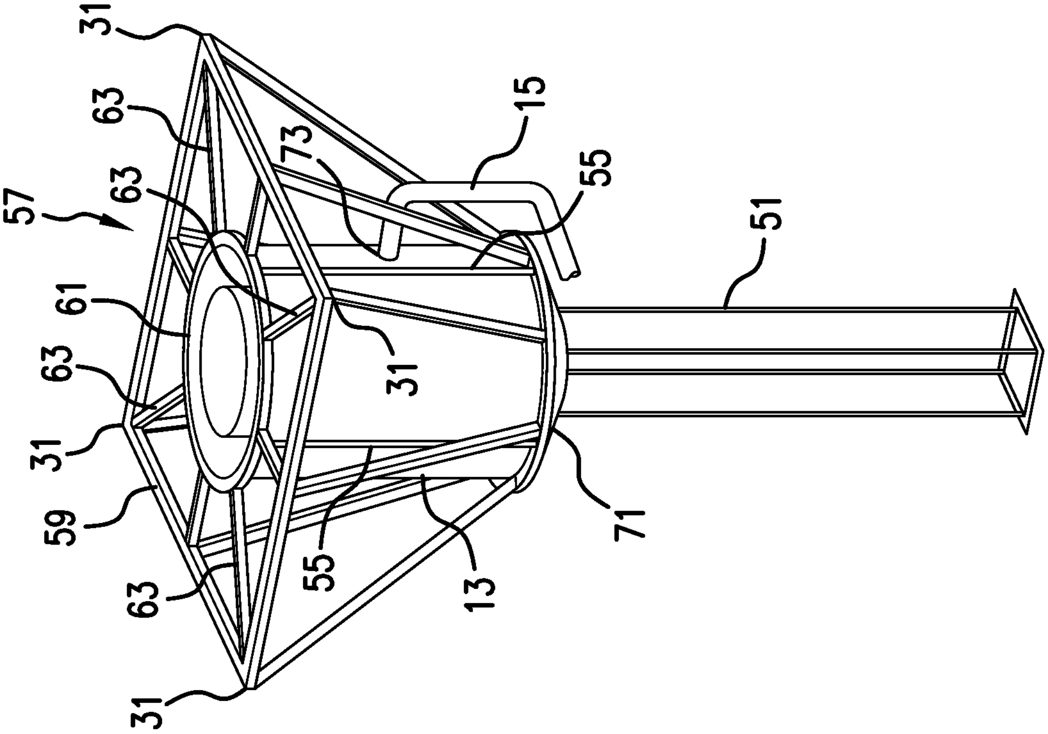


FIG.10

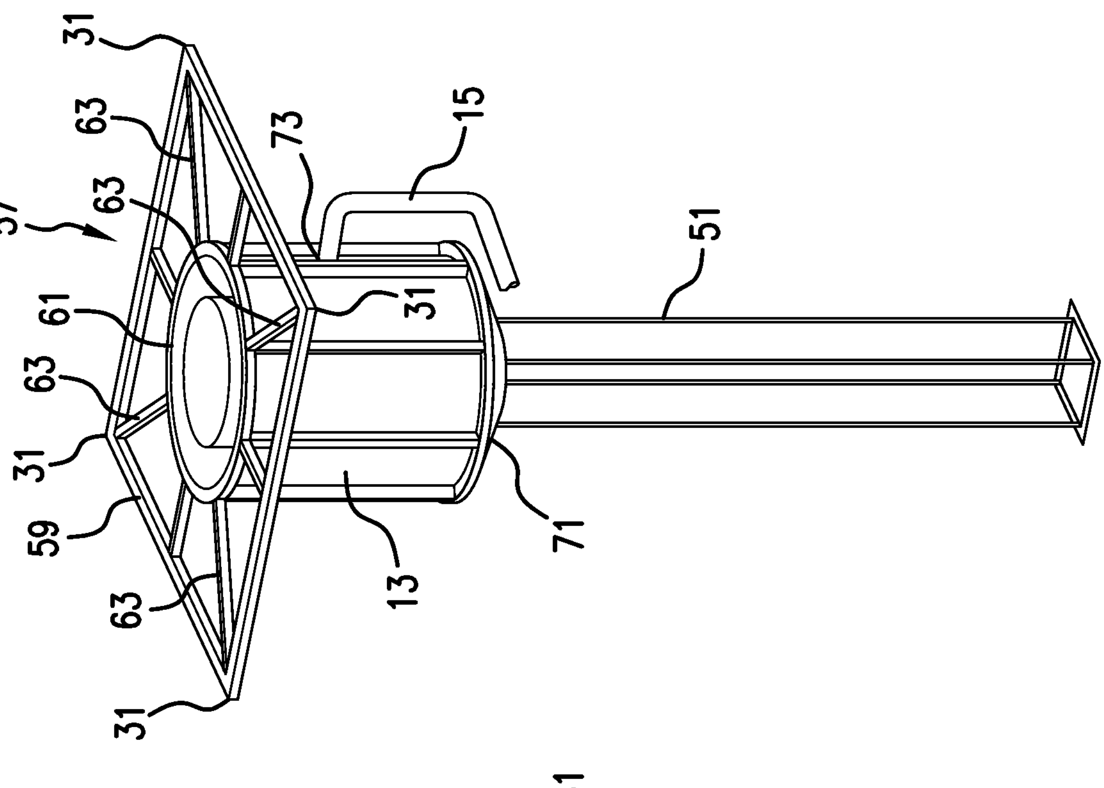


FIG.9

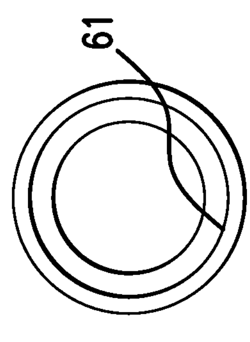


FIG.8

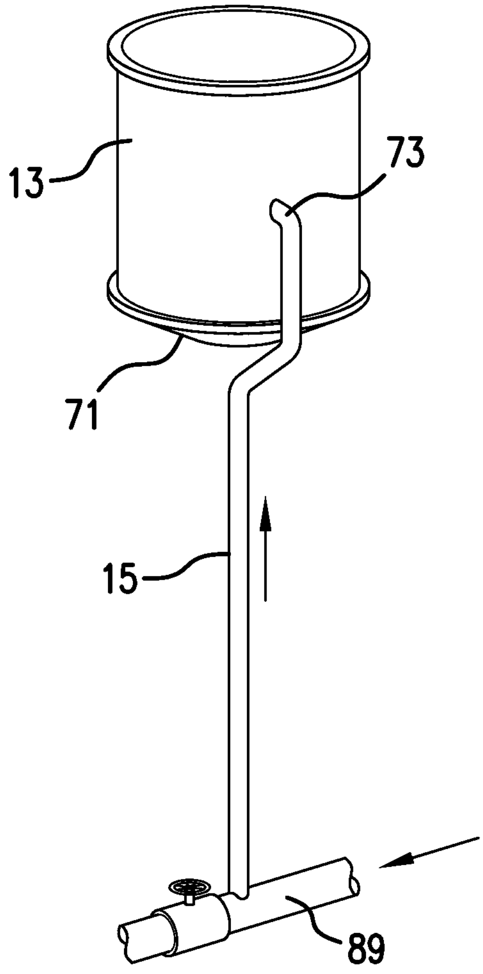


FIG.11A

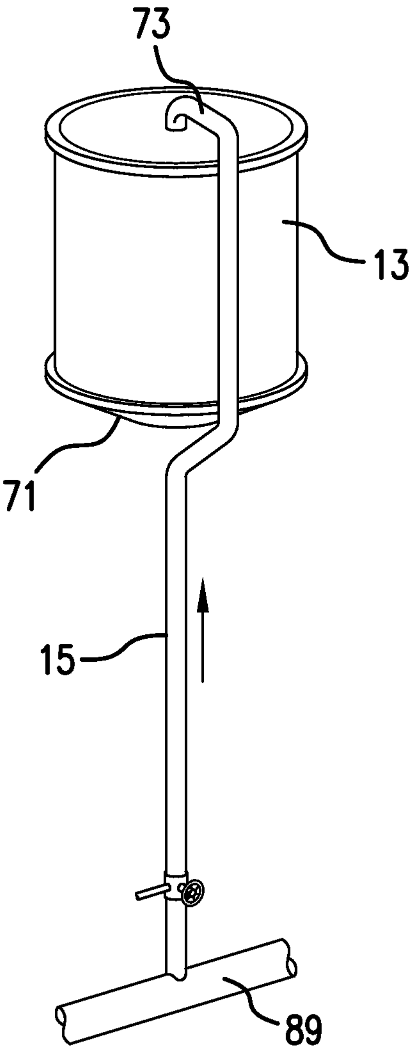
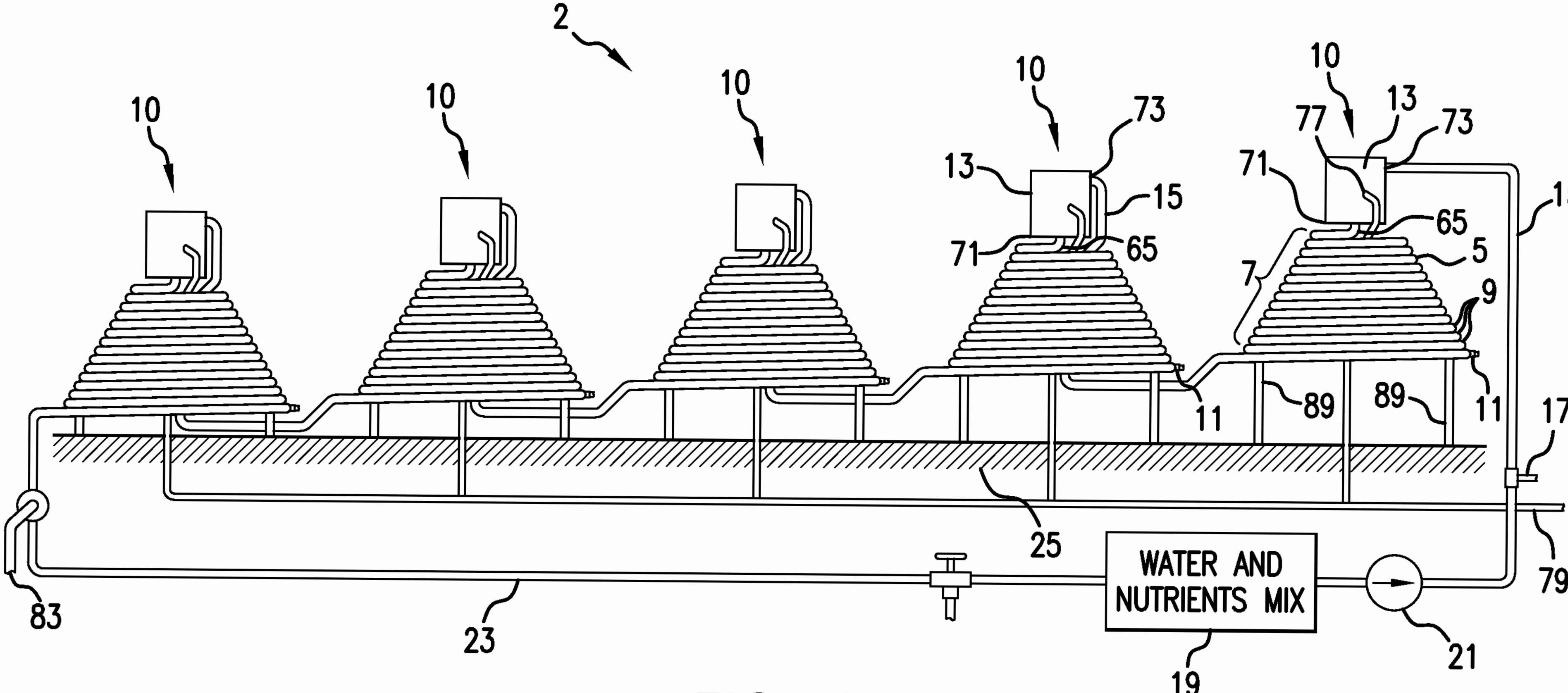


FIG.11B



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WATER AND NUTRIENTS MIX
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FIG.12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 10/45687

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - C12M 1/00 (2010.01)
USPC - 435/292.1
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - C12M 1/00 (2010.01)
USPC - 435/292.1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
IPC(8) - C12M 3/00 (2010.01)
USPC - 435/283.1, 289.1, 293.1 search term limited

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
USPTO - PubWEST; Google. Search terms: algae array bioreactor cable conduit conical exchange frame framework frustoconical gas hang harvest helical helix hold hung light liquid photo photocell photosynthetic pipe pump pyramid reactor solar spiral strap sun sunlight support support supporting tube tubular wrap

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,970,166 A (Mori) 13 November 1990 (13.11.1990) fig 1, 2; title, abstract, col 1-3	1-22, 25-62
Y	US 4,184,481 A (Tornquist) 22 January 1980 (22.01.1980) fig 4, 13, 14; title; col 1-5	1-22, 25-62
Y	US 2005/0064577 A1 (Berzin) 24 March 2005 (24.03.2005) fig 1; para [0062], [0068], [0074], [0076], [0090], [0199], [0200]	1-9, 11-22, 25-32, 43-61
Y	US 6,679,247 B1 (Gozikowski) 20 January 2004 (20.01.2004) fig 2; col 3, 4	7-9, 22, 40, 50-52, 62

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 October 2010 (11.10.2010)	21 OCT 2010

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 10/45687

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 23 and 24
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.