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D. R. DEWEY II
SYSTEM FOR PHOTOSYNTHESIS

2,732,663

Filed May 21, 1952

3 Sheets-Sheet 1

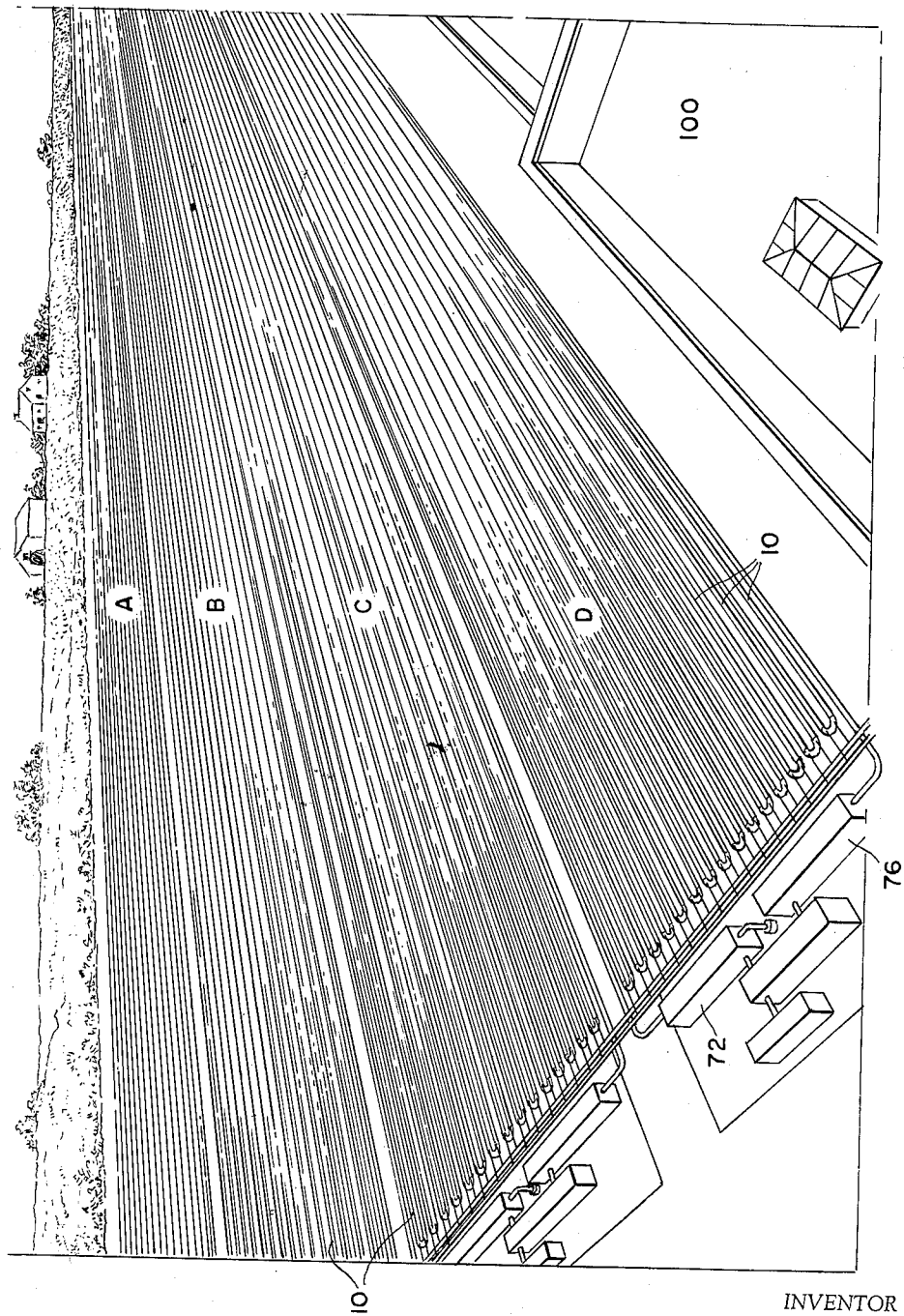


FIG. 1.

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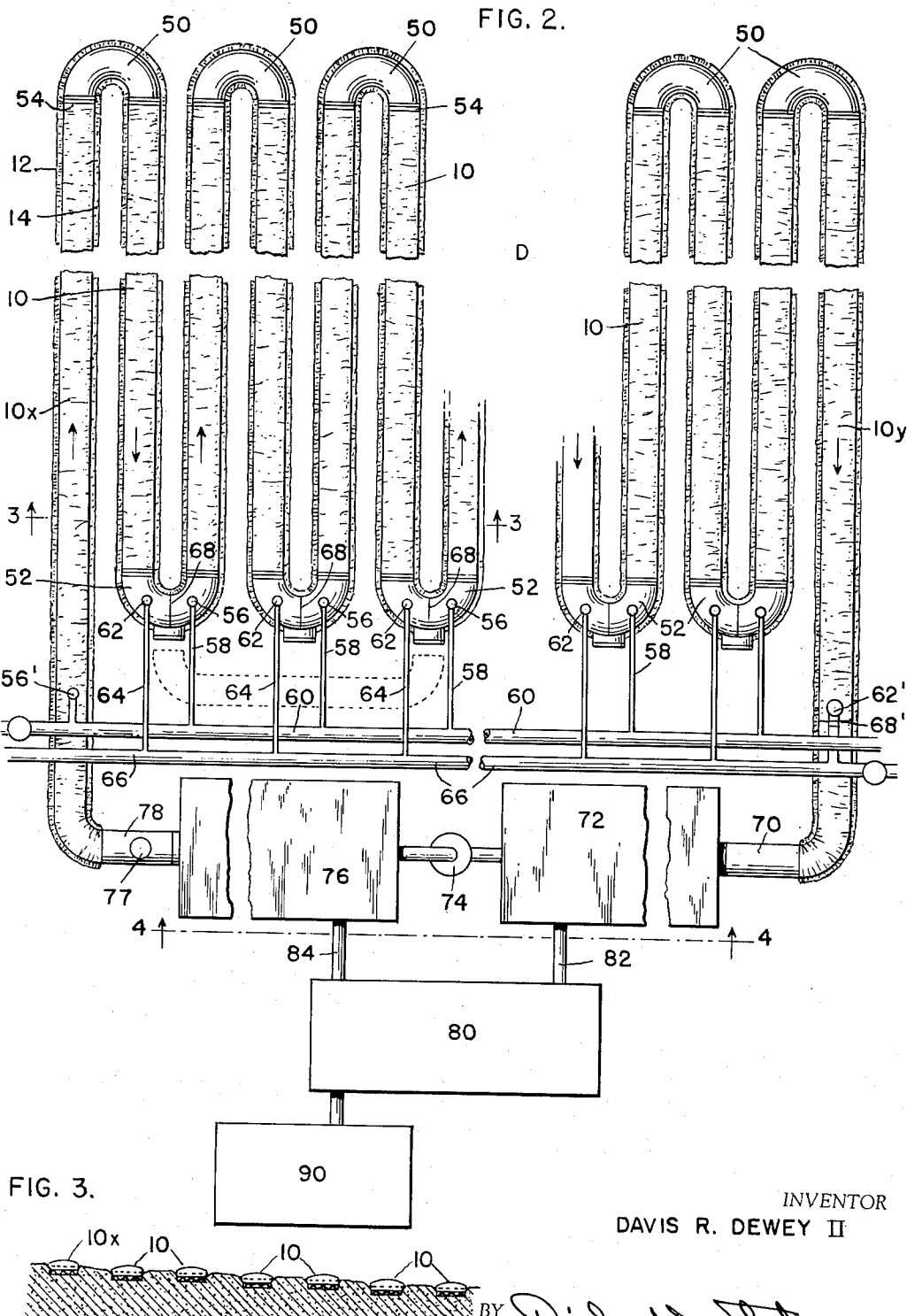
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3 Sheets-Sheet 2



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3 Sheets-Sheet 3

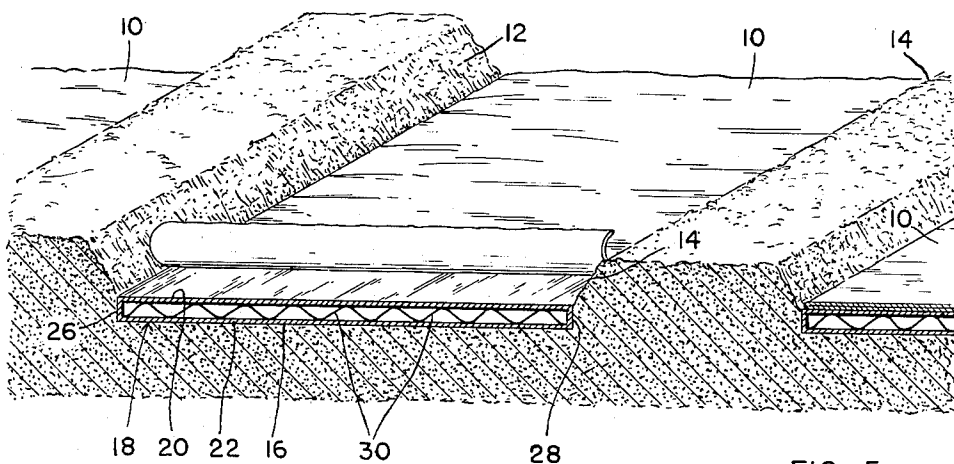


FIG. 5.

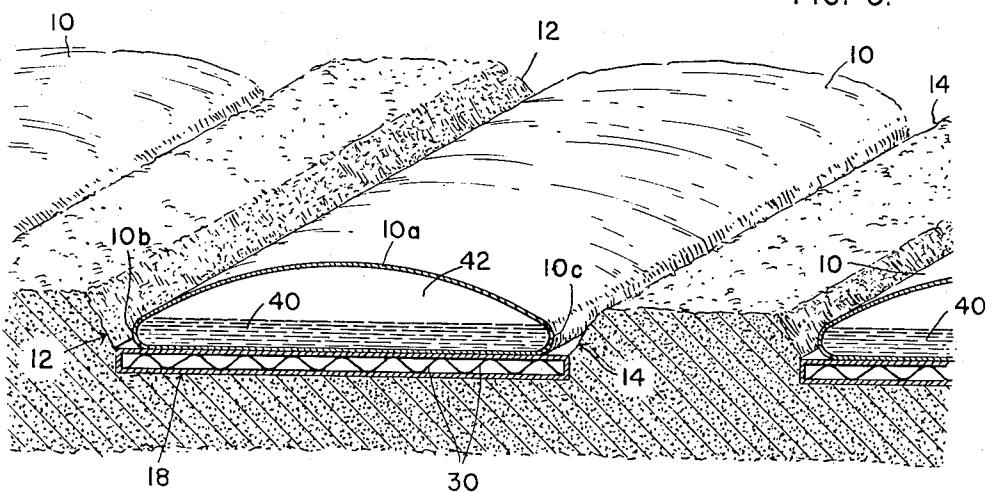


FIG. 6.

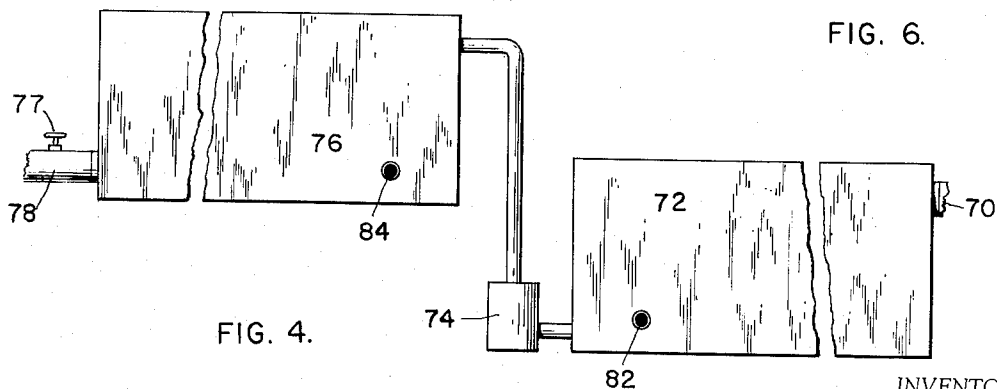


FIG. 4.

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2,732,663

SYSTEM FOR PHOTOSYNTHESIS

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13 Claims. (Cl. 47—58)

This invention relates to the culture of microorganisms, such as algae, by photosynthesis and particularly to the commercial production of mass quantities of algae as a source of protein, carbohydrate and lipide. The object of the invention is an efficient, low cost system for exposing to sunlight large volumes of culture liquid in contact with an artificial atmosphere of a carbon dioxide enriched gas while the liquid and gas are sealed against contamination by foreign organisms.

The system of this invention, in its preferred form, is characterized by one or more very long, thin-walled, highly flexible, translucent tubes, such as may be located on the ground, in shallow trenches if desired, to serve as conduits for the liquid and gas, in combination with mechanism for controlling the flow of liquid and gas through the flexible conduits. Means may be used for controlling the temperature of the liquid during its exposure to the sun.

The tubes are made of a plastic material of which many suitable types are available, and they are very inexpensive as a capital investment in relation to the volume of liquid and gas they will accommodate. Because of their extreme thinness and flexibility, the tubes, when empty, collapse to a double layer sheet, lengths of which may be readily stored in rolls of a size that is convenient for shipment and for use in laying the tubes. In a plant for mass culture, individual tubes of lengths of the order of thousands of feet may be used. The operation of laying the tubes by merely unwinding long strips from a supply roll and, where necessary, connecting successive sections together end to end, is a very inexpensive way of setting up a photosynthetic culture system for mass production.

When laid, the tubes conform to minor ground surface irregularities so that smoothing of the ground after grading, while desirable, is not critical. Replacement and maintenance are also very simple; the tubes may be patched, if punctured, or entire sections may be replaced with facility.

The nutrient liquid with suspended culture is introduced to the tube to cover the bottom to the desired depth, which may vary in accordance with operating requirements, and the flexible tube walls readily yield to receive the liquid and assume the cross-sectional shapes to accommodate different volumes. Gas, such as air or nitrogen, enriched with carbon dioxide is introduced to the tube over the liquid at low pressures such that the tube walls flex and become inflated. Although the tube is so flexible or limp as to collapse when empty, it does not require structural support or stiffening as it distorts into an approximation of the cross-sectional shape shown in Figure 6 when fluid is introduced into it. The precise geometrical cross-section varies but is very roughly an ellipse. The variation in shape depends partly upon the variations in internal pressure and partly upon external pressure, largely due to wind. If the tube billows excessively in a high wind, its upper surface may be made more taut by a reduction in the gas volume or by an increase in depth of the liquid,

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which increases the sidewise pressure of the liquid against the tube so widening and flattening the tube cross-section. Thus, the tube has the property of some adjustability of its cross-sectional configuration, if that is desired during operation and an optimum liquid depth can therefore easily be obtained.

Sunlight is efficiently transmitted through the tube wall and its thinness contributes to its translucence.

The thinness of the tube wall enhances its heat conductivity so that the application of cooling means such as a cold water spray over the top of the tube, or a liquid cooled metal plate located beneath and supporting the tube, efficiently and economically safeguards against overheating.

The dimensions of the tube, as to wall thickness and tube circumference, may vary depending upon tube materials and operating conditions. A thinner wall will have adequate tensile strength when used in a tube of smaller diameter, but tubes that are too small will add to the costs of installation and in operation may add excessively to the power costs for pumping. Within these limitations, tubes having circumferences of from about 8 inches up to about 20 feet may be used, and the wall thickness will range from about 1 mil to about 15 mils. The preferred circumference is from 8 to 12 feet, using a wall thickness ranging from about 2 to 6 mils, depending upon the material strength. Typically, a polyethylene tube 8 feet in circumference and of a 4 mils wall thickness has been used satisfactorily.

A number of tube materials are available which are adequately translucent, flexible and strong, in thicknesses within the desired range. Polyethylene is a preferred material because it is inherently flexible without resort to a plasticizer, but other plastic materials which have been made flexible by added plasticizer carefully selected as inert to the algae under culture and relatively permanent under the conditions of operation, may be used. Such other plastic materials include, for example, polymers of vinyl chloride, vinyl acetate, vinylidene chloride, polyvinyl acetals, styrenes, and acrylic esters and methacrylic esters or copolymers of one or more of these several polymerizable materials. Still other useful plastics are synthetic rubbers such as polydienes and copolymers thereof with styrene or acrylonitrile. Some of these materials are available under such commercial names as Vinylite, Cry-O-Vac, Saran and Tygon. Gas- and moisture-proof Cellophane may be used. As inert plasticizers, there may be used the relatively inert, high molecular weight ester type plasticizers such as the di octyl phthalate, esters or ethers of pentaerythritol, and others well known in the art.

A typical culture system layout is diagrammatically shown in the drawings, in which:

Fig. 1 is a perspective view of a system suggesting the extensiveness of the area of exposure for photosynthesis desired in a commercial mass culture plant;

Fig. 2 is a diagrammatic plan view of one of the sections of the system of Fig. 1 on a larger scale;

Fig. 3 is a vertical section on the line 3—3 of Fig. 2;

Fig. 4 is an elevation view partly in section along the line 4—4 of Fig. 2;

Fig. 5 is a perspective view on still larger scale showing one of the tubes being laid in place; and

Fig. 6 is a perspective view showing the tube in operation.

The numeral 10 in Fig. 5 designates a tube being laid in a trench having sloping side walls 12 and 14, which are desirably well packed or grouted, and a bottom 16 on which a cooler 18 rests. The cooler 18 may take any desired form but is shown as having a top plate 20 of metal and bottom plate 22 with side walls 26 and 28 forming a box-like enclosure containing the corrugated sheet metal 30. The corrugations form conduits for the pas-

sage of cold water in contact with the upper plate 20 of metal on which the tube rests. The cooler, of a length commensurate with the tube, is connected into the system by cold water supply and return headers (not shown) at opposite ends. In many instances adequate cooling does not require contact of the entire bottom surface of all tubes with the plate 20 as only a fraction of that contact area may be needed. The heat exchange apparatus may, of course, be used for heating by circulating warm water in winter operation, if desired.

Fig. 6 shows the tube in use with the nutrient liquid containing suspended algae designated at 40, and the gaseous medium containing carbon dioxide occupying the space 42. Upon the admission of the liquid and before the gas is introduced, the side walls 10b and 10c of the tube flex sufficiently to accommodate the liquid and recede slightly from the side walls 12 and 14 of the trench which they may have abutted when the tube was laid. The admission of gas inflates the top of the tube from a position in contact with the upper surface of the liquid to its position 10a of Fig. 6. The walls of the tube are very much thinner than the exaggerated thickness in the drawings, a typical dimension being, as stated, of the order of 4 mils thickness for a tube 8 feet in circumference.

The tubes may be laid out in parallel courses connected at their ends by suitable headers for a parallel flow arrangement or, if desired, they may be connected as shown in Fig. 2 by the U-tubes 50 and 52, so arranged that the conduits are connected in series to provide an effective continuous tube length of the order of perhaps several miles. The U-tubes 50 and 52 may be of coated sheet metal or of light or heavy plastic. The connections are tightly secured and sealed by suitable means such as clamps 54. In tubes of great length, the carbon dioxide enriched air should be periodically refreshed and the U-tubes 52 can conveniently serve as gas inlets and outlets for that purpose. 56 are the inlets connected by pipes 58 with supply conduits 60, and 62 are outlets leading through pipes 64 to return conduits 66. Dams 68 in the U-tubes serve to obstruct flow of the gas around the tube while permitting the liquid flow to continue. Inlet 56' supplies the initial inlet course 10x of the tube and a gas outlet 62' adjacent an appropriate dam 68' serves the outlet course 10y of the tube.

Nutrient liquid with suspended algae leaving the system through pipe 70 enters tank 72 from which it may be pumped by pump 74 into supply tank 76 for recirculation through the system by pipe 78. Valve 77 controls the rate of flow. The system shown operates by gravity, the ground area being appropriately sloped, either continuously or in steps, as suggested by Fig. 3, to provide a sufficient drop in level from inlet to outlet to overcome the resistance due to friction. The drop need not be great, something of the order of one foot or less per mile of conduit length for a eight-foot tube, and with the pump 74 affording the necessary hydrostatic head, as indicated by the difference in elevation of the tanks 72 and 76 in Fig. 4.

The numeral 80 designates diagrammatically the location of a housing which encloses, and maintains in uncontaminated condition, ancillary operating equipment such as circulating and harvesting pumps, centrifuges, control instruments, storage facilities, and the like, indicated as connected to the receiving tank 72 by pipe 82, and to the supply tank 76 by pipe 84. Desirably, a laboratory 90 is provided as a source of fresh inoculum made in small quantities under artificial or natural light and closely controlled conditions for use by the main system as required.

The layout of Fig. 1 suggests the extensiveness of a system which is needed for the culture by photosynthesis in sunlight of sufficiently large quantities of algae to make such microorganisms a commercially feasible source of vegetable by-product. Several independently oper-

ated tube systems A, B, C and D, each comparable to the system described with reference to Fig. 2 are serviced by ancillary equipment and laboratories located in the central processing house 100.

In operation, a nutrient liquid suitably inoculated with algae cells such as *Chlorella pyrenoidosa* is admitted to plastic tubing 10 by way of duct 78, the rate of flow being regulated by valve 77 to distribute the fluid culture, at desired depth, throughout the conduit system. Circulation is maintained by withdrawing the culture from the end of the system through pipe 70 and recirculating as desired by way of pump 74. Simultaneously, there is introduced gas enriched in carbon dioxide at various intermediate points 56, 56'. The gas and liquid establish an interface within the tube between the liquid phase and the gaseous phase by which the tube is partially inflated. The low pressure gas constituting the upper phase is circulated with or against the direction of liquid flow through the tube. The gas is withdrawn for replenishment through pipes 62, 62'.

This invention affords apparatus entailing exceptionally low capital, operational and maintenance costs for the photosynthesis of mass quantities of algae by a sealed system which handles large volumes of nutrient liquid at a high ratio of exposed surface area to volume.

Although continuous flow operation has been described as preferred because of its advantages, the system is adapted as well for batch operation with the culture liquid entering and returning periodically. The operation of harvesting may involve entrifuging all the culture, using fresh starting inoculum from the laboratory 90 or, if desired, a portion of the culture may be harvested by centrifuging and the remainder recirculated as inoculum. The nutrient liquid separated out in the harvesting operation is preferably restored to its optimum mineral nutrient content and then recirculated. Such details may be varied to suit specific requirements without departing from the spirit of this invention.

I claim:

1. A device for large scale culture of photosynthetic microorganisms comprising a light-permeable flexible limp tube, means for supporting said tube in an approximately horizontal position, means for introducing a liquid culture medium into one end of said approximately horizontal tube and thereby distending said tube into a cross-sectional shape having a predetermined height and width, and means for introducing a gaseous nutrient into said tube under pressure effective further to distend said tube into another cross-sectional shape having a height greater than and a width less than said predetermined height and width.

2. A device for large scale culture of photosynthetic microorganisms comprising a light-permeable flexible limp tube, means for supporting said tube in an approximately horizontal position, means for introducing liquid culture medium and gaseous nutrient into said tube, and means for releasing material from said tube at a rate to maintain said tube under an internal pressure establishing a predetermined cross-sectional shape of said tube.

3. A method for large scale culture of photosynthetic microorganisms comprising confining said microorganisms with a culture medium and a nutrient gas in a limp, light-permeable, horizontal envelope, and maintaining said envelope under an internal pressure effective to distend said envelope.

4. A method for large scale culture of photosynthetic microorganisms comprising supporting a light-permeable limp tube in a substantially horizontal position, introducing a liquid culture medium inoculated with said microorganisms into said tube, and also introducing a nutrient gas into said tube under a pressure effective to distend said tube into an approximately elliptical cross-sectional shape.

5. As an apparatus for large scale culture of photosynthetic microorganisms, a horizontally disposed light-

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permeable limp envelope distended into tubular form by internal fluid pressure, means for supplying fluid under pressure to one end of said envelope, and means for releasing fluid from the other end of said envelope.

6. A device for large scale culture of photosynthetic microorganisms comprising a horizontal supporting trough, a light-permeable envelope disposed in said trough, and means for establishing an internal pressure in said envelope to distend said envelope into a tube fitting and extending above said trough.

7. A system for photosynthesis of microorganisms including a horizontally disposed, flexible, translucent, tubular, plastic conduit, means for distorting said conduit by disposing a fluid culture medium as a layer in said conduit for exposure to light admitted through the translucent wall of said conduit, means for introducing a microorganism culture into said medium, means for distorting said conduit by disposing a carbon dioxide enriched gas in said conduit for exposure of said fluid medium thereto, and means for withdrawing cultured microorganisms from said conduit.

8. Apparatus as defined in claim 7 wherein means are provided for continuously circulating the fluid culture medium through the conduit under pressure required to maintain the conduit distended.

9. Apparatus as defined in claim 7 including means for cooling the fluid culture medium during its exposure to

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light, said cooling means including a support for said flexible conduit.

10. Apparatus as defined in claim 7 wherein the translucent tubing is formed of a highly flexible plastic material.

11. Apparatus as defined in claim 7 wherein the translucent tubing is formed of a highly flexible polyethylene.

12. Apparatus as defined in claim 7 wherein the flexible tubular conduit is disposed in a shallow trench cut into the earth in supporting relationship to the lower surface of said flexible conduit.

13. Apparatus as defined in claim 7 wherein the flexible tubular plastic conduit is superimposed on the cooling apparatus disposed in trenches cut into the earth in supporting relationship to a lower portion of said flexible conduit.

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