

Description

The present invention relates to an apparatus for photosynthesis comprising a photosynthetic reaction bath, a plurality of photoradiators arranged upright in said reaction bath in parallel with each other and a conduit communicating the reaction bath to a source of CO₂-containing air supply.

Photosynthetic apparatuses heretofore proposed include an apparatus for culturing chlorella (unicellular microorganism containing chlorophyll). Difficulty experienced in culturing chlorella is that illumination with intensities higher than a certain level destructs the chlorophyll and produces a toxin (phaeophorbite) while illumination with intensities lower than a certain level fails to cause photosynthesis altogether. It is therefore a primary requisite for effective photosynthesis that all the cells containing a photosynthetic substance be constantly supplied with light in even distribution. Generally, organisms in a swarm increase not only their multiplying ability per unit volume but their resistance to other fungi. The culturing efficiency, therefore, grows poor unless a predetermined light radiating area per one liter of culture medium is ensured. With this in view, it has been customary to promote the transmission of light by reducing the number of individuals of a photosynthetic substance. This involves an inconsistency, however, because an increase in the number of individuals lowers the transmissibility to light and, therefore, requires collection of the individuals, but the resulting decrease in the number of individuals weakens the resistance to the fungi. Another drawback hitherto encountered is that the light intensity is excessively high for the individuals near a light source but is insufficient for those remote from the light source and, additionally, the light is absorbed by water to have its wavelength component varied. An ideal situation is, therefore, that a photosynthetic substance be passed through a very narrow clearance while a predetermined intensity of light is directed perpendicular to the clearance. Then, sufficient light will be evenly applied to all the cells containing the photosynthetic substance with a minimum of attenuation and without any change in its wavelength component.

A photosynthetic apparatus presently in use includes a number of fluorescent lamps arranged in a reaction bath (e.g. chlorella culturing bath) and causes a photosynthetic substance to flow through the spaces between the lamps. However, the use of fluorescent lamps renders the apparatus bulky, increases power consumption and requires an awkward measure against heat generation by the lamps.

An apparatus as mentioned above is disclosed in US patent US-A-2 815 607 to Schroeder. This patent discloses a container having a false bottom with apertures so as to provide a series of streams of air. However, the upper end of the container is open to the atmosphere. The air

entering through the apertures in the false bottom merely passes upwardly through the medium and then out to the atmosphere through the open-ended top of the container. The photoradiators are spiral formed photoradiators.

From US-A-3 986 297, a photosynthetic apparatus is known comprising four light sources, being supported at the top of the apparatus. The CO₂-containing air is fed into the reaction bath by means of a nozzle bar.

From WO-A-7 900 282, a method of dispersing a light beam in a liquid culture medium is known. The photoradiators arranged in the culture medium form a screen. Nothing is disclosed in said document with regard to the entrance or the guiding of CO₂-containing air through the reaction bath.

It is the object of the present invention to provide an apparatus for photosynthesis which sets up an even distribution of CO₂-containing air for all the cells in the reaction bath and which automatically keeps its interior clear for a long period of time to facilitate services.

This task is solved with an apparatus having the features of claim 1. According to these features, the CO₂-containing air is fed into the reaction bath and is guided in the reaction bath along a predetermined path. This function can be established by the use of a baffle plate being disposed below the photoradiators and having a number of apertures in a predetermined area thereof which may be a radially central area or a generally annular peripheral area.

The function of the baffle plate may also be performed by plugging which blocks the passage of the air through the spacings between the lower ends of the adjacent photoradiators in the predetermined area. The recirculation of the air along a predetermined, but variable, path may be caused so more possible by a rotor which is positioned below the photoradiators and rotatable by ejecting the air while supplying it to the interior of the reaction bath. The rotor is cushioned and rotatably supported by the air ejected therefrom during operation.

Other objects, together with the foregoing, are attained in the embodiments described in the following description and illustrated in the accompanying drawings.

Brief description of the drawings

Fig. 1 is a sectional side elevation of an apparatus for photosynthesis embodying the present invention;

Fig. 2 is a section along line II—II of Fig. 1;

Fig. 3 is a section along line III—III of Fig. 1;

Fig. 4 is a fragmentary sectional side elevation of another embodiment of the present invention;

Fig. 5 is a section along line V—V of Fig. 4;

Fig. 6 is a view similar to Fig. 4 but showing another embodiment of the present invention;

Fig. 7 is a section along line VII—VII of Fig. 6;

Figs. 8 and 9 are sectional side elevations showing different examples of a check valve mechanism applicable to the present invention;

Fig. 10 is a fragmentary sectional side elevation of still another embodiment of the present invention; and

Fig. 11 is a section along line XI—XI of Fig. 10.

Description of the preferred embodiments

While the apparatus for photosynthesis of the present invention is susceptible of numerous physical embodiments, depending upon the environment and requirements of use, substantial numbers of the herein shown and described embodiments have been made, tested and used, and all have performed in an eminently satisfactory manner.

Referring to Figs. 1—3 of the drawings, the photosynthetic apparatus includes a reaction bath which is generally designated by the reference numeral 10. A number of photoradiators 12 in the form of narrow tubes are arranged upright and in parallel with each other within the reaction bath 10. Each of the photoradiators 12 is rigidly fit in a short tube 14 at its lower end in a fluid tight manner. The photoradiator 12 comprises a transparent tube or sheath 16, an optical rod 18 and a mirror 20 located at a lower end portion of each photoradiator 12. A lid 22 removably covers the top of the reaction bath 10 and has threaded openings 22a in which threaded upper portions 16a of the respective tubes 16 are engaged. Thus, when the lid 22 is removed from the reaction bath 10, it is accompanied by the photoradiators 12 to facilitate cleaning of the reaction bath 10 or the photoradiators 12. Fiber optic cables 24 are in threaded engagement respectively with the upper ends of the threaded portions 16a of the tubes 16 at their light output ends. In this position of each cable 24, its optical fiber 24a is aligned at its end with the end of the optical rod 18 in the associated photoradiator 12, so that the light propagating through the optical fiber 24a is effectively transferred to the optical rod 18.

Each optical rod 18 is made of quartz, plastics or the like. The rod 18 carries thereon a light diffusing material 18a at desirably spaced locations along its length. The light diffusing material 18a has a refractive index which is larger than that of quartz or plastics, thereby causing the light to break through the material 18a out of the rod 18.

A conduit 26 is communicated with the reaction bath 10 to supply CO₂-containing air thereinto. As shown in Fig. 3, the short tubes 14 in which the lower ends of the photoradiators 12 are fit are bonded together at their outer surfaces while defining gaps 28 therebetween. In the illustrated embodiment, the gaps 28 are stopped up in a central area of the reaction bath 10 (black gaps 28 in Fig. 3). CO₂-containing air fed into the reaction bath 10 by the conduit 26 flows through the open gaps 28 adjacent to the periphery of the bath 10, advances upward through the spaces between the photoradiators 12 as indicated by arrow A in Fig. 1, flows toward the center of the bath 10 at the upper end of the latter, flows down along the center as indicated by arrows B, and is then redirected by the closed gaps 28 in the central

area toward the periphery of the reaction bath 10, thus recirculating within the reaction bath 10. With this arrangement, the recirculating air moves at a substantial velocity along the outer periphery of each photoradiator 12 while entraining the culture medium, thereby preventing the photosynthetic substance from becoming deposited on the photoradiators 12. This frees the output light of the photoradiators 12 from interception to thereby supply all the photosynthetic substance with optical energy and CO₂ each in an even distribution.

It will be seen in the above embodiment that, if the area is made smaller at the region where the air flows downward than at the region where the air flows upward, the velocity of water will be increased at the downward flow region to minimize contamination to the photoradiators 12 in this region. While the gaps 28 in the central area of the bath 10 are stopped up in the illustrated embodiment, those in the peripheral area may be stopped up instead.

An auxiliary bath 27 is mounted on an upper side portion of the reaction bath 10 and communicated with the latter through openings 30 and 32 which are located one above the other. A valve 34 is positioned in the vicinity of the lower end of the auxiliary bath 27 so as to discharge the product of photosynthesis from the apparatus. A second valve 36 is mounted on the top of the auxiliary bath 27. This valve 36 is operable to supplement the culture medium and pH control solution to make up for the shortage which results from the discharge of the product through the valve 34. A third valve 38 is mounted on an upper side portion of the auxiliary bath 27 in order to controllably let the air out of the reaction bath 10 to control the pressure inside the reaction bath 10. Where use is made of a pressure regulating valve as the valve 38 for automatically controlling the bath pressure to a reference level, the CO₂ concentration in the water can be increased to promote photosynthesis and, at the same time, the pressure in the reaction bath 10 is prevented from lowering to change CO₂ into M⁺HCO₃⁻. Disposed inside the auxiliary bath 27 are various instruments 40 for monitoring the photosynthetic reaction in the reaction bath 10, e.g. thermometer, pressure gauge, pH meter and densitometer. The conditions inside the reaction bath 10 are so controlled as to effect photosynthesis in an optimum manner in response to outputs of such instruments. For example, the temperature in the reaction bath 10 may be controlled by controlling a heat generating/absorbing device 42 which is positioned in the auxiliary bath 27. Also, the outputs of the instruments are processed to notify the timing to collect the product.

As long as the photosynthetic reaction is to be carried out without interruption, the product will be collected through the auxiliary bath 27. When interruption of the reaction is permissible, the end (not shown) of the conduit 26 may be communicated to a vacuum source (not shown) or the like instead of the CO₂-containing air supply, so that

the product can be collected through the conduit 26.

Referring to Figs. 4 and 5, another embodiment of the present invention is shown which makes it needless to stop up the selected gaps 28 between the adjacent photoradiators 12. As previously described, the lower ends of the photoradiators 12 are respectively fit fluid-tight in the short tubes 14. The reference numeral 44 designates a baffle plate or obstruction plate which is rigidly supported by the reaction bath 10 in intimate contact with the bottoms of the photoradiators 12. The baffle plate 44 is formed with apertures 46 in its predetermined region A (corresponding to the region in Fig. 3 which contains the black gaps 28) and in positions corresponding to the gaps 28. The remaining region B of the baffle plate 44 is not formed with such apertures. In operation, the CO₂-containing air coming in through the conduit 26 is passed through the apertures 46 in the baffle plate 44 and caused to recirculate in the reaction bath 10 in the manner described with reference to Figs. 1-3. Thus, the baffle plate 44 unnecessitates the operation for plugging the selected gaps 28 in the desired area, thereby cutting down the production cost of the apparatus.

Referring to Figs. 6 and 7, another embodiment of the present invention is shown which is essentially similar to the embodiment of Figs. 4 and 5 but different therefrom in the position of the apertured baffle plate 44. As shown, the baffle plate 44 formed with the apertures 46 are supported by the reaction bath 10 at a predetermined spacing from the lower ends of the photoradiators 12. The apertures 46 are formed through the baffle plate 44 in the same region A as in the embodiment shown in Figs. 4 and 5. In this construction, the air supply through the conduit 26 causes part of the downwardly flowing culture medium to recirculate radially outward through the gaps between the photoradiators 12. However, the rest of the culture medium is allowed to flow straight onto the baffle plate 44 and then recirculate radially outward through the clearance between the bottoms of the photoradiators 12 and the baffle plate 44. This reduces the contamination to the upper end portions of the short tubes 14. Where the baffle plate 44 is spaced apart from the bottoms of the photoradiators 12 as in the embodiment shown in Figs. 6 and 7, the photoradiators 12 may be arranged in intimate contact with each other without using the short tubes 14, in order to substantially eliminate the contamination to the outer walls of the photoradiators 12. In this case, it is necessary to make the diameter of each photoradiator 12 smaller at the upper end than the lower end so that a passage is defined for the culture medium flown upward along the periphery (or the center) of the reaction bath 10 to be recirculated toward the center (or the periphery).

Where the baffle plate 44 is employed in the position shown in Figs. 4 and 5 or in the position shown in Figs. 6 and 7, the diameter of the

apertures 46 may be determined to allow the culture medium to pass therethrough so that the product can be collected through the conduit 26 (Fig. 1) by the vacuum source or the like (not shown). Alternatively, the apertures 46 may be provided with a diameter which passes air therethrough but not the culture medium. Figs. 8 and 9 illustrate other possible implements for allowing the air to pass through the apertures 46 into the reaction zone, while checking the culture medium in the reaction zone. In Fig. 8, each aperture 46 is generally tapered toward the reaction zone. In Fig. 9, a valve seat member 48 having a passageway 50 is threaded into each aperture 46 which is tapered as in the configuration of Fig. 8. The valve seat 48 coacts with a ball 52 movably received in the aperture 46. In any case, the aperture 46 furnished with such a checking function prevents the conduit 26 from being stopped up by the culture medium or the like.

Referring to Figs. 10 and 11, a farther embodiment of the present invention is shown which is designed to achieve more efficient and positive recirculation of the culture medium within the reaction bath 10. In this embodiment, the conduit 26 (Fig. 1) has an extension 26' which protrudes into the reaction bath 10 to a position below the photoradiators 12. The conduit extension 26' is shaped at its upper end portion to have an axial passageway 26'a and a plurality of radial passageways 26'b which extend obliquely and radially outwardly from the axial passageway 26'a. A rotor 56 is movably coupled over the top of the conduit extension 26'. The rotor 56 is formed with passageways 58 and a plurality of air ejection ports 60 which extend throughout the rotor 56 from each of the passageway 58 as illustrated.

In operation, air fed through the axial passageway 26'a of the conduit extension 26' is discharged from the radial passageways 26'b to impinge on side wall portions 58a of the respective passageways 58, thereby giving the rotor 56 the tendency to rotate clockwise as indicated by arrows R in Fig. 11. The air passed through the passageways 58 are ejected from the ejection ports 60 to drive the rotor 56 in the direction R. The rotor 56 is caused to float by the air coming out through the upper end of the axial passageway 26'a of the conduit extension 26', a clearance d_1 thus developing between the upper end of the conduit extension 26' and the rotor 56. This part of the air, therefore, flows radially outward through the clearance d_1 as indicated by arrows in Fig. 10. Meanwhile, the air flowing through the gap d_1 and the air discharged from the radial passageways 26'b is partly routed through an annular clearance d_2 between the outer surface of the conduit extension 26' and the inner wall of the rotor 56 into a clearance d_3 between the bottom of the rotor 56 and the bottom of the reaction bath 10. As a result, the air streams in the clearances d_1 and d_3 serve as an air cushion for supporting the rotor 56 while the air stream in the clearance d_2 functions as an air

bearing for rotatably supporting the rotor 56. The major torque acting on the rotor 56 is created by the air jets from the ejection ports 60. If desired, the rotor 56 may be formed with a through upward passageway 66 to pass the air into a clearance d_4 between the bottoms of the photoradiators 12 and the top of the rotor 56. The air stream in this clearance d_4 will more effectively air-cushion the rotor 56 in cooperation with the other air streams.

The embodiment described above with reference to Figs. 10 and 11 achieves various advantages. Because the rotation of the rotor 56 affects the pneumatic pressure distribution in the bottom section of the reaction bath 10, the air recirculation path in the reaction bath 10 progressively changes moment by moment. This as a whole distributes CO_2 -containing air uniformly to all the air stream paths and, thereby, causes the reaction to occur more effectively. The culture medium, photosynthetic substance and the like falling toward the bottom of the reaction bath 10 are entrained upwardly by the air jets from the ejection ports 60, whereby dead part of the photosynthetic substance or the like is prevented from accumulating in the bottom of the reaction bath 10. If any such undesired accumulation is anticipated, the ejection ports 60 may be directed somewhat downwardly so that the accumulation will be scattered upwardly by the air jets. The bottom of the reaction bath 10 can thus be maintained clean for a long time. While the rotor 56 has been shown and described as being rotatably supported by the air bearing and air cushioning, use may be made of an ordinary mechanical bearing for the same purpose. The air bearing is still advantageous over the mechanical bearing because the rotor 56 needs only be placed between the conduit 26 and the photoradiators 12 and, therefore, it can be readily mounted and demounted to facilitate services.

Where the reaction bath 10 is formed not circular but polygonal such as hexagonal as in the foregoing embodiments, the passageways 58 formed in the rotor 56 may be extended to eject the air radially outward from the ends 58b of the rotor 56 and thereby effectively direct the air to the gaps 28 adjacent to the periphery of the reaction bath 10. Supposing that the outermost ends of the rotor 56 move along the locus indicated by a dotted circle Q in Fig. 3, the resistance to the air ejection is larger when the ports 58b are in the positions as close to the wall of the reaction bath 10 than when they are in the positions b remote from the bath wall. The air, therefore, can be supplied substantially evenly to the air passages in both sections a and b. The rotor 56 may be formed with air ejection ports which are directed upwardly toward the photoradiators 12, thereby forcibly causing the air to flow through the gaps 28 in accordance with the movement of the rotor 56. Furthermore, the forced recirculation of air makes it needless to plug the selected gaps 28 (see Fig. 3).

In summary, it will be seen that the present

invention provides an apparatus for photosynthesis which promotes efficient photosynthetic reaction despite its simple and compact construction. Also, the apparatus can be kept clean over a long period of time to facilitate maintenance and inspection.

Various modifications will become possible for those skilled in the art after receiving the teachings of the present disclosure without departing from the scope thereof. For example, each photoradiator 12 may have a structure whose refractive index is larger in a peripheral section than in a central section, omitting the light diffusing material 12a shown in Fig. 1. In this connection, the use of rod-shaped optical conductors 18 as in Fig. 1 ensures linearity and facilitates their installation in the photoradiators 12. Two or more optical fibers 24a may be accommodated in each fiber optic cable 24; at least one of the optical fibers may be supplied with converged sunlight and at least one of the rest with artificial light. This allows the natural and artificial light to be used selectively: only the sunlight when it is intense, both the sunlight and artificial light in the morning and evening as well as in cloudy weather, and only the artificial light when the sunlight is unavailable at all as in the night. The cross-section of the tubes 16 of the photoradiators 12 is not limited to the illustrated circle but may be a polygon such as a triangle, a square or a hexagon. Likewise, the hexagonal cross-section of the reaction bath 10 is not restrictive but may be replaced with any other desired one.

Claims

1. An apparatus for photosynthesis comprising:
 - a photosynthetic reaction bath (10);
 - a plurality of photoradiators (12) arranged upright in said reaction bath in parallel with each other;
 - a conduit (26) communicating the reaction bath to a source of CO_2 -containing air supply characterised in that
 - the photoradiators (12) have an elongated tubular form, and
 - means (14, 22, 28, 44) are provided for recirculating the CO_2 -containing air in the reaction bath along a certain predetermined loop-like path (A, B), said path being provided along the outer periphery of each photoradiator (12), thus preventing the photosynthetic substance from becoming deposited on the photoradiators (12).
2. An apparatus as claimed in claim 1, in which the photoradiators are spaced from each other, the recirculation means comprising plug members for plugging the spacings (28) between lower portions of the adjacent photoradiators (12) in a predetermined area (B).
3. An apparatus as claimed in claim 2, in which the spacings (28) between the adjacent photoradiators are defined by short tubes (14) in which lower end portions of the respective photoradiators (12) are fit fluid-tight.
4. An apparatus as claimed in claim 2, in which

bearing for rotatably supporting the rotor 56. The major torque acting on the rotor 56 is created by the air jets from the ejection ports 60. If desired, the rotor 56 may be formed with a through upward passageway 66 to pass the air into a clearance d_4 between the bottoms of the photoradiators 12 and the top of the rotor 56. The air stream in this clearance d_4 will more effectively air-cushion the rotor 56 in cooperation with the other air streams.

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invention provides an apparatus for photosynthesis which promotes efficient photosynthetic reaction despite its simple and compact construction. Also, the apparatus can be kept clean over a long period of time to facilitate maintenance and inspection.

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 - a conduit (26) communicating the reaction bath to a source of CO_2 -containing air supply characterized in that
 - the photoradiators (12) have an elongated tubular form, and
 - means (14, 22, 28, 44) are provided for recirculating the CO_2 -containing air in the reaction bath along a certain predetermined loop-like path (A, B), said path being provided along the outer periphery of each photoradiator (12), thus preventing the photosynthetic substance from becoming deposited on the photoradiators (12).
2. An apparatus as claimed in claim 1, in which the photoradiators are spaced from each other, the recirculation means comprising plug members for plugging the spacings (28) between lower portions of the adjacent photoradiators (12) in a predetermined area (B).
3. An apparatus as claimed in claim 2, in which the spacings (28) between the adjacent photoradiators are defined by short tubes (14) in which lower end portions of the respective photoradiators (12) are fit fluid-tight.
4. An apparatus as claimed in claim 2, in which



the predetermined area (B) is a radially central area in the reaction bath (10).

5 5. An apparatus as claimed in claim 2, in which the predetermined area (B) is a generally annular area adjacent to the periphery of the reaction bath (10).

6. An apparatus as claimed in claim 2, in which the predetermined area (B) is smaller than the rest.

7. An apparatus as claimed in claim 1, in which the recirculation means comprises a plate (44) formed with a plurality of apertures (46) in a predetermined area (A) thereof and located below the bottoms of the photoradiators (12).

8. An apparatus as claimed in claim 7, in which the plate (44) is engaged with the bottoms of the photoradiators (12) which are spaced from each other.

9. An apparatus as claimed in claim 8, in which the spacings (28) between the adjacent photoradiators (12) are defined by short tubes (14) in which lower end portions of the respective photoradiators (12) are fit fluid-tight.

10. An apparatus as claimed in claim 8, in which the predetermined area (A) is a radially central area in the reaction bath (10).

11. An apparatus as claimed in claim 8, in which the predetermined area (A) is a generally annular area adjacent to the periphery of the reaction bath (10).

12. An apparatus as claimed in claim 8, in which the predetermined area (A) is larger than the rest.

13. An apparatus as claimed in claim 7, in which the plate (44) is spaced from the bottoms of the photoradiators (12) which are engaged with each other.

14. An apparatus as claimed in claim 13, in which the predetermined area (A) is a radially central area in the reaction bath.

15. An apparatus as claimed in claim 13, in which the predetermined area (A) is a generally annular area adjacent to the periphery of the reaction bath.

16. An apparatus as claimed in claim 13, in which the predetermined area (A) is larger than the rest.

17. An apparatus as claimed in claim 13, in which each of the photoradiators (12) has a diameter which is smaller at the upper end than at the lower end.

18. An apparatus as claimed in claim 7, in which each of the apertures (46) has a diameter which allows a culture medium to pass therethrough, the conduit (26) being communicatable to a vacuum source during collection of the product of photosynthesis.

19. An apparatus as claimed in claim 7, in which each of the apertures (46) has a diameter which passed the air while blocking a culture medium.

20. An apparatus as claimed in claim 7, further comprising check valve means (48, 50, 52) for preventing a culture medium from dropping through the apertures (46) while permitting the air to pass therethrough.

21. An apparatus as claimed in claim 20, in

which the check valve means comprises an upwardly tapered bore (46) which is defined by each of the apertures.

22. An apparatus as claimed in claim 21, in which the check valve means comprises a valve seat member (48) screwed into the lower end of the tapered bore (46) and a ball (52) movably seated on said valve seat member (48) inside the tapered bore (46).

23. An apparatus as claimed in claim 1, in which the recirculation means (56, 60) causes the air to recirculate along a certain but loop-like variable path in the reaction bath.

24. An apparatus as claimed in claim 23, in which the recirculation means comprises a recirculation member (56, 60) which varies the recirculation path by varying the pneumatic pressure distribution in a bottom portion of the reaction bath.

25. An apparatus as claimed in claim 24, in which the conduit (26) has an extension (26') which projects into the bottom portion of the reaction bath (10), the recirculation member comprising a rotor (56) rotatably coupled over the conduit extension (26') and constructed to rotate ejecting jets of the air supplied from the conduit from air ejection ports (60) formed therein, said rotor (56) supplying the air into the reaction bath (10) during rotation thereof.

26. An apparatus as claimed in claim 25, in which the rotor is supported by an air bearing (d_2) formed by the air during rotation thereof.

27. An apparatus as claimed in claim 25, the reaction bath (10) has polygonal cross-section, the rotor (56) further comprising air ejection ports which are respectively open radially outwardly of the rotor.

28. An apparatus as claimed in claim 1, further comprising an auxiliary bath (27) communicated with an upper portion of the reaction bath (10).

29. An apparatus as claimed in claim 28, in which the auxiliary bath (27) is communicated with the reaction bath (10) by at least two vertically spaced ports (30, 32).

30. An apparatus as claimed in claim 28, in which the auxiliary bath (27) is formed with a product outlet (34) at a lower end portion thereof and an air outlet (38) and a culture medium inlet (36) at an upper portion thereof.

31. An apparatus as claimed in claim 30, in which a pressure regulator valve (38) is associated with the air outlet for automatically regulating the pressure inside the reaction bath (10).

32. An apparatus as claimed in claim 28, further comprising a heat generating and absorbing unit (42) disposed in the auxiliary bath (27) for controlling the temperature inside the reaction bath.

33. An apparatus as claimed in claim 1, in which each of the photoradiators (12) comprises a transparent tubular sheath (16), an optical rod (18) extending through said tubular sheath (16), and a light diffusing means (18a) for diffusing light transmitted through said optical rod to the outside into the reaction chamber.

34. An apparatus as claimed in claim 33, in



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which the light diffusing means (18a) comprises a light diffusing material carried on the optical rod (18) at spaced locations along the length of the rod.

35. An apparatus as claimed in claim 33, in which the light diffusing means (18a) comprises a radially outer section of the optical rod (18) which is larger in refractive index than the remaining part of the optical rod.

36. An apparatus as claimed in claim 33, further comprising fiber optic cables (24a) each having at least two optical fibers therein and optically connected with the optical rod (18) in one of the photoradiators (12), at least one of the optical fibers being supplied with converged sunlight and at least one of the rest being supplied with artificial light.

37. An apparatus as claimed in claim 1, further comprising reflector means (20) which defines the inner surface of the lower end of each of the photoradiators (12).

38. An apparatus as claimed in claim 1, further comprising a lid (24) which removably covers the upper end of the reaction bath (10), the photoradiators (12) being mounted fluid-tight on the lid (24) at upper end portions thereof.

Patentansprüche

1. Photosynthesevorrichtung mit einem Reaktionsbad (10) für die Photosynthese; mit mehreren Leuchtkörpern (12), die aufrecht in dem Reaktionsbad parallel zueinander angeordnet sind und mit einer Leitung (26), die das Reaktionsbad mit einer Versorgungsquelle für CO₂ enthaltende Luft verbindet, dadurch gekennzeichnet,

daß die Leuchtkörper (12) eine längliche Röhrenform aufweisen und daß eine Einrichtung (14, 22, 28, 44) vorgesehen ist, mit der CO₂ enthaltende Luft in dem Reaktionsbad entlang eines vorbestimmten schleifenartigen Weges (A, B) rezirkuliert wird, wobei sich der Weg entlang des Außenumfangs jedes Leuchtkörpers (12) erstreckt, so daß photosynthetische Substanzen daran gehindert werden, sich auf den Leuchtkörpern (12) niederzuschlagen.

2. Vorrichtung nach Anspruch 1, wobei die Leuchtkörper beabstandet zueinander angeordnet sind, und wobei die die Rezirkulation bewirkende Einrichtung Steckerelemente aufweist, mit denen Zwischenräume (25) zwischen den unteren Bereichen benachbarter Leuchtkörper (12) in einem bestimmten Flächenbereich (B) zugestopft werden können.

3. Vorrichtung nach Anspruch 2, wobei die Zwischenräume (28) zwischen benachbarten Leuchtkörpern durch kurze Röhren (14) festgelegt werden, in deren unteren Enden entsprechende Leuchtkörper (12) flüssigkeitsdicht angepaßt sind.

4. Vorrichtung nach Anspruch 2, wobei der vorbestimmte Flächenbereich (B) ein radial in der Mitte gelegener Flächenbereich in dem Reaktionsbad (10) ist.

5. Vorrichtung nach Anspruch 2, wobei der

bestimmte Flächenbereich (B) die Form einer Ringfläche hat, die sich entlang des Umfangsbereichs des Reaktionsbades (10) erstreckt.

6. Vorrichtung nach Anspruch 2, wobei die bestimmte Fläche (B) kleiner als die übrige Fläche ist.

7. Vorrichtung nach Anspruch 1, wobei die die Rezirkulation bewirkende Einrichtung eine Platte (44) aufweist, die mehrere Öffnungen (46) in einem bestimmten Bereich (A) besitzt und die unter den Sockeln der Leuchtkörper (12) angeordnet ist.

8. Vorrichtung nach Anspruch 7, wobei die Platte (44) in Eingriff mit den Sockeln der Leuchtkörper (12) steht, die beabstandet zueinander angeordnet sind.

9. Vorrichtung nach Anspruch 8, wobei die Zwischenräume (28) zwischen benachbarten Leuchtkörpern (12) von kurzen Röhren (14) gebildet werden, in denen die unteren Endbereiche der entsprechenden Leuchtkörper (12) flüssigkeitsdicht angepaßt sind.

10. Vorrichtung nach Anspruch 8, wobei die vorbestimmte Fläche (A) der radial in der Mitte gelegene Flächenbereich des Reaktionsbades (10) ist.

11. Vorrichtung nach Anspruch 8, wobei der bestimmte Flächenbereich (A) im wesentlichen ein ringförmiger Flächenbereich ist, der sich im Umfangsbereich des Reaktionsbades (10) erstreckt.

12. Vorrichtung nach Anspruch 8, wobei der bestimmte Flächenbereich (A) größer als die übrige Fläche ist.

13. Vorrichtung nach Anspruch 7, wobei die Platte (44) beabstandet zu den Sockeln der Leuchtkörpern (12) angeordnet ist, die miteinander in Verbindung gebracht sind.

14. Vorrichtung nach Anspruch 13, wobei der bestimmte Flächenbereich (A) der radial mittig gelegene Flächenbereich im Reaktionsbad ist.

15. Vorrichtung nach Anspruch 13, wobei der vorbestimmte Flächenbereich (A) die Form einer ringförmigen Fläche hat, die am Umfangsbereich des Reaktionsbades sich erstreckt.

16. Vorrichtung nach Anspruch 13, wobei der vorbestimmte Flächenbereich (A) größer als der übrige Flächenbereich ist.

17. Vorrichtung nach Anspruch 13, dadurch gekennzeichnet, daß jeder Leuchtkörper (12) einen Durchmesser hat, der am oberen Ende kleiner als am unteren Ende ist.

18. Vorrichtung nach Anspruch 7, wobei jede Öffnung (46) einen Durchmesser hat, der es ermöglicht, daß ein Züchtmedium hindurchtreten kann, und wobei die Leitung (26) an eine Vakuumquelle während des Einsammelns des Produktes der Photosynthese anschließbar ist.

19. Vorrichtung nach Anspruch 7, wobei jede Öffnung (46) einen Durchmesser hat, die zwar Luft hindurchläßt, das Züchtmedium jedoch sperrt.

20. Vorrichtung nach Anspruch 7, die weiterhin ein Sperrventil (48, 50, 52) aufweist, das verhindert, daß das Züchtmedium durch die Öffnungen



(46) fällt, während es jedoch einen Luftdurchtritt ermöglicht.

21. Vorrichtung nach Anspruch 20, wobei das Ventil eine nach oben zulaufende Bohrung (46) aufweist, die jeweils von den Öffnungen gebildet wird.

22. Vorrichtung nach Anspruch 21, wobei das Sperrventil einen Ventilsitz (48) aufweist, der in das untere Ende der zulaufenden Bohrung (46) eingeschraubt ist und eine Ventilkugel (52); die beweglich auf dem Ventilsitzelement (48) innerhalb der zulaufenden Bohrung (46) gelagert ist.

23. Vorrichtung nach Anspruch 1, wobei die die Rezirkulation bewirkende Einrichtung (56, 60) eine Luftzirkulation entlang eines bestimmten, schlaufenförmigen variablen Weges in dem Reaktionsbad hervorruft.

24. Vorrichtung nach Anspruch 23, wobei die Rezirkulationseinrichtung ein Rezirkulationselement (56, 60) aufweist, das den Rezirkulationsweg verändert, indem die pneumatische Druckverteilung im Bodenbereich des Reaktionsbades verändert wird.

25. Vorrichtung nach Anspruch 24, wobei die Leitung (26) einen Fortsatz (26') hat, der sich in den Bodenbereich des Reaktionsbades (10) hinein erstreckt, und wobei die Rezirkulationseinrichtung einen Rotor (56) aufweist, der drehbar auf dem Fortsatz (26') der Leitung gelagert ist und der so ausgestaltet ist, daß er unter Drehung über die Leitung zugeführte Luft aus Luftausströmöffnungen (60), die darin ausgebildet sind, austreten läßt, und wobei der Rotor (56) unter Eigendrehung Luft in das Reaktionsbad (10) einleitet.

26. Vorrichtung nach Anspruch 25, wobei der Rotor über ein Luftkissen (D2) gelagert ist, das von der Luft während der Drehung des Rotors erzeugt wird.

27. Vorrichtung nach Anspruch 25, wobei das Reaktionsbad (10) einen Polygonquerschnitt hat, und wobei der Rotor (56) weiterhin Luftaustrittsöffnungen aufweist, die radial zur Außenseite des Rotors hin öffnen.

28. Vorrichtung nach Anspruch 1, wobei weiterhin ein Hilfsbad (21) vorgesehen ist, das mit einem oberen Teil des Reaktionsbades (10) in Verbindung steht.

29. Vorrichtung nach Anspruch 28, wobei das Hilfsbad (27) mit dem Reaktionsbad (10) über wenigstens zwei vertikal beabstandete Öffnungen (30, 32) in Verbindung steht.

30. Vorrichtung nach Anspruch 28, wobei das Hilfsbad (27) mit einem Produktauslaß (34) am unteren Ende und einem Luftauslaß (38) und einem Züchtmediumeinlaß (36) am oberen Bereich versehen ist.

31. Vorrichtung nach Anspruch 30, wobei ein Druckregelventil (38) im Luftauslaß zur automatischen Regulierung des Drucks innerhalb des Reaktionsbades (10) angeordnet ist.

32. Vorrichtung nach Anspruch 28, wobei weiterhin eine wärmeerzeugende und absorbierende Einheit (42) in dem Hilfsbad (27) angeordnet ist, um die Temperatur im Reaktionsbad zu steuern.

33. Vorrichtung nach Anspruch 1, wobei jeder

Leuchtkörper (12) eine transparente röhrenförmige Ummantelung (16) aufweist, einen optischen Leiterstab (18), der sich durch die röhrenförmige Ummantelung hindurch erstreckt und lichtabgebende Einrichtungen (18a), die das durch den optischen Leiterstab hindurchtretende Licht auskoppelt und in die Reaktionskammer strahlt.

34. Vorrichtung nach Anspruch 33, wobei die lichtauskoppelnde Einrichtung (18a) ein lichtstreuendes Material aufweist, das auf dem optischen Leiterstab (18) in bestimmten Abständen über die Länge des Stabes aufgetragen ist.

35. Vorrichtung nach Anspruch 33, wobei die lichtauskoppelnde Einrichtung (18a) einen radialen äußeren Bereich des optischen Leiterstabs (18) umfaßt, dessen Brechungsindex größer als der übrige Teil des optischen Leiterstabes ist.

36. Vorrichtung nach Anspruch 33, wobei weiterhin faseroptische Kabel (24a) vorgesehen sind, die im Inneren jeweils wenigstens zwei optische Fasern aufweisen und optisch mit dem optischen Leiterstab (18) in einem der Leuchtkörper (12) verbunden sind, wobei wenigstens eine optische Faser mit gesammeltem Sonnenlicht gespeist wird und wenigstens eine der übrigen Fasern mit Kunstlicht versorgt wird.

37. Vorrichtung nach Anspruch 1, mit einem Reflektor (20), der die Innenfläche der unteren Enden jedes Leuchtkörpers (12) bildet.

38. Vorrichtung nach Anspruch 1, mit einem Deckel (24), der abnehmbar das obere Ende des Reaktionsbades (10) abdeckt, wobei die Leuchtkörper (12) flüssigkeitsdicht mit ihren oberen Enden an diesem Deckel (24) befestigt sind.

Revendications

1. Un appareil de photosynthèse comprenant:
un bain de réaction de photosynthèse (10);
une pluralité de photoradiateurs (12) disposés verticalement dans ledit bain de réaction parallèlement entre eux;

un conduit (26) mettant en communication le bain de réaction avec une source d'alimentation en air contenant du CO₂, caractérisé en ce que les photoradiateurs (12) ont une forme tubulaire allongée, et il est prévu des moyens (14, 22, 28, 44) pour recirculer l'air contenant du CO₂ dans le bain de réaction le long d'un certain trajet prédéterminé en forme de boucle (A, B), ledit trajet étant placé le long de la périphérie extérieure de chaque photoradiateur (12), en empêchant ainsi la substance de photosynthèse de se déposer sur les photoradiateurs (12).

2. Un appareil tel que revendiqué dans la revendication 1, dans lequel les photoradiateurs sont espacés l'un de l'autre, les moyens de recirculation comprennent des éléments formant tampons pour obturer les espaces (28) existant entre des parties inférieures des photoradiateurs adjacents (12) dans une zone prédéterminée (B).

3. Un appareil tel que revendiqué dans la revendication 2, dans lequel les espacements (28) existant entre les photoradiateurs adjacents sont





définis par de courts tubes (14) dans lesquels sont montées de façon étanche au fluide des parties extrêmes inférieures des photoradiateurs respectifs (12).

4. Un appareil tel que revendiqué dans la revendication 2, dans lequel la zone prédéterminée (B) est une zone radialement centrale dans le bain de réaction (10).

5. Un appareil tel que revendiqué dans la revendication 2, dans lequel la zone prédéterminée (B) est une zone annulaire dans l'ensemble et adjacente à la périphérie du bain de réaction (10).

6. Un appareil tel que revendiqué dans la revendication 2, dans lequel la zone prédéterminée (B) est plus petite que le reste.

7. Un appareil tel que revendiqué dans la revendication 1, dans lequel les moyens de recirculation comprennent une plaque (44) pourvue d'une pluralité d'orifices (46) dans une zone prédéterminée (A) et située en dessous des bases des photoradiateurs (12).

8. Un appareil tel que revendiqué dans la revendication 7, dans lequel la plaque (44) est en contact avec les bases des photoradiateurs (14) qui sont espacés l'un de l'autre.

9. Un appareil tel que revendiqué dans la revendication 8, dans lequel les espacements (28) entre les photoradiateurs adjacents (12) sont définis par de courts tubes (14) dans lesquels sont montées de façon étanche au fluide les parties extrêmes inférieures des photoradiateurs respectifs (12).

10. Un appareil tel que revendiqué dans la revendication 8, dans lequel la zone prédéterminée (A) est une zone radialement centrale dans le bain de réaction (10).

11. Un appareil tel que revendiqué dans la revendication 8, dans lequel la zone prédéterminée (A) est une zone annulaire dans l'ensemble et adjacente à la périphérie du bain de réaction (10).

12. Un appareil tel que revendiqué dans la revendication 8, dans lequel la zone prédéterminée (A) est plus grande que le reste.

13. Un appareil tel que revendiqué dans la revendication 7, dans lequel la plaque (44) est espacée des bases des photoradiateurs (12) qui sont en contact l'un avec l'autre.

14. Un appareil tel que revendiqué dans la revendication 13, dans lequel la zone prédéterminée (A) est une zone radialement centrale dans le bain de réaction.

15. Un appareil tel que revendiqué dans la revendication 13, dans lequel la zone prédéterminée (A) est une zone annulaire dans l'ensemble et adjacente à la périphérie du bain de réaction.

16. Un appareil tel que revendiqué dans la revendication 13, dans lequel la zone prédéterminée (A) est plus grande que le reste.

17. Un appareil tel que revendiqué dans la revendication 13, dans lequel chacun des photoradiateurs (12) a un diamètre qui est plus petit à son extrémité supérieure qu'à son extrémité inférieure.

18. Un appareil tel que revendiqué dans la revendication 7, dans lequel chacun des orifices

(46) a un diamètre qui permet le passage d'un milieu de culture, le conduit (26) pouvant communiquer avec une source de vide pendant une collecte du produit de photosynthèse.

19. Un appareil tel que revendiqué dans la revendication 7, dans lequel chacun des orifices (46) a un diamètre qui laisse passer l'air tout en arrêtant un milieu de culture.

20. Un appareil tel que revendiqué dans la revendication 7, comprenant en outre une valve d'arrêt (48, 50, 52) pour empêcher un milieu de culture de descendre par les orifices (46) tout en permettant à l'air de passer par ces derniers.

21. Un appareil tel que revendiqué dans la revendication 20, dans lequel la valve d'arrêt comprend un trou (46) de profil conique vers le haut qui est défini par chacun des orifices.

22. Un appareil tel que revendiqué dans la revendication 21, dans lequel la valve d'arrêt comprend un siège de valve (48) vissé dans l'extrémité inférieure du trou conique (46) et une bille (52) déplaçable de façon à s'appuyer contre le siège (48) à l'intérieur du trou conique (46).

23. Un appareil tel que revendiqué dans la revendication 1, dans lequel les moyens de recirculation (56, 60) assurent une recirculation de l'air le long d'un certain trajet variable en forme de boucle dans le bain de réaction.

24. Un appareil tel que revendiqué dans la revendication 23, dans lequel le moyen de recirculation comprend un élément de recirculation (56, 60) qui modifie le trajet de recirculation en faisant varier la distribution de pression pneumatique dans une partie de base du bain de réaction.

25. Un appareil tel que revendiqué dans la revendication 24, dans lequel le conduit (26) comporte un prolongement (26') qui fait saillie dans la partie de base du bain de réaction (10), l'élément de recirculation comprenant un rotor (56) monté de façon tournante sur le prolongement de conduit (26) et agencé pour tourner en éjectant des jets d'air provenant du conduit à partir d'orifices d'éjection d'air (60) formés dans le rotor, ledit rotor (56) alimentant en air le bain de réaction (10) pendant sa rotation.

26. Un appareil tel que revendiqué dans la revendication 25, dans lequel le rotor est supporté par un palier pneumatique (d_2) formé par l'air au cours de sa rotation.

27. Un appareil tel que revendiqué dans la revendication 25, dans lequel le bain de réaction (10) a une section droite polygonale, le rotor (56) comprenant en outre des orifices d'éjection d'air qui sont respectivement ouverts radialement vers l'extérieur du rotor.

28. Un appareil tel que revendiqué dans la revendication 1, comprenant en outre un bain auxiliaire (27) en communication avec une partie supérieure du bain de réaction (10).

29. Un appareil tel que revendiqué dans la revendication 28, dans lequel le bain auxiliaire (27) est en communication avec le bain de réaction (10) par au moins deux orifices espacés verticalement (30, 32).

30. Un appareil tel que revendiqué dans la



(9)

revendication 28, dans lequel le bain auxiliaire (27) est pourvu d'une sortie de produit (34) dans une partie extrême inférieure et d'une sortie d'air (38) ainsi que d'une entrée de milieu de culture (36) dans une partie supérieure.

31. Un appareil tel que revendiqué dans la revendication 30, dans lequel une valve de régulation de pression (38) est associée à la sortie d'air pour assurer une régulation automatique de la pression à l'intérieur du bain de réaction (10).

32. Un appareil tel que revendiqué dans la revendication 28, comprenant en outre une unité de génération et d'absorption de chaleur (42) disposée dans le bain auxiliaire (27) pour commander la température à l'intérieur du bain de réaction.

33. Un appareil tel que revendiqué dans la revendication 1, dans lequel chacun des photoradiateurs (12) comprend une gaine tubulaire transparente (16), une tige optique (18) s'étendant au travers de ladite gaine tubulaire (16) et un moyen de diffusion de lumière (18a) pour diffuser de la lumière transmise par l'intermédiaire de ladite tige optique vers l'extérieur jusque dans la chambre de réaction.

34. Un appareil tel que revendiqué dans la revendication 33, dans lequel le moyen de diffusion de lumière (18a) comprend une matière de diffusion de lumière portée sur la tige optique

(18) en des endroits espacés sur la longueur de la tige.

35. Un appareil tel que revendiqué dans la revendication 33, dans lequel le moyen de diffusion de lumière (18a) comprend une section radialement extérieure de la tige optique (18) qui a un indice de réfraction plus grand que celui de la partie restante de la tige optique.

36. Un appareil tel que revendiqué dans la revendication 33, comprenant en outre des câbles optiques à fibres (24a) comportant chacun au moins deux fibres optiques à l'intérieur et optiquement connectés avec la tige optique (18) dans un des photoradiateurs (12), au moins une des fibres optiques recevant de la lumière solaire concentrée et au moins une fibre restante recevant une lumière artificielle.

37. Un appareil tel que revendiqué dans la revendication 1, comprenant en outre un moyen réflecteur (20) qui définit la surface intérieure de l'extrémité inférieure de chacun des photoradiateurs (12).

38. Un appareil tel que revendiqué dans la revendication 1, comprenant en outre un couvercle (24) qui recouvre de façon amovible l'extrémité supérieure du bain de réaction (10), les photoradiateurs (12) étant montés de façon étanche sur le couvercle (24) dans des parties extrêmes supérieures de celui-ci.

