

AN APPARATUS AND PROCESSES FOR HARVESTING AND OPTIONALLY CULTIVATING MICROALGAE

[001] FIELD OF THE INVENTION

5 [002] The present application is related to apparatuses and processes for harvesting and optionally cultivating microalgae in a clean environment.

[003] BACKGROUND OF THE INVENTION

[004] Microalgae are a promising source of oil for clean biodiesel production. They have several advantages over traditional oilseed crops, and their unicellular
10 structure allows for potentially high oil productivity, however, one of the major difficulties is the lack of a large scale cost effective harvesting technique. Microalgae cells are usually less than 10 μm in diameter with densities just exceeding water, thus, harvesting them proves to be difficult. Microalgae can be harvested by flocculation, floatation, sedimentation, centrifugation and filtration.
15 Unfortunately, none of the common industrial approaches have been proven to be economical and suitable for large-scale microalgae separation or removal. Experience has also demonstrated that a universal harvesting method does not exist. There is a need for research and development of an appropriate and economical harvesting system for any algal species. Algae cultured in seawater
20 or brackish water is the least economical to harvest. There is a need to improve the performance of harvesting, and/or extraction of algae particularly algae cultured in seawater or brackish water.

[005] Algal cultivation requires large volumes of clean water. The initial volume of water would preferably be from a clean water source such as potable fresh
25 water or fresh clean seawater or filtered water. Preferably the water is recirculated to minimize excessive use of water but it is difficult to keep recycled water clean with no or little bacterial contamination and over time this water becomes contaminated and needs to be replaced. Adding clean water adds to

the cost and slows down the process making harvesting both less efficient and more costly.

[006] SUMMARY

[007] It is an object of the invention to have a system that is efficient and/or cost effective particularly in harvesting algae cultured in seawater or brackish water.

[008] A first aspect of the invention includes an apparatus for harvesting microalgae comprising: a vessel for containing a liquid volume; two electrodes capable of providing a potential difference across the liquid; an microalgae culture inlet; a microalgae collection outlet; a liquid return outlet; a power supply; and a sterilizer for destroying prokaryotes.

[009] Another aspect of the invention relates to a process of harvesting microalgae comprising: Introducing a liquid containing microalgae into a vessel; providing a potential difference within the liquid between two electrodes so that the microalgae aggregates; collecting the microalgae aggregate; sterilizing the liquid depleted of microalgae by destroying any prokaryotes therein and removing the liquid depleted of microalgae from the vessel.

[0010] Another aspect of the invention relates to a system for harvesting microalgae comprising: a vessel for containing a liquid volume; two electrodes for providing a potential difference across the liquid; a power supply for creating an electrical current between the electrodes; an algae culture inlet for inflow of a liquid containing microalgae; a collection outlet for collection of microalgae; a liquid return outlet for removal of the liquid depleted of microalgae; and a sterilizer for destroying prokaryotes.

[0011] Other aspects of the invention will be apparent to a person skilled in the art with reference to the following drawings and description of various non-limiting embodiments.

[0012] BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The drawings are not necessarily drawn to scale, emphasis instead generally being placed upon illustrating the principles of various embodiments. In

the following description, various embodiments of the invention are described with reference to the following drawings.

[0014] **Figure 1** is a diagram showing a cross-section portion of the sedimentation type harvester.

5 [0015] **Figure 2** is a diagram showing a cross-section portion of a floatation type harvester.

[0016] **Figure 3** is a diagram showing a cross-section portion of the floatation type harvester.

10 [0017] **Figure 4** is a diagram showing a cross-section portion of another variation of floatation type harvester

[0018] **Figure 5** is the Process Flow Diagram of the integrated PBR system with harvester.

[0019] DETAILED DESCRIPTION

15 [0020] The harvesting system is capable of performing the desired solid-liquid separation and is also capable of being used for large scale application.

[0021] A first aspect of the invention includes an apparatus for harvesting microalgae comprising: a vessel 2 for containing a liquid volume; two electrodes 4A and 4B capable of providing a potential difference across the liquid; a microalgae culture inlet 6; a microalgae collection outlet 8; a liquid return outlet 10; a power supply; and a sterilizer for destroying prokaryotes.

25 [0022] Microalgae, or microphytes, are microscopic, photosynthetic algae that may be found in freshwater, brine or marine ecosystems. They are unicellular, existing individually or in chains or groups. Depending on species, their sizes can range from about 0.1 micrometer to a few hundreds of micrometers, usually less than 10 micrometers in diameter. Microalgae are important industrially and may be harvested for a wide range of products that they are capable of producing, for example, carotenoids, antioxidants, fatty acids (e.g. omega-3-fatty acids), enzymes, polymers, peptides, fuels, toxins and sterols. Any suitable species of algae may be used in the apparatus, the choice of which depends on the type of

bio-product that is desired to be produced. *Chlorella*, *Dunaliella* and *Nannochloropsis* are few examples of microalgae that could be used in the present apparatus.

[0023] Cultivation of algae occurs in a cell culture medium comprising necessary nutrients and factors for algae growth. Such nutrients and factors are well known in the art and depend on the species of algae being cultivated. The main component of the culture medium/liquid is water. Preferably clean water such as potable fresh water or fresh clean seawater or filtered water. In various embodiments the liquid volume comprises a seawater culture liquid.

[0024] The vessel 2 may be rectangular cylindrical or any geometric shape which holds a culture volume. The vessel 2 may be predominantly made of plastic, PVC or any other non conductive material. In some embodiments a section of the vessel wall may be made of metal. In various embodiments the vessel may hold about 20 liters of liquid.

[0025] The electrodes preferably comprise a negatively charged cathode 4A and a positively charged anode 4B. The electrodes are metal. The metal may be aluminum, iron, steel, stainless steel, titanium or other suitable metals able to provide a potential difference across a liquid. The potential difference between a cathode 4A and an anode 4B neutralizes the charge around the microalgae cells which induces the cells to form flocs. Negatively charged microalgae cells migrate together to form aggregates (floculates) of microalgae cells. These cell floculates can then either be collected as a sediment at the bottom of the vessel 2 or as a flotilla on the surface of the water in the vessel 2. The cell floculates may then be conveniently collected.

[0026] The term sterilizer as used herein refers to a mechanism for destroying or rendering harmless or prohibiting the growth or reproduction of prokaryotes such as bacteria. This may be achieved either by electromagnetic radiation in the UV wavelengths or via increased voltage to the electrodes. In various embodiments the sterilizer generates electromagnetic radiation in a range of 400-200nm. In various other embodiments the sterilizer generates electromagnetic radiation in a

range of 315-200nm, preferably at 254nm. Electromagnetic radiation at 254nm will break the molecular bonds within DNA, producing thymine dimmers in the DNA. Within the wavelength range prokaryotes such as bacteria will be destroyed, rendered harmless, prohibited from growing or reproducing.

5 [0027] In one embodiment the microalgae collection outlet 8 is located near a point that is close to the base nearest the earth/ground in operation as the microalgae aggregate gravitationally settles at a base of the vessel 2. The potential difference between a cathode 4A and an anode 4B neutralizes the charge around the microalgae cells which induces the cells to form flocs that
10 increase the density of the aggregated microalgae. These aggregated microalgae or flocculated cells sink to the bottom of the harvester. The location of the microalgae collection outlet 8 at this location allows collection of these cells. In this embodiment the cathode 4A and the anode 4B are placed parallel to each other and each is substantially perpendicular to the microalgae collection outlet 8.
15 Such an embodiment is depicted in Figure 1 whereby a section of the vessel wall is made of metal which serves as the anode 4B. The anode 4B may be aluminum, iron, steel, stainless steel, titanium or other suitable metals. This embodiment may additionally include an alternative microalgae collection outlet 8A located near a point at the surface of the liquid containing microalgae for collection of any
20 microalgae aggregate that float towards the outlet.

[0028] In another embodiment the microalgae collection outlet is located near the upper portion of the vessel 2 at a point near the surface of the liquid containing microalgae when in operation. This allows for the collection of microalgae aggregates that float. The location of the microalgae collection outlet 8 near the
25 top of the vessel 2 allows the microalgae to be able to float towards the collection outlet 8.

[0029] In one embodiment the microalgae collection outlet 8 further comprises guides 12 for directing the floating microalgae into the collection outlet. In various embodiments such as that depicted in Figure 2 the guides 12 comprises slopping
30 sides wider at the opening sloping inwards forming a funnel into the collection

outlet 8. The embodiment of Figure 2 has a conical shaped vessel 2. The cathode 4A is formed of a metal mesh located across the lower part of the vessel 2. Below the cathode 4A spargers 16 are located to flush gas through the liquid. The anode 4B is a metal rod on top of and adjacent the cathode 4A. Such a formation of the cathode 4A, the anode 4B and spargers 16 releases gas and/or air bubbles that aid in the flotation of the flocs of microalgae cells.

[0030] In various other embodiments such as that depicted in Figure 3 and 4 the guides 12 comprise a fin that moves across a zone at or near the surface of the culture when it is in operation to push the floating microalgae into the collection outlet 8. In both Figure 3 and 4, the cathode 4A is formed of a metal mesh located across the base of the vessel 2. The anode 4B is a metal rod on top of and adjacent the cathode 4A. Such a formation of the cathode 4A and the anode 4B releases air bubbles that aid in the flotation of the flocs of microalgae cells.

[0031] In the embodiment depicted in figure 3 the guide fin 12 is moved along a track in a continuous circular motion, whereby when the guide fin 12 moves toward the microalgae collection outlet 8 it is at an angle with the surface between 0 and 180 degrees able to push the microalgae aggregates across the surface of the water. In various embodiments the angle may be from 45 to 90 degrees to the surface. When the guide fin 12 moves in the opposite direction it moves over the surface, preferably parallel to the surface above the culture.

[0032] In the embodiment depicted in figure 4 the guide fin 12 is rotated about a pivot point on either side of the vessel 2 to push the floating microalgae into the collection outlet 8.

[0033] The apparatus may be connected to any algal cultivation/production system such as ponds or apparatus' such as photobioreactors. Photobioreactors may include tubular or flat plate systems or any other bioreactor known in the art. Tubular photobioreactors generally comprise a cylindrical reservoir having a curved outer wall at least a portion of which is transparent. Flat plate photobioreactors generally comprise at least two opposed outer walls, at least part of or at least one of which is transparent. Whatever the basic design, the

photobioreactor comprises a reservoir within which the microalgae is cultivated. The reservoir comprises walls for containing the microalgae and the cell culture medium. Since microalgae are photosynthetic organisms, they require light in order to grow and reproduce. The light is generally of a frequency in the visible
5 region of the electromagnetic spectrum. In order to permit light to enter the reservoir, at least a portion of or at least one wall of the reservoir is transparent or open to sunlight. Transparency may be attained by constructing the transparent portion of the reservoir from a transparent material, for example, glass, plastic, fiber glass or mixtures thereof. More light can be permitted to enter
10 the vessel by increasing the surface area of the transparent portion in relation to the total surface area of the reservoir. If desired, the entire reservoir may be constructed from transparent material. The wall of the reservoir for which at least a portion is transparent is preferably an outer wall of the reservoir.

[0034] In various embodiments the apparatus further comprising a
15 photobioreactor 14 that pumps microalgae culture into the microalgae culture inlet 6 and receives sterilized culture liquid via the liquid return outlet 10.

[0035] Figure 5 depicts a schematic representation of an integrated system whereby the harvester vessel 2 takes in microalgae culture pumped in preferable with a pump 18 from a photobioreactor 14. The collection outlet 8 collects the
20 microalgae in a storage compartment 20. In various embodiments the apparatus may further comprise a sensor 22 to determine the parameters of the microalgae in the system when in operation. The storage compartment 20 may have a weight sensor 22A to determine the mass of the harvested microalgae. The system may include a sensor 22 for cell density using various parameters such
25 as turbidity, cell count or spectrophotometric detection of substances contained in the cells such as chlorophyll. An automated control system may be included which will monitor, record required parameters and give warning via visuals, audio or sent remotely to an electronic device in the event of errors. In various
30 embodiments the value of the sensor 22 can be set to direct the flow of the microalgae culture between the harvesting vessel 2 and the photobioreactor 13.

[0036] Another aspect of the invention relates to a process of harvesting microalgae comprising: Introducing a liquid containing microalgae into a vessel 2; providing a potential difference within the liquid between two electrodes 4A and 4B so that the microalgae aggregates; collecting the microalgae aggregates; 5 sterilizing the liquid depleted of microalgae by destroying any prokaryotes therein and removing the liquid depleted of microalgae from the vessel 2.

[0037] In various embodiments any prokaryotes are destroyed by exposing the liquid depleted of microalgae to electromagnetic radiation or high voltage. In various embodiments any prokaryotes are destroyed by exposing the liquid 10 depleted of microalgae to electromagnetic radiation in a range of 400-200nm, or by exposing the liquid depleted of microalgae to electromagnetic radiation in a range of 315-200nm, or by exposing the liquid depleted of microalgae to electromagnetic radiation at 254nm. In various embodiments the sterilization will occur after the vessel has been depleted of microalgae.

15 [0038] In various embodiments the microalgae is collected at an outlet located near a point that is close to the base near the earth/ground as the microalgae aggregates gravitationally settle at a base of the vessel as described above.

[0039] In various embodiments the microalgae is collected at an outlet located near a point at the surface of the liquid containing microalgae as the microalgae 20 aggregates float towards the outlet as described above.

[0040] In various embodiments the floating microalgae is directed into the outlet 8 for example by using the guides 12 as described above.

[0041] In various embodiments the process further includes determining cell density using any of the methods described above.

25 [0042] Another aspect of the invention relates to a system for harvesting microalgae comprising: a vessel 2 for containing a liquid volume; two electrodes 4A, 4B for providing a potential difference across the liquid; a power supply for creating an electrical current between the electrodes 4A, 4B; an algae culture inlet 6 for inflow of a liquid containing microalage; a collection outlet 8 for

collection of microalgae; a liquid return outlet 10 for removal of the liquid depleted of microalgae; and a sterilizer for destroying prokaryotes.

[0043] Other parts of the system are the same as those described above in relation to the apparatus.

5 [0044] The system may be connected to any algal cultivation/production system such as ponds or apparatus' such as photobioreactors as described above. This means one day the apparatus or system may have algae fed into it from a pond and harvested and the next day from a photobioreactor for harvesting. the apparatus or system may also harvest *Chlorella* on day one, *Dunaliella* on day
10 two and *Nannochloropsis* on day three. This makes the system very versatile.

[0045] The system works without any pH adjustment or the addition of any flocculants making the process of harvesting microalgae very cost effective.

[0046] The step of sterilizing the culture liquid before returning it to a bioreactor minimizes the addition of clean water to the system. This saves the costs
15 involved with downtime of the system that is required when new water is added and the cost of the clean water itself.

[0047] Generally, the terms used herein have, unless explicitly stated otherwise, the accepted meaning in the art.

[0048] By "comprising", as used herein, it is meant including, but not limited to,
20 whatever follows the word "comprising". Thus, use of the term "comprising" indicates that the listed elements are required or mandatory, but that other elements are optional and may or may not be present.

[0049] By "consisting of" is meant including, and limited to, whatever follows the phrase "consisting of". Thus, the phrase "consisting of" indicates that the listed
25 elements are required or mandatory, and that no other elements may be present.

[0050] The inventions illustratively described herein may suitably be practiced in the absence of any element or elements, limitation or limitations, not specifically disclosed herein. Thus, for example, the terms "comprising", "including", "containing", etc. shall be read expansively and without limitation. Additionally,

the terms and expressions employed herein have been used as terms of description and not of limitation, and there is no intention in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the invention claimed. Thus, it should be understood that although the present invention has been specifically disclosed by preferred embodiments and optional features, modification and variation of the inventions embodied therein herein disclosed may be resorted to by those skilled in the art, and that such modifications and variations are considered to be within the scope of this invention.

[0051] The invention has been described broadly and generically herein. Each of the narrower species and sub-generic groupings falling within the generic disclosure also form part of the invention. This includes the generic description of the invention with a proviso or negative limitation removing any subject matter from the genus, regardless of whether or not the excised material is specifically recited herein.

[0052] The following examples are illustrative of the invention and its preferred embodiments, and are not to be taken as limiting the disclosure or claims in any way.

EXAMPLES

1. Sedimentation Harvester Results (*Dunaliella tertiolecta*)

[0053] Culture Media containing 2M NaCl was used to cultivate the growth of *Dunaliella tertiolecta*. Using the sedimentation harvester depicted in Figure 1, this culture medium was provided into the harvesting vessel and the density was measured to have (Co), Initial Concentration (biomass concentration of culture): 0.7 g/L.

[0054] The Current was set and maintained to a specific value to achieve highest harvesting yield and the algae were harvested by collecting the algal cell

[0061] Algae were harvested by collecting the algal cell flocculates at the top of the vessel. The (Cf), Final Concentration of the Harvested Culture was measured and is listed in table 1.

5 Table 1: results of growing *Dunaliella tertiolecta* in a flotation harvester.

	Experiment 1	Experiment 2	Experiment 3
Inlet volume g/l	0.36	0.68	0.78
Outlet algae concentrate g/l	3.86	9.09	12.45
Concentration factor	10.72	13.37	15.96
% water removal	90.71%	92.58%	93.81%

[0062] Salt water algae were successfully harvested at a high concentration in the floatation harvester.

Claims

1. An apparatus for harvesting microalgae comprising:
 - a vessel for containing a liquid volume;
 - 5 two electrodes capable of providing a potential difference across the liquid;
 - a microalgae culture inlet;
 - a microalgae collection outlet;
 - a liquid return outlet;
 - 10 a power supply; and
 - a sterilizer for destroying prokaryotes.
2. The apparatus according to claim 1, wherein the sterilizer generates electromagnetic radiation in a range of 400-200nm.
3. The apparatus according to claim 1, wherein the sterilizer generates
15 electromagnetic radiation in a range of 315-200nm.
4. The apparatus according to claim 1, wherein the sterilizer generates electromagnetic radiation at 254nm.
5. The apparatus according to any one of claims 1-4 wherein the microalgae collection outlet is located near a point that is near a base of the vessel in
20 operation as the microalgae gravitationally settles at the base of the vessel.
6. The apparatus according to any one of claims 1-4, wherein the microalgae collection outlet is located near a point at the surface of the liquid containing microalgae in operation as the microalgae float towards the outlet.
7. The apparatus according to claim 6, further comprising guides for directing
25 the floating microalgae into the collection outlet.
8. The apparatus according to claim 7, wherein the guide comprises slopping sides wider at the opening forming a funnel into the collection outlet.
9. The apparatus according to claim 7, wherein the guide comprises a fin that moves across a zone at or near the surface of the culture when it is in
30 operation to push the floating microalgae into the collection outlet.

10. The apparatus according to any one of claims 1-9, further comprising a photobioreactor that pumps microalgae culture into the microalgae culture inlet and receives sterilized culture liquid via the liquid return outlet.
11. The apparatus according to claim 10, further comprising a sensor to
5 determine the parameters of the microalgae in the system when in operation.
12. The apparatus according to claim 11, wherein the value of the sensor can be set to direct the flow of the microalgae culture between the harvesting vessel and the photobioreactor.
13. A process of harvesting microalgae comprising:
10 Introducing a liquid containing microalgae into a vessel;
providing a potential difference within the liquid between two electrodes so that the microalgae aggregates;
collecting the microalgae aggregate;
sterilizing the liquid depleted of microalgae by destroying any prokaryotes
15 therein and
removing the liquid depleted of microalgae from the vessel.
14. The process according to claim 13, wherein any prokaryotes are destroyed by exposing the liquid depleted of microalgae to electromagnetic radiation in a range of 400-200nm.
- 20 15. The process according to claim 13, wherein any prokaryotes are destroyed by exposing the liquid depleted of microalgae to electromagnetic radiation in a range of 315-200nm.
16. The process according to claim 13, wherein any prokaryotes are destroyed by exposing the liquid depleted of microalgae to electromagnetic
25 radiation at 254nm.
17. The process according to any one of claims 13-16 wherein the microalgae is collected at an outlet located near a point that is at a base of the vessel in operation as microalgae aggregates gravitationally settles at the base of the vessel.
- 30 18. The process according to any one of claims 13-16, wherein the microalgae is collected at an outlet located near a point at the surface of the

liquid containing microalgae as the microalgae aggregates float towards the outlet.

19. The process according to claim 18, further comprising directing the floating microalgae into the outlet.

5 20. The process according to claim 13 further comprising determining cell density.

21. A system for harvesting microalgae comprising:

a vessel for containing a liquid volume;

two electrodes for providing a potential difference across the liquid;

10 a power supply for creating an electrical current between the electrodes;

an algae culture inlet for inflow of a liquid containing microalgae;

a collection outlet for collection of microalgae;

a liquid return outlet for removal of the liquid depleted of microalgae; and

a sterilizer for destroying prokaryotes.

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