

SYSTEM FOR MASS CULTIVATION OF MICROORGANISMS AND PRODUCTS THEREFROM

Technical Field

[0001] The invention relates to a system for growing biomass in an outdoor environment.

Advantageously, downtime for cleaning the system can be minimized or eliminated. Another advantage of the invention includes harvesting a portion of the cultivated biomass without interrupting the growth of the biomass.

Background

[0002] The photobioreactor has been a key component as a culture bearing vessel, allowing photonic energy input and suitable for various biological cultures and is utilized in the algae cultivation process. The photobioreactor is a key hardware in that it minimizes the contamination risks from outdoor cultivation, culture media evaporation, allows for better media nutrients and process parameters control.

[0003] Virtually every day the global media contains news regarding the crucial need for renewable energy sources to replace fossil fuels. Various biofuels have been under development for a number of years in an attempt to meet this need. However, two key issues challenge their commercialization: a) the use of land and related crops that compete and in effect reduce the food supply and b) the traditional high-cost of biofuels production.

[0004] Production of sustainable algal based products such as feeds and biofuel from algae is a very potential and promising industry. Among alternative energy sources, algae represent a renewable biomass resource that is ready to be implemented on a large scale without any environmental or economic penalty and the remaining biomass by product is a potential source of food subsistence. Due to CO₂ fixation by the algae, all the organic matter biodegraded is converted

into biomass under photosynthetically treatments. The photosynthetic efficiency of algae is much higher (6-8%, on average) than that of terrestrial plants (1.8-2.2%, on average). Also, algae strains are diverse and readily adaptable to growing in different conditions, including marine and fresh river waters or waste water post treatment.

[0005] Current generation biofuels from photosynthetic microalgae is a promising alternate source of renewable energy, its practicality is however hindered by low productivity and thus high cost.

[0006] Therefore, there remains a need to provide for a system that overcomes, or at least alleviates, the above problems.

Summary

[0007] Present inventors have provided a system suitable for outdoor production of microalgal biomass. The design features of the system may readily be adopted in a new photobioreactor system or an existing photobioreactor system at relatively low costs. The implementation of these design features may further enhance the principles of continuous flow, high volume and promotion of a healthy high growth algae cultivation production system achieved through the maintenance of culture temperature within a lower specified range and avoidance of contamination from bio-fouling. Therefore, the downtime due to cleaning may be minimized or eliminated from conventional photobioreactor process consisting of growth, harvest, cleaning. This allows a great increase in the overall cultivation volume of algae and also promotes the optimal growth/maturing of the algae cultivation. The production system has the flexibility in scalability in construction to varying volume depths, sizes and build in series to match the required output to be harvested.

[0008] Accordingly, in a first aspect of the invention, a system for growing biomass is disclosed.

[0009] The system includes a photobioreactor module including a plurality of bioreactors fluidly connected to one another. The photobioreactor module includes an inlet end and an outlet end.

[0010] The system further includes a cooling system, where the photobioreactor module is subjected to the cooling system for regulating the temperature of a nutrient medium.

[0011] The system may optionally further includes a reservoir for containing the nutrient medium for the biomass growth, where the reservoir includes an inlet end and an outlet end. The outlet end of the reservoir may be fluidly connected to the inlet end of the photobioreactor module and the inlet end of the reservoir may be fluidly connected to the outlet end of the photobioreactor module. Alternatively, the inlet end and the outlet end of the photobioreactor module may be connected by a pipe, such as a vertical pipe.

[0012] The photobioreactor module further includes at least one cleaning device moveable within the plurality of bioreactors for cleaning the interior surface of the plurality of bioreactors.

Brief Description of the Drawings

[0013] In the drawings, like reference characters generally refer to the same parts throughout the different views. 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] Fig. 1 shows a set-up of the present system.

Description

[0015] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the invention may be practised. These embodiments are described in sufficient detail to enable those skilled in the art to practise the invention. Other embodiments may be utilized and structural, logical, and electrical changes may

be made without departing from the scope of the invention. The various embodiments are not necessarily mutually exclusive, as some embodiments can be combined with one or more other embodiments to form new embodiments.

[0016] Present disclosure relates in general to continuous flow, high volume, high growth production of biological biomass. For example, microalgae cultivation may be employed in the extraction of lipids for the creation of biofuels, and more particularly, to the production of algae in enclosed environments such as photobioreactors (or simply termed bioreactors herein), tubular vessels well as in environments where the culture mode is photoautotrophic and/or heterotrophic. The algae cultivated may be useful for its oil content and other applications such as nutraceuticals, fuel, bulk chemicals, feed and aquacultures.

[0017] According to one aspect of the disclosure as illustrated in **Fig. 1**, a system **100** for growing biomass is described herein. The production system is particularly suitable for use in an outdoor environment, although the production system may also be used indoors.

[0018] Advantageously, the system **100** provides bioreactors or continuous flow vessels bearing biomass cultures that consists of the following design elements to improve the culture biomass growth characteristics and performance (may also be relevant to other organisms growth applications which utilizes the similar vessels and bioreactors):

- Mitigate the warming up effect during the daily operation and maintain the culture in a temperature zone through the cooling effect on the surface of the vessel;
- Minimize the maintenance downtime and downtime cleaning duration and frequency required for the cleaning of the vessel interiors. Hence the maintenance cleaning downtime in between each production harvest cycle is reduced, thereby allowing for

- longer productivity periods and better utilization of the capital equipment consisting of the photobioreactor system;
- Minimize the accumulation in growth over time due to biofilm and microbes contamination effects on the biomass being cultivated. This ensures the culture health and facilitates its growth rate;
- Recover and reuse of the culture media with the top up of necessary nutrients for the next growth cycle;
- Affords the flexibility for the addition of a continuous flow inline harvesting system to efficiently dewater and concentrate the micro algae harvest.

[0019] The system 100 includes a photobioreactor module 10 including a plurality of bioreactors fluidly connected to one another. The photobioreactor module includes an inlet end 12 and an outlet end 14.

[0020] A bioreactor is an installation for the production of microorganisms outside their natural but inside an artificial environment. The prefix “photo” particularly describes the bioreactor’s property to cultivate phototrophic microorganisms, or organisms which grow on by utilizing light energy. These organisms use the process of photosynthesis to build their own biomass from light and carbon dioxide. Members of this group may include plants, mosses, macroalgae, microalgae, cyanobacteria and purple bacteria. Key objective of a photobioreactor, or PBR, is the controlled supply of specific environmental conditions for respective species. Thus, a photobioreactor allows much higher growth rates and purity levels than anywhere in natural or habitats similar to nature. Basically, photobioreactors can grow phototropic biomass even from nutrient polluted waste water.

[0021] The system 100 further includes a cooling system 20. The photobioreactor module 10 is subjected to the cooling system 20 for regulating the temperature of a nutrient medium.

[0022] The system 100 may optionally further includes a reservoir 30 for containing the nutrient medium for the biomass growth. The reservoir 30 includes an inlet end 32 and an outlet end 34. The outlet end 34 of the reservoir 30 may be fluidly connected to the inlet end 12 of the photobioreactor module 10 and the inlet end 32 of the reservoir 30 may be fluidly connected to the outlet end 14 of the photobioreactor module 10. In such an arrangement, fresh nutrient medium in the reservoir 30 may exit the reservoir 30 at the outlet end 34 of the reservoir 30 and may enter the photobioreactor module 10 at the inlet end 12 of the photobioreactor module 10. Similarly, spent nutrient medium from the photobioreactor module 10 may exit at the outlet end 14 of the photobioreactor module 10 and may enter the reservoir 30 at the inlet end 32 of the reservoir 30. Alternatively, the inlet end and the outlet end of the photobioreactor module may simply be connected by a pipe, such as a vertical pipe.

[0023] In the embodiment illustrated in Fig. 1, there is shown an intermediate piping section 50 positioned between the reservoir 30 and the photobioreactor module 10. The intermediate piping section 50 may include a bypass pipe 52 fluidly connecting the outlet end 14 of the photobioreactor module 10 to the inlet end 12 of the photobioreactor module 10 such that a portion of the spent nutrient medium exiting at the outlet end 14 of the photobioreactor module 10 re-enters the photobioreactor module 10 at the inlet end 12 of the photobioreactor module 10 without entering the reservoir 30. In other embodiments, the intermediate piping section 50 may be absent.

[0024] The photobioreactor module 10 further includes at least one cleaning device 40 moveable within the plurality of bioreactors for cleaning the interior surface of the plurality of bioreactors. Use of an internal cleaning device allows an independent, self-supporting and continuous cleaning process of the inner surface of the bioreactor during the cultivation activity or during the maintenance routine. The cleaning device may be powered and transported by the flow pressure of

the existing culture media or water typical during operation, thereby dispensing the need for additional or intricate cleaning mechanisms.

[0025] In the embodiment illustrated in **Fig. 1**, the cleaning device **40** may move along the flow of the nutrient medium in the photobioreactor module **10** from an upstream bioreactor to a downstream bioreactor, thereby cleaning the interior surface of each bioreactor as it moves along. When the cleaning device **40** reaches the farthest downstream bioreactor, the cleaning device **40** may be propelled to move into the bypass pipe **52** so that the cleaning device **40** re-enters the photobioreactor module **10** at the inlet end **12** of the photobioreactor module **10** with the portion of re-circulated spent nutrient medium. In this way, the cleaning device **40** may be made to move within the plurality of bioreactors in the photobioreactor module **10** and continuously clean the interior surface of the bioreactors, thereby reducing or even eliminate downtime of the system.

[0026] In alternative embodiments, the cleaning device **40** may be battery-powered to move in the photobioreactor module **10**. In such embodiments, the cleaning device **40** may or may not be moved by the flow of the circulating nutrient medium. The cleaning device **40** may be controlled such that it stays and cleans a selected portion of a bioreactor for a longer period of time. The cleaning device **40** may also be controlled such that it skips cleaning a selected portion of a bioreactor, for example.

[0027] In yet other embodiments, the cleaning device **40** may be externally controlled to move in the photobioreactor module **10**. In such embodiments, the cleaning device **40** may or may not be moved by the flow of the circulating nutrient medium. For example, the cleaning device **40** may be magnetically coupled to a control device positioned on the exterior of a bioreactor and may be manually controlled and moved about in the bioreactor.

[0028] The cleaning device 40 allows online agitation and cleaning of the interior surfaces of the bioreactors during cultivation activity and may be transported by the culture media during normal operation. Downtime due to the need to interior cleaning may now be reduced or even eliminated by this self-cleaning system.

[0029] In various embodiments, the photobioreactor module 10 may include 3 to 10 bioreactors. The bioreactors may be connected in series. Other than the most upstream and most downstream bioreactors, the intermediate bioreactors are fluidly connected such that the respective outlet of an upstream bioreactor is fluidly connected to the respective inlet of a neighbouring downstream bioreactor. The plurality of bioreactors may be joined by elbow pipes. The inlet end of the most upstream bioreactor may form the inlet end 12 of the photobioreactor module 10. The outlet end of the most downstream bioreactor may form the outlet end 14 of the photobioreactor module 10.

While it has been illustrated in Fig. 1 that the nutrient medium is pumped from the bottom of the photobioreactor module 10 to the top, other forms of connection of the bioreactors may also be possible. For example, the bioreactors may be arranged such that the nutrient medium is pumped through a vertical height and then allowed to flow down from the top to the bottom via gravity.

[0030] In various embodiments, the photobioreactor module 10 may include a plurality of tubular bioreactors.

[0031] In certain embodiments, the photobioreactor module 10 may include a plurality of planar bioreactors.

[0032] In other embodiments, the photobioreactor module 10 may include other shapes and configuration of bioreactors. For example, the photobioreactor module 10 may include a mixture of tubular bioreactors and planar bioreactors.

[0033] In various embodiments, the system 100 may further include at least one pump for circulating the nutrient medium. For example, the pump may be positioned near or before the outlet end of the reservoir. Other positions of the pump may also be possible.

[0034] The reservoir 30 may be a single container for both supply and return of the algae culture including the nutrient medium. The reservoir 30 may include a mixer to agitate or stir the contents therein to improve mixing. Alternatively, the reservoir 30 may include more than one container.

[0035] In various embodiments, the cooling system 20 may include a supply of cooling water shower over the photobioreactor module 10. The cooling water shower helps to maintain proper and optimal algae culture temperature for high photosynthesis efficiency. A cooling water tank may be provided for storing water, for example rain water, and water is pumped to the cooling system 20 when required to cool down or to maintain surface temperature of the photobioreactor module 10.

[0036] Present system may make use of natural resources for normal operation. As an example, sea, river or rain water may be harvested/collected and filtered through for use in the cultivation media. Sunlight may be used to power the electricity required by sensors and pumps.

[0037] Thus, in various embodiments, the system 100 may further include a mains control station to regulate the pumping system and monitoring sensors.

[0038] Advantageously, the system 100 allows both online and offline monitoring and record of the critical parameters, such as pH, temperature, levels of nitrates, ammonia, dissolved carbon dioxide, flow rates, turbidity, dissolved oxygen, or light intensity. Based on the measured readings, the system 100 further allows for automated adjustment of the required critical parameters in accordance to a set of predetermined control parameters.

[0039] In various embodiments, the system 100 may further include at least one monitoring device in contact with the nutrient medium or cultivation medium. The monitoring device may monitor parameters in the nutrient medium or cultivation medium, such as pH, temperature, levels of nitrates, ammonia, dissolved carbon dioxide, flow rates, turbidity, dissolved oxygen, or light intensity. As an example, if the measured pH falls below the predetermined pH value set by an operator, a basic solution may be introduced to adjust and increase the pH value until the predetermined pH value is achieved and maintained. In another example, there may be a plurality of injectors configured to emit fluids and solids into the nutrient medium or cultivation media which may include nutrients, carbon dioxide and other materials required for the algae growth and cultivation. Gas containing carbon dioxide for fixation can also be introduced into the cultivation tank through a gas-supply conduit. The gas can come from a source such as a power generation plant and can include components other such as nitrogen, carbon monoxide, sulfur (SO_x) and nitrogen (NO_x) containing compounds. As another example, carbon dioxide can effectively be added to the system as dissolved carbonate or bicarbonate salts. In some embodiments, carbon dioxide can be dissolved in an aqueous nutrient mixture and then added to the cultivation system. To increase the durations available for the growth of the algae in the cultivation systems, a plurality of light transmitting elements are installed to provide a substitute to sunlight during periods when the lighting conditions are detected to be poor or insufficient such as in the night or when there is an overcast sky. To maintain the consistent quality and yield of the harvested algae, it can be desirable to monitor the conditions within the cultivation tank or bioreactor in order to ensure that optimal growth conditions are maintained. By way of example, it can be desirable to monitor parameters such as fluid media level, flow and circulation rates, temperature, nutrient

concentrations, carbon dioxide concentration, pH and algae population density, amongst others in order to adjust accordingly these parameters to match the required design operating profile.

[0040] In various embodiments, the system 100 may further include a sterilization module for sterilizing the nutrient medium. The sterilization module may be integrated a part of the system 100 or as a standalone module operating in the recovery and reuse of the culture media for the follow on cycle stage. The sterilization module may be located at either the inlet end 12 or at the outlet end 14 to the photobioreactor module 10.

[0041] The system 100 may further include a harvester unit integrated to the photobioreactor module 10 or as a standalone module. The harvester may operate during the harvest of the algae culture media. During harvesting, an allocated portion of the circulating cultivation media may be directed out of the photobioreactor module 10, sterilized by the sterilization module, and collected in the harvester unit. The algae can be harvested in a variety of techniques such as sedimentation, flocculation, filtration, dissolved air floatation, hydrogen bubbling or centrifugation. For example, the harvester unit could utilise dissolved air or hydrogen bubbles via a series of filter nettings to gather (or concentrate) and lift the algae mass towards the top of the harvester unit. Clear water may gather at the bottom of the harvester unit and separated out of the harvester unit and collected in a separate chamber, thereby allowing the convenient collection of algae and reuse of the culture media.

[0042] At scheduled timings during the cultivation growth process, a portion or all of the algae cells/volume could be directed to the inline harvester and sterilization modules. This allows the remaining portion of algae media to continue with the growth uninterrupted during the harvesting process. The dewatered algae harvested may be collected for other processing as required. In this

event, top up of new culture volumes and nutrients could be added to the photobioreactor module to makeup the harvested algae media.

[0043] The inline harvesting and cleaning processes occurring in present integrated production module can occur without any interruption to the algae growing process on-going inside the photobioreactor module. Hence, with this mode of high volume cultivation of algae and continual monitoring of the algae growth conditions, daily production levels can be greatly increased.

[0044] By "comprising" it is meant including, but not limited to, 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.

[0045] By "consisting of" is meant including, and limited to, whatever follows the phrase "consisting of". Thus, the phrase "consisting of" indicates that the listed elements are required or mandatory, and that no other elements may be present.

[0046] 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.

[0047] By "about" in relation to a given numerical value, such as for temperature and period of time, it is meant to include numerical values within 10% of the specified value.

[0048] 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.

[0049] Other embodiments are within the following claims and non-limiting examples. In addition, where features or aspects of the invention are described in terms of Markush groups, those skilled in the art will recognize that the invention is also thereby described in terms of any individual member or subgroup of members of the Markush group.

Claims

1. A system for growing biomass, comprising:
 - a photobioreactor module comprising a plurality of bioreactors fluidly connected to one another, wherein the photobioreactor module has an inlet end and an outlet end, and
 - a cooling system, wherein the photobioreactor module is subjected to the cooling system for regulating the temperature of a nutrient medium;wherein the photobioreactor module further comprises at least one cleaning device moveable within the plurality of bioreactors for cleaning the interior surface of the plurality of bioreactors, the at least one cleaning device is externally controlled to move in the photobioreactor module independently of the flow of the circulating medium.
2. The system of claim 1, wherein the at least one cleaning device is magnetically coupled to a control device positioned on the exterior of the bioreactor to externally control the movement of the at least one cleaning device.
3. The system of claim 1, wherein the at least one cleaning device is battery-powered to move in the photobioreactor module.
4. The system of any one of claims 1 to 3, wherein the cooling system comprises a supply of cooling water shower over the photobioreactor module.
5. The system of claim 1, wherein the photobioreactor module comprises plurality of tubular bioreactors.
6. The system of claim 1, wherein the photobioreactor module comprises plurality of planar bioreactors.

7. The system of any one of claims **1 to 6**, wherein the plurality of bioreactors are joined by elbows.
8. The system of any one of claims **1 to 7**, wherein each bioreactor of the photobioreactor module has an inlet end and an outlet end, wherein the outlet end of an upstream bioreactor is fluidly connected to an inlet end of a downstream bioreactor.
9. The system of claim **8**, wherein the inlet end of a first upstream bioreactor forms the inlet end of the photobioreactor module.
10. The system of claim **8**, wherein the outlet end of a last downstream bioreactor forms the outlet end of the photobioreactor module.
11. The system of any one of claims **1 to 10**, further comprising at least one pump for circulating the nutrient medium.
12. The system of any one of claims **1 to 11**, further comprising a monitoring device in contact with the nutrient medium.
13. The system of claim **12**, wherein the monitoring device measures at least one of pH, temperature, levels of nitrates, ammonia, dissolved carbon dioxide, flow rates, turbidity, and dissolved oxygen in the nutrient medium, and light intensity.
14. The system of claim **12**, wherein the monitoring device allows for automated adjustment of at least one of pH, temperature, levels of nitrates, ammonia, dissolved carbon dioxide, flow rates, turbidity, and dissolved oxygen in the nutrient medium in accordance to a set of predetermined control parameters.
15. The system of any one of claims **1 to 14**, further comprising a sterilization module for sterilizing the nutrient medium.

16. The system of claim 15, wherein the sterilization module is positioned at the inlet end or the outlet end of the photobioreactor module.
17. The system of any one of claims 1 to 16, further comprising a harvester unit for harvesting the biomass.
18. The system of claim 17, wherein the harvester unit is integrated to the photobioreactor module allowing a portion of the biomass to be directed to the harvester unit and a remaining portion of biomass to continue uninterrupted within the photobioreactor module.
19. The system of any one of claims 1 to 17, further comprising a reservoir for containing the nutrient medium for the biomass growth, wherein the reservoir has an inlet end and an outlet end, the outlet end of the reservoir being fluidly connected to the inlet end of the photobioreactor module and the inlet end of the reservoir fluidly connected to the outlet end of the photobioreactor module.
20. The system of any one of claims 1 to 17, wherein the inlet end and the outlet end of the photobioreactor module are connected by a pipe.
21. The system of claim 19, wherein the inlet end and the outlet end of the photobioreactor module are connected by a vertical pipe.