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CULTURE METHOD AND CULTURE DEVICE

Abstract

A culture device comprises: a gas supply unit; and a plurality of containers. The gas supply unit is connected with the plurality of containers through a plurality of gas supply lines, respectively. The plurality of gas supply lines are provided with a plurality of valves, respectively. While microalgae are cultured in the plurality of containers, the opening degrees of the plurality of valves are adjusted. By such adjustment of the opening degrees, a greater amount of gas is supplied to one of the plurality of containers than those of the other containers.

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Background/Summary

TECHNICAL FIELD

[0001] The present invention relates to a culture method and a culture device for culturing microalgae in a culture solution.

BACKGROUND ART

[0002] Heretofore, efforts aimed at mitigating climate change or reducing its impact have continued, and toward the realization thereof, research and development in relation to the reduction of carbon dioxide emissions are being carried out. From this point of view, attention has been focused on microalgae. This is because microalgae consume carbon dioxide through photosynthesis. Accordingly, a culture device for culturing microalgae is anticipated as a device that contributes to mitigating climate change or reducing its impact.

[0003] A culture solution and microalgae are accommodated in an accommodation unit. A sufficient amount of a culturing gas used in culturing for carrying out photosynthesis of the microalgae is supplied to the accommodation unit. Although the culture solution and the microalgae are subjected to diffusion to some extent by the culturing gas, the microalgae undergo settling or sedimentation within the culture solution. When the microalgae undergo settling, the amount of light received by the microalgae decreases. As a result, the amount of photosynthesis becomes inadequate. From this standpoint, in the related art disclosed in JP 2018-537948 A, a gas used to prevent settling is intermittently supplied to the culture solution inside the accommodation unit. In this related art, the gas used to prevent settling is supplied to the culture solution once every 30 minutes, and thereby causes the microalgae that have settled to float or be suspended within the culture solution.

SUMMARY OF THE INVENTION

[0004] It is assumed that microalgae are simultaneously cultured in a plurality of accommodation units. In this case, a large amount of microalgae can be cultured, and thus a large amount of carbon dioxide can be expected to be consumed.

[0005] In this case, the gas used to prevent settling is supplied to the plurality of accommodation units. In this configuration, when the gas used to prevent settling is simultaneously supplied to all the accommodation units, then as shown in FIG. **4**, valves respectively provided in the plurality of accommodation units are simultaneously opened, and a large amount of the gas used to prevent settling is temporarily supplied from a gas supply unit. For this reason, in spite of the fact that the gas used to prevent settling is supplied intermittently, the gas supply unit must have an ability to simultaneously supply a large amount of the gas used to prevent settling.

[0006] A gas supply unit having such a capacity consumes a large amount of electric power per unit time period. Accordingly, in performing culturing in this manner, it is not easy to reduce the running cost.

[0007] The present invention has the object of solving the aforementioned problem.

[0008] According to one aspect of the present invention, there is provided a culture method for culturing microalgae in a culture device including a plurality of accommodation units configured to accommodate a culture solution and the microalgae, a gas supply unit configured to supply a gas to the plurality of accommodation units, and a plurality of gas supply lines configured to connect the gas supply unit with the plurality of accommodation units, respectively, wherein the plurality of gas supply lines are provided with a plurality of valves, respectively, the culture method comprising: an opening degree adjustment step of adjusting an opening degree of at least one of the plurality of

valves during culturing of the microalgae in the plurality of accommodation units; and an agitation step of culturing the microalgae in a state in which the opening degree of the at least one of the plurality of valves is adjusted, wherein, in the opening degree adjustment step, by adjusting the opening degree of the at least one of the plurality of valves, supply of the gas to at least one accommodation unit of the plurality of accommodation units is stopped or a supply flow rate of the gas supplied to the at least one accommodation unit is decreased, and a supply flow rate of the gas supplied to at least one remaining accommodation unit is increased.
[0009] According to another aspect of the present invention, there is provided a culture device that cultures microalgae in a culture solution, the culture device comprising: a plurality of accommodation units configured to accommodate the culture solution and the microalgae; a gas supply unit configured to supply a gas to the plurality of accommodation units; a plurality of gas supply lines configured to connect the gas supply unit with the plurality of accommodation units, respectively; a plurality of valves provided in the plurality of gas supply lines, respectively; and a control unit configured to individually adjust an opening degree of each of the plurality of valves, wherein, by adjusting the opening degree of at least one of the plurality of valves during culturing of the microalgae in the plurality of accommodation units, the control unit stops supply of the gas to at least one accommodation unit of the plurality of accommodation units or decreases a supply flow rate of the gas supplied to the at least one accommodation unit, and increases a supply flow rate of the gas supplied to at least one remaining accommodation unit.
[0010] By adjusting the opening degree, the supply of the gas is stopped or the supply flow rate is decreased in at least one of the plurality of accommodation units. In contrast, the supply flow rate of the gas is increased in at least one remaining accommodation unit. That is, the supply flow rate of the gas is adjusted.
[0011] Therefore, even if the supply flow rate of the gas from the gas supply unit is constant, a large amount of gas can be temporarily supplied to at least one of the plurality of accommodation units. Therefore, it is not necessary to select a gas supply unit having an excessive capacity. In this instance, the excessive capacity is a capacity capable of simultaneously supplying, to the plurality of accommodation units, a gas for agitation in addition to a gas supplied in a general step.
[0012] That is, according to the present invention, it is possible to use a gas supply unit that has an appropriate capacity and consumes a small amount of electric power per unit time period. Therefore, in performing culturing, it is possible to reduce the running cost.
[0013] In the accommodation unit in which the supply flow rate of the gas is temporarily increased, the microalgae and the culture solution are agitated. Therefore, settling or flocculation of the microalgae is suppressed. Accordingly, the light is incident on the microalgae substantially evenly. Further, since the culture solution is also agitated, carbon dioxide becomes diffused throughout the entirety of the accommodation unit. Due to this reason, the microalgae actively carry out photosynthesis. Since a large amount of carbon dioxide becomes fixed in the microalgae by way of photosynthesis, such a feature can be expected to contribute to mitigating climate change or reducing its impact.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0014] FIG. **1** is a schematic system diagram of a culture device according to an embodiment of the present invention;
[0015] FIG. **2** is a schematic process flow diagram of a culture method according to an embodiment of the present invention;
[0016] FIG. **3** is a graph showing the opening degrees of valves provided in first to third accommodation units during culturing, and changes in the gas supply flow rates according to the

opening degrees of the valves; and

[0017] FIG. **4** is a graph showing changes in the opening degrees of valves provided in a plurality of accommodation units and changes in the gas supply flow rates according to the opening degrees of the valves in the related art.

DETAILED DESCRIPTION OF THE INVENTION

[0018] FIG. **1** is a schematic system diagram of a culture device **10** according to a present embodiment. The culture device **10** includes a plurality of accommodation units. In a first embodiment, for ease of understanding, a case where the number of accommodation units is three will be described as an example. Further, in order to easily distinguish the three accommodation units, the accommodation unit located on the leftmost side in FIG. **1** is referred to as a first accommodation unit **12***a*. In FIG. **1**, the accommodation unit adjacent to the first accommodation unit **12***a* on the right side is referred to as a second accommodation unit **12***b*. The accommodation unit located on the rightmost side in FIG. **1** is referred to as a third accommodation unit **12***c*. The first accommodation unit **12***a*, the second accommodation unit **12***b*, and the third accommodation unit **12***c* have the same shape and volume.

[0019] A culture solution L and microalgae are accommodated in each of the first accommodation unit **12***a* to the third accommodation unit **12***c*. As understood from the above, the first accommodation unit **12***a* to the third accommodation unit **12***c* are culturing tanks for culturing microalgae. The culture solution L is typically water. Phosphorus, nitrogen, potassium, and the like are preferably added in advance to the culture solution L.

[0020] The first accommodation unit **12***a*, the second accommodation unit **12***b*, and the third accommodation unit **12***c* are accommodated in a first water storage unit **14***a*, a second water storage unit **14***b*, and a third water storage unit **14***c*, respectively. The first water storage unit **14***a*, the second water storage unit **14***b*, and the third water storage unit **14***c* are each formed of a material that transmits light. Water W is stored in each of the first water storage unit **14***a*, the second water storage unit **14***b*, and the third water storage unit **14***c*. The water W serves as a cooling medium for cooling the culture solution L inside the first accommodation unit **12***a* to the third accommodation unit **12***c*.

[0021] The culture device **10** includes an air pump **16** serving as a gas supply unit. The air pump **16** draws in and compresses the atmospheric air. The air pump **16** is electrically connected to a control unit **18**.

[0022] An upstream end portion of a flow pipe **20** is connected to the air pump **16**. The flow pipe **20** extends toward the third accommodation unit **12***c*. A first branch pipe **22***a* and a second branch pipe **22***b* are provided in the extending flow pipe **20**. The first branch pipe **22***a* extends toward the first accommodation unit **12***a*, and the second branch pipe **22***b* extends toward the second accommodation unit **12***b*. Each of the first branch pipe **22***a*, the second branch pipe **22***b*, and a downstream end portion **23** of the flow pipe **20** is a gas supply line. In other words, the culture device **10** includes a plurality of (three in the present embodiment) gas supply lines.

[0023] The first branch pipe **22***a* is provided with a first solenoid valve **24***a*. The second branch pipe **22***b* is provided with a second solenoid valve **24***b*, and the downstream end portion **23** of the flow pipe **20** is provided with a third solenoid valve **24***c*. The first solenoid valve **24***a*, the second solenoid valve **24***b*, and the third solenoid valve **24***c* are electrically connected to the control unit **18**. That is, the first solenoid valve **24***a*, the second solenoid valve **24***b*, and the third solenoid valve **24***c* are opened and closed in response to command signals from the control unit **18**. The control unit **18** can set the first solenoid valve **24***a*, the second solenoid valve **24***b*, and the third solenoid valve **24***c* to any opening degree between fully opening and fully closing.

[0024] A first main pipe **28***a* is provided at the bottom of the first water storage unit **14***a*. The first branch pipe **22***a* is connected to the first main pipe **28***a*. The first main pipe **28***a* extends along the horizontal direction at the bottom of the first water storage unit **14***a*. A plurality of first auxiliary pipes **30***a* branch from the first main pipe **28***a*. The first auxiliary pipes **30***a* extend along a

substantially vertical direction.
[0025] A plurality of first guide members **32***a* are provided inside the first accommodation unit **12***a*. The first guide members **32***a* are disposed above the first auxiliary pipes **30***a*, respectively, and receive a gas (compressed air) discharged from the first auxiliary pipes **30***a*. The entire first guide member **32***a* is immersed in the culture solution L.
[0026] The first accommodation unit **12***a* is provided with a first temperature sensor **36***a* and a first light amount meter **38***a*. The first temperature sensor **36***a* detects the temperature of the culture solution L inside the first accommodation unit **12***a*. The first light amount meter **38***a* measures the amount of light incident on the first accommodation unit **12***a*.
[0027] The second accommodation unit **12***b* and the third accommodation unit **12***c* are both configured in the same manner as the first accommodation unit **12***a*. Specifically, the second accommodation unit **12***b* includes a second main pipe **28***b*, second auxiliary pipes **30***b*, and second guide members **32***b*. The second branch pipe **22***b* is connected to the second main pipe **28***b*. The second accommodation unit **12***b* is provided with a second temperature sensor **36***b* and a second light amount meter **38***b*. The third accommodation unit **12***c* includes a third main pipe **28***c*, third auxiliary pipes **30***c*, and third guide members **32***c*. The downstream end portion **23** of the flow pipe **20** is connected to the third main pipe **28***c*. The third accommodation unit **12***c* is provided with a third temperature sensor **36***c* and a third light amount meter **38***c*. The first temperature sensor **36***a*, the second temperature sensor **36***b*, and the third temperature sensor **36***c* are temperature detectors. The first light amount meter **38***a*, the second light amount meter **38***b*, and the third light amount meter **38***c* are light amount measurement devices.
[0028] The first temperature sensor **36***a*, the second temperature sensor **36***b*, and the third temperature sensor **36***c* are electrically connected to the control unit **18**. The control unit **18** receives the temperatures detected by the first temperature sensor **36***a*, the second temperature sensor **36***b*, and the third temperature sensor **36***c* as information signals. Specifically, the temperature of the culture solution L in the first accommodation unit **12***a*, the temperature of the culture solution L in the second accommodation unit **12***b*, and the temperature of the culture solution L in the third accommodation unit **12***c* are input to the control unit **18**.
[0029] The first light amount meter **38***a*, the second light amount meter **38***b*, and the third light amount meter **38***c* are electrically connected to the control unit **18**. The control unit **18** receives the amounts of light measured by the first light amount meter **38***a*, the second light amount meter **38***b*, and the third light amount meter **38***c* as information signals. Specifically, the amount of light incident on the first accommodation unit **12***a*, the amount of light incident on the second accommodation unit **12***b*, and the amount of light incident on the third accommodation unit **12***c* are input to the control unit **18**.
[0030] The control unit **18** includes a first time measurement circuit **40** and a second time measurement circuit **42**. The first time measurement circuit **40** measures an elapsed time period from a gas supply starting step S**1** to be described later or an elapsed time period from the end of a general step S**5** to be described later. The second time measurement circuit **42** individually measures an elapsed time period from the start of an opening degree adjustment step S**3** to be described later.
[0031] A threshold temperature which is an allowable lower limit value of the temperature, and a threshold amount of light which is an allowable lower limit value of the amount of light, are input in advance to the control unit **18**. The control unit **18** compares the temperatures of the culture solution L detected by the first temperature sensor **36***a* to the third temperature sensor **36***c* with the threshold temperature. The control unit **18** compares the amounts of light measured by the first light amount meter **38***a* to the third light amount meter **38***c* with the threshold amount of light. Further, a predetermined time period is input to the control unit **18** in advance. The control unit **18** compares the elapsed time period measured by the first time measurement circuit **40** or the second time measurement circuit **42** with the predetermined time period.

[0032] Next, with reference to the schematic process flow diagram shown in FIG. **2**, a description will be given concerning the culture method according to the present embodiment. The culture method includes the gas supply starting step S**1**, a first determination step S**2**, the opening-degree adjustment step S**3**, a second determination step (agitation step) S**4**, the general step S**5**, and a third determination step S**6**. These steps S**1** to S**6** are executed based on sequence control executed by the control unit **18**.

[0033] An operator inputs a command signal to "execute the gas supply starting step S**1**" to the control unit **18**. Such a command signal is input to the control unit **18**, for example, accompanying a switch provided in the control unit **18** being turned ON.

[0034] Upon receiving the command signal, the control unit **18** activates the air pump **16**. Further, the control unit **18** adjusts the opening degrees of the first solenoid valve **24***a*, the second solenoid valve **24***b*, and the third solenoid valve **24***c* to, for example, about one third of full opening. The air pump **16** draws in and compresses the atmospheric air. Since the atmospheric air contains carbon dioxide, the atmospheric air compressed by the air pump **16** is a carbon dioxide-containing gas.

[0035] After being activated, the air pump **16** discharges the carbon dioxide-containing gas at a constant amount. That is, the air pump **16** is operated at a constant output in a rated operation mode. Hereinafter, this state is also referred to as "steady operation".

[0036] Since the opening degrees of the first solenoid valve **24***a*, the second solenoid valve **24***b*, and the third solenoid valve **24***c* are the same, the carbon dioxide-containing gas flowing from the air pump **16** to the flow pipe **20** is substantially equally distributed to the first accommodation unit **12***a*, the second accommodation unit **12***b*, and the third accommodation unit **12***c*. That is, about one third of the carbon dioxide-containing gas discharged from the air pump **16** is distributed to the first branch pipe **22***a* and flows into the first main pipe **28***a*. Another about one third of the carbon dioxide-containing gas discharged from the air pump **16** is distributed to the second branch pipe **22***b* and flows into the second main pipe **28***b*. The remaining about one third of the carbon dioxide-containing gas discharged from the air pump **16** flows into the third main pipe **28***c* from the downstream end portion **23** of the flow pipe **20**.

[0037] FIG. **3** is a graph showing changes in the opening degrees of the first solenoid valve **24***a*, the second solenoid valve **24***b*, and the third solenoid valve **24***c*, and changes in the supply flow rates of the carbon dioxide-containing gas supplied to the first main pipe **28***a*, the second main pipe **28***b*, and the third main pipe **28***c*. A region A in FIG. **3** represents a situation where the air pump **16** is operated in a steady state and the opening degrees of the first solenoid valve **24***a*, the second solenoid valve **24***b*, and the third solenoid valve **24***c* are the same.

[0038] In the first accommodation unit **12***a*, the carbon dioxide-containing gas flows into the culture solution L from the first branch pipe **22***a* through the first main pipe **28***a* and the first auxiliary pipes **30***a*, and then flows into the first guide members **32***a*. Similarly, in the second accommodation unit **12***b*, the carbon dioxide-containing gas flows into the culture solution L from the second branch pipe **22***b* through the second main pipe **28***b* and the second auxiliary pipes **30***b*, and then flows into the second guide members **32***b*. Similarly, in the third accommodation unit **12***c*, the carbon dioxide-containing gas flows into the culture solution L from the downstream end portion **23** of the flow pipe **20** through the third main pipe **28***c* and the third auxiliary pipes **30***c*, and then flows into the third guide members **32***c*.

[0039] In the first accommodation unit **12***a* to the third accommodation unit **12***c*, microalgae carry out photosynthesis using carbon dioxide in the carbon dioxide-containing gas. Consequently, microalgae are cultured in the first accommodation unit **12***a* to the third accommodation unit **12***c*. Through this culturing, carbon dioxide in the culture solution L is fixed in the microalgae. As can be understood from the above, based on the carbon dioxide being consumed by culturing the microalgae, it is possible to contribute to mitigating climate change or reducing its impact. In a case where phosphorus, nitrogen, potassium, and the like are added to the culture solution L, the microalgae take in such inorganic substances as nutrients.

[0040] The culture solution L and the microalgae are agitated in the first accommodation unit **12***a* to the third accommodation unit **12***c* by the carbon dioxide-containing gas supplied to the culture solution L. However, there is a tendency for the microalgae to settle over time. The microalgae also tend to settle when the temperature decreases or the amount of light decreases. In order to prevent the microalgae from settling, the control unit **18** performs control for temporarily supplying a large amount of carbon dioxide-containing gas to the first accommodation unit **12***a* to the third accommodation unit **12***c*. Hereinafter, a description will be given in detail concerning this feature.
[0041] The step in which culturing of the microalgae proceeds in a situation where the air pump **16** is operated in the steady state is a general step. During the general step, the first determination step S**2** is executed. In the first determination step S**2**, the control unit **18** determines whether or not a predetermined condition set in advance in the control unit **18** is satisfied. In the present embodiment, the predetermined condition includes a first condition, a second condition, and a third condition described below. The first condition is that "a predetermined time period elapses after the execution of the gas supply starting step S**1**". The second condition is that "the temperature of the culture solution L in each of the first accommodation unit **12***a* to the third accommodation unit **12***c* reaches the threshold temperature". The third condition is that "the amount of light incident on each of the first accommodation unit **12***a* to the third accommodation unit **12***c* reaches the threshold amount of light".
[0042] In order to determine the above, the temperatures detected by the first temperature sensor **36***a* to the third temperature sensor **36***c*, and the amounts of light measured by the first light amount meter **38***a* to third light amount meter **38***c* are input to the control unit **18**. When the culture device **10** is installed outdoors, the light incident on the first accommodation unit **12***a* to the third accommodation unit **12***c* is sunlight. In the daytime, the temperature and the amount of light hardly differ greatly. Therefore, the temperature hardly reaches the threshold temperature, and the amount of light hardly reaches the threshold amount of light. That is, the second condition and the third condition are hardly satisfied in the daytime.
[0043] Meanwhile, the first time measurement circuit **40** of the control unit **18** measures an elapsed time period immediately after the execution of the gas supply starting step S**1**. When the elapsed time period reaches the predetermined time period input in advance to the control unit **18**, the first condition is satisfied ("YES" in S**2**). In this case, the control unit **18** first executes the opening degree adjustment step S**3**, and then maintains a state in which the opening degrees of the first solenoid valve **24***a* to the third solenoid valve **24***c* have been adjusted. That is, the control unit **18** executes the second determination step S**4**. Thereafter, the control unit **18** executes the general step S**5**.
[0044] In the present embodiment, a case will be described as an example where the opening degree adjustment step S**3** mainly targeted on the first solenoid valve **24***a* is executed first, the opening degree adjustment step S**3** mainly targeted on the second solenoid valve **24***b* is executed next, and the opening degree adjustment step S**3** mainly targeted on the third solenoid valve **24***c* is executed last. Here, the "opening degree adjustment mainly targeted on the first solenoid valve **24***a*" indicates that the opening degree of the first solenoid valve **24***a* is increased and the opening degrees of the second solenoid valve **24***b* and the third solenoid valve **24***c* are decreased in the opening degree adjustment step S**3**. The "opening degree adjustment mainly targeted on the second solenoid valve **24***b*" indicates that the opening degree of the second solenoid valve **24***b* is increased and the opening degrees of the first solenoid valve **24***a* and the third solenoid valve **24***c* are decreased in the opening degree adjustment step S**3**. The "opening degree adjustment mainly targeted on the third solenoid valve **24***c*" indicates that the opening degree of the third solenoid valve **24***c* is increased and the opening degrees of the first solenoid valve **24***a* and the second solenoid valve **24***b* are decreased in the opening degree adjustment step S**3**.
[0045] On the other hand, as described above, the general step S**5** is a step of culturing microalgae under a situation where the air pump **16** is operated in the steady state and the opening degrees of

the first solenoid valve **24***a* to the third solenoid valve **24***c* are not adjusted.

[0046] As described above, in the present embodiment, the opening degree adjustment mainly targeted on the first solenoid valve **24***a*, the opening degree adjustment mainly targeted on the second solenoid valve **24***b*, and the opening degree adjustment mainly targeted on the third solenoid valve **24***c* are executed in this order. In other words, the opening degree adjustment mainly targeted on the first solenoid valve **24***a*, the opening degree adjustment mainly targeted on the second solenoid valve **24***b*, and the opening degree adjustment mainly targeted on the third solenoid valve **24***c* are not simultaneously executed (do not overlap). In this manner, a time difference is provided between the opening degree adjustment mainly targeted on the first solenoid valve **24***a* and the opening degree adjustment mainly targeted on the second solenoid valve **24***b*. Similarly, a time difference is provided between the opening degree adjustment mainly targeted on the second solenoid valve **24***b* and the opening degree adjustment mainly targeted on the third solenoid valve **24***c*.

[0047] The opening degree adjustment mainly targeted on the first solenoid valve **24***a* will be described. In this case, when the elapsed time period from the execution of the gas supply starting step S**1** reaches the predetermined time period, the control unit **18** makes the opening degree of the first solenoid valve **24***a* larger than the opening degree thereof up to this point. At the same time, the control unit **18** makes the opening degrees of the second solenoid valve **24***b* and the third solenoid valve **24***c* smaller than the opening degrees thereof up to this point. For example, the control unit **18** fully opens the first solenoid valve **24***a* and fully closes the second solenoid valve **24***b* and the third solenoid valve **24***c*. As a result, the entire amount of the carbon dioxide-containing gas from the air pump **16** is supplied to the first accommodation unit **12***a*. In contrast, the supply flow rate of the carbon dioxide-containing gas supplied to the second accommodation unit **12***b* and the third accommodation unit **12***c* is 0. This situation is represented by a region B of FIG. **3**.

[0048] The second time measurement circuit **42** of the control unit **18** measures an elapsed time period immediately after the execution of the opening degree adjustment step S**3** mainly targeted on the first solenoid valve **24***a*. During this measurement, the second determination step S**4** is executed. Specifically, the control unit **18** determines whether or not the elapsed time period from the execution of the opening degree adjustment step S**3** mainly targeted on the first solenoid valve **24***a* reaches a predetermined time period input in advance to the control unit **18**.

[0049] When the elapsed time period reaches the predetermined time period ("YES" in S**4**), the control unit **18** shifts the culture method to the general step S**5**. Specifically, when the elapsed time period from the execution of the opening degree adjustment step S**3** reaches the predetermined time period, the control unit **18** makes the opening degree of the first solenoid valve **24***a* smaller than the opening degree thereof at the time of the opening degree adjustment step S**3**. At the same time, the control unit **18** makes the opening degrees of the second solenoid valve **24***b* and the third solenoid valve **24***c* larger than the opening degrees thereof at the time of the opening degree adjustment step S**3**. For example, the control unit **18** sets the first solenoid valve **24***a* to the original opening degree (one third of the full opening) and sets the second solenoid valve **24***b* and the third solenoid valve **24***c* to the original opening degrees (one third of the full opening). As a result, the carbon dioxide-containing gas from the air pump **16** is substantially equally distributed to the first accommodation unit **12***a* to the third accommodation unit **12***c* in the same manner as described above. This situation is represented by a region C of FIG. **3**. As the predetermined time period, for example, an appropriate time period between several tens of seconds and several minutes is selected. The same applies to the following.

[0050] In this manner, a large amount of carbon dioxide-containing gas is supplied to the first accommodation unit **12***a* during a period from the execution of the opening degree adjustment step S**3** to the transition to the general step S**5** (during the period in which the second determination step S**4** is executed). The culture solution L in the first accommodation unit **12***a* is agitated by the large amount of carbon dioxide-containing gas. Therefore, the microalgae in the culture solution L are also agitated. In this manner, the second determination step S**4** serves as an agitation step of strongly agitating the culture solution L and the microalgae.

[0051] Since the culture solution L and the microalgae are strongly agitated, settling or flocculation of the microalgae in the first accommodation unit **12***a* is avoided. Therefore, light is substantially evenly incident on the microalgae in the first accommodation unit **12***a*. Consequently, the microalgae in the first accommodation unit **12***a* actively perform photosynthesis and sufficiently fix carbon dioxide. As a result, a sufficient amount of carbon dioxide can be consumed.

[0052] In the third determination step S**6**, the first time measurement circuit **40** of the control unit **18** measures an elapsed time period immediately after the execution of the general step S**5**. When the elapsed time period reaches a predetermined time period input in advance to the control unit **18** ("YES" in S**6**), the control unit **18** executes the opening degree adjustment step S**3** mainly targeted on the second solenoid valve **24***b*.

[0053] Specifically, when the elapsed time period from the execution of the general step S**5** reaches the predetermined time period, the control unit **18** makes the opening degree of the second solenoid valve **24***b* larger than the opening degree thereof up to this point. At the same time, the control unit **18** makes the opening degrees of the first solenoid valve **24***a* and the third solenoid valve **24***c* smaller than the opening degrees thereof up to this point. For example, the control unit **18** fully opens the second solenoid valve **24***b* and fully closes the first solenoid valve **24***a* and the third solenoid valve **24***c*. As a result, the entire amount of the carbon dioxide-containing gas from the air pump **16** is supplied to the second accommodation unit **12***b*. In contrast, the supply flow rate of the carbon dioxide-containing gas supplied to the first accommodation unit **12***a* and the third accommodation unit **12***c* is 0. This situation is represented by a region D of FIG. **3**.

[0054] The second time measurement circuit **42** of the control unit **18** measures an elapsed time period immediately after the execution of the opening degree adjustment step S**3** mainly targeted on the second solenoid valve **24***b*. During this measurement, the second determination step S**4** is executed. Specifically, the control unit **18** determines whether or not the elapsed time period from the execution of the opening degree adjustment step S**3** mainly targeted on the second solenoid valve **24***b* reaches a predetermined time period input in advance to the control unit **18**.

[0055] When the elapsed time period reaches the predetermined time period, the control unit **18** shifts the culture method to the general step S**5**. Specifically, when the elapsed time period from the execution of the opening degree adjustment step S**3** mainly targeted on the second solenoid valve **24***b* reaches the predetermined time period, the control unit **18** makes the opening degree of the second solenoid valve **24***b* smaller than the opening degree thereof at the time of the opening degree adjustment step S**3**. At the same time, the control unit **18** makes the opening degrees of the first solenoid valve **24***a* and the third solenoid valve **24***c* larger than the opening degrees thereof at the time of the opening degree adjustment step S**3**. For example, the control unit **18** sets the second solenoid valve **24***b* to the original opening degree (one third of the full opening) and sets the first solenoid valve **24***a* and the third solenoid valve **24***c* to the original opening degrees (one third of the full opening). As a result, the carbon dioxide-containing gas from the air pump **16** is substantially equally distributed to the first accommodation unit **12***a* to the third accommodation unit **12***c* in the same manner as described above. This situation is represented by a region E of FIG. **3**.

[0056] A large amount of carbon dioxide-containing gas is supplied to the second accommodation unit **12***b* during a period from when the opening degree adjustment step S**3** mainly targeted on the second solenoid valve **24***b* is executed until when the general step S**5** is executed. The culture solution L in the second accommodation unit **12***b* is agitated by the large amount of carbon dioxide-containing gas. Therefore, the microalgae in the culture solution L are also agitated. For this reason, settling or flocculation of the microalgae in the second accommodation unit **12***b* is avoided. Therefore, light is substantially evenly incident on the microalgae in the second accommodation unit **12***b*. Consequently, the microalgae in the second accommodation unit **12***b* actively perform photosynthesis and sufficiently fix carbon dioxide. As a result, a sufficient amount of carbon dioxide can be consumed.

[0057] The first time measurement circuit **40** of the control unit **18** measures an elapsed time period immediately after the execution of the general step S**5**. When the elapsed time period reaches a predetermined time period input in advance to the control unit **18**, the control unit **18** executes the opening degree adjustment step S**3** mainly targeted on the third solenoid valve **24***c*.

[0058] Specifically, when the elapsed time period from the execution of the general step S**5** reaches the predetermined time period, the control unit **18** makes the opening degree of the third solenoid valve **24***c* larger than the opening degree thereof up to this point. At the same time, the control unit **18** makes the opening degrees of the first solenoid valve **24***a* and the second solenoid valve **24***b* smaller than the opening degrees thereof up to this point. For example, the control unit **18** fully opens the third solenoid valve **24***c* and fully closes the first solenoid valve **24***a* and the second solenoid valve **24***b*. As a result, the entire amount of the carbon dioxide-containing gas from the air pump **16** is supplied to the third accommodation unit **12***c*. In contrast, the supply flow rate of the carbon dioxide-containing gas supplied to the first accommodation unit **12***a* and the second accommodation unit **12***b* is 0. This situation is represented by a region F of FIG. **3**.

[0059] The second time measurement circuit **42** of the control unit **18** measures an elapsed time period immediately after the execution of the opening degree adjustment step S**3** mainly targeted on the third solenoid valve **24***c*. During this measurement, the second determination step S**4** is executed. Specifically, the control unit **18** determines whether or not the elapsed time period from the execution of the opening degree adjustment step S**3** mainly targeted on the third solenoid valve **24***c* reaches a predetermined time period input in advance to the control unit **18**.

[0060] When the elapsed time period reaches the predetermined time period, the control unit **18** shifts the culture method to the general step S**5**. Specifically, when the elapsed time period from the execution of the opening degree adjustment step S**3** mainly targeted on the third solenoid valve **24***c* reaches the predetermined time period, the control unit **18** makes the opening degree of the third solenoid valve **24***c* smaller than the opening degree thereof at the time of the opening degree adjustment step S**3**. At the same time, the control unit **18** makes the opening degrees of the first solenoid valve **24***a* and the second solenoid valve **24***b* larger than the opening degrees thereof at the time of the opening degree adjustment step S**3**. For example, the control unit **18** sets the third solenoid valve **24***c* to the original opening degree (one third of the full opening) and sets the first solenoid valve **24***a* and the second solenoid valve **24***b* to the original opening degrees (one third of the full opening). As a result, the carbon dioxide-containing gas from the air pump **16** is substantially equally distributed to the first accommodation unit **12***a* to the third accommodation unit **12***c* in the same manner as described above. This situation is represented by a region G of FIG. **3**.

[0061] A large amount of carbon dioxide-containing gas is supplied to the third accommodation unit **12***c* during a period from when the opening degree adjustment step S**3** mainly targeted on the third solenoid valve **24***c* is executed until when the general step S**5** is executed. The culture solution L in the third accommodation unit **12***c* is agitated by the large amount of carbon dioxide-containing gas. Therefore, the microalgae in the culture solution L are also agitated. For this reason, settling or flocculation of the microalgae in the third accommodation unit **12***c* is avoided. Therefore, light is substantially evenly incident on the microalgae in the third accommodation unit **12***c*. Consequently, the microalgae in the third accommodation unit **12***c* actively perform photosynthesis and sufficiently fix carbon dioxide. As a result, a sufficient amount of carbon dioxide can be consumed.

[0062] As described above, microalgae can be favorably cultured in the first accommodation unit **12***a* to the third accommodation unit **12***c*.

[0063] At night, the temperature of the culture solution L is lower than that in the daytime, and the amount of light incident on each of the first accommodation unit **12***a* to the third accommodation unit **12***c* decreases. Under such a situation, the second condition or the third condition may be satisfied before the first condition is satisfied. In this case as well, in the same manner as described above, the control unit **18** sequentially executes the opening degree adjustment mainly targeted on the first solenoid valve **24***a*, the opening degree adjustment mainly targeted on the second solenoid valve **24***b*, and the opening degree adjustment mainly targeted on the third solenoid valve **24***c*. Therefore, even under a situation in which microalgae tend to settle in a relatively short time, such as at night, microalgae can be favorably cultured in the first accommodation unit **12***a* to the third accommodation unit **12***c*.

[0064] In this manner, according to the present embodiment, a large amount of carbon dioxide-containing gas can be temporarily supplied to the culture solution L by executing the opening degree adjustment step S**3**. Therefore, while microalgae are cultured in the manner as described above, the air pump **16** is maintained in steady operation. That is, even when a large amount of carbon dioxide-containing gas is supplied to the culture solution L in order to agitate microalgae, it is not necessary to increase the carbon dioxide-containing gas discharge amount of the air pump **16**. For the above reason, it is not necessary to select the air pump **16** having an excessive capacity for discharging a large amount of carbon dioxide-containing gas.

[0065] In other words, according to the present embodiment, it is possible to select the air pump **16** having an appropriate capacity for discharging the carbon dioxide-containing gas in an amount sufficient for culturing microalgae. Therefore, an increase in electric power consumption per unit time period is avoided. This can reduce the running cost in culturing microalgae.

[0066] As described above, the present embodiment discloses the culture method for culturing microalgae in the culture device (**10**) including the plurality of accommodation units (**12***a* to **12***c*) configured to accommodate the culture solution (L) and the microalgae, the gas supply unit (**16**) configured to supply a gas to the plurality of accommodation units, and the plurality of gas supply lines (**20**, **22***a*, **22***b*) configured to connect the gas supply unit with the plurality of accommodation units, respectively, wherein the plurality of gas supply lines are provided with the plurality of valves (**24***a* to **24***c*), respectively, the culture method including: the opening degree adjustment step (S**3**) of adjusting the opening degree of at least one of the plurality of valves during culturing of the microalgae in the plurality of accommodation units; and an agitation step (S**4**) of culturing the microalgae in a state in which the opening degree of the at least one of the plurality of valves is adjusted, wherein, in the opening degree adjustment step, by adjusting the opening degree of the at least one of the plurality of valves, the supply of the gas to at least one accommodation unit of the plurality of accommodation units is stopped or the supply flow rate of the gas supplied to the at least one accommodation unit is decreased, and the supply flow rate of the gas supplied to at least one remaining accommodation unit is increased.

[0067] The present embodiment discloses the culture device (**10**) that cultures microalgae in the culture solution (L), the culture device including: the plurality of accommodation units (**12***a* to **12***c*) configured to accommodate the culture solution and the microalgae; the gas supply unit (**16**) configured to supply a gas to the plurality of accommodation units; the plurality of gas supply lines (**20**, **22***a*, **22***b*) configured to connect the gas supply unit with the plurality of accommodation units, respectively; the plurality of valves (**24***a* to **24***c*) provided in the plurality of gas supply lines, respectively; and the control unit (**18**) configured to individually adjust the opening degree of each of the plurality of valves, wherein, by adjusting the opening degree of at least one of the plurality of valves during culturing of the microalgae in the plurality of accommodation units, the control unit stops the supply of the gas to at least one accommodation unit of the plurality of accommodation units or decreases the supply flow rate of the gas supplied to the at least one accommodation unit, and increases the supply flow rate of the gas supplied to at least one remaining accommodation unit.

[0068] By adjusting the opening degree, the supply of the gas is stopped, or the supply flow rate is

decreased in at least one of the plurality of accommodation units. In contrast, the supply flow rate of the gas is increased in at least one remaining accommodation unit. That is, the supply flow rate of the gas is adjusted.
[0069] Therefore, even if the supply flow rate of the gas from the gas supply unit is constant, a large amount of gas can be temporarily supplied to at least one of the plurality of accommodation units. Therefore, it is not necessary to select a gas supply unit having an excessive capacity.
[0070] That is, in the present embodiment, it is possible to use a gas supply unit that consumes a small amount of electric power per unit time period. Therefore, in performing culturing, it is possible to reduce the running cost.
[0071] In the accommodation unit in which the supply flow rate of the gas is temporarily increased, the microalgae and the culture solution are agitated. Therefore, settling or flocculation of the microalgae is suppressed. Accordingly, the light is incident on the microalgae substantially evenly. Further, since the culture solution is agitated, carbon dioxide becomes diffused throughout the entirety of the accommodation unit. Due to this reason, the microalgae actively carry out photosynthesis. Since a large amount of carbon dioxide becomes fixed in the microalgae by way of photosynthesis, such a feature can be expected to contribute to mitigating climate change or reducing its impact.
[0072] The present embodiment discloses the culture method including a plurality of opening degree adjustment steps including the opening degree adjustment step, wherein the supply flow rate of the gas is increased in all of the plurality of accommodation units by performing the plurality of opening degree adjustment steps.
[0073] The present embodiment discloses the culture device wherein the control unit performs a plurality of times of opening degree adjustments including the adjusting of the opening degree performed on the at least one of the plurality of valves, and increases the supply flow rate of the gas in all of the plurality of accommodation units by performing the plurality of times of opening degree adjustments.
[0074] According to this feature, the supply flow rate of the gas supplied to all of the accommodation units can be sequentially and temporarily increased. Therefore, even if the supply flow rate of the gas from the gas supply unit is constant, it is possible to prevent the microalgae from settling or flocculating in all of the plurality of accommodation units. As a result, the microalgae can actively perform photosynthesis in all the accommodation units.
[0075] The present embodiment discloses the culture method wherein the plurality of opening degree adjustment steps for the plurality of accommodation units do not overlap each other.
[0076] The present embodiment discloses the culture device wherein the control unit performs the plurality of times of opening degree adjustments for the plurality of accommodation units without causing the opening degree adjustments to overlap each other.
[0077] In this case, the supply flow rates of the gas supplied to the plurality of accommodation units are prevented from being simultaneously adjusted. Therefore, the gas can be supplied at a sufficient supply flow rate to the accommodation unit in which the culture solution needs to be agitated.
[0078] The present embodiment discloses the culture method wherein, in the opening degree adjustment step, the opening degree of the at least one of the plurality of valves is set to full opening, and the opening degree of at least one remaining valve is set to full closing.
[0079] The present embodiment discloses the culture device wherein the control unit sets the opening degree of the at least one of the plurality of valves to full opening and sets the opening degree of at least one remaining valve to full closing.
[0080] In this case, the gas is not distributed to the accommodation unit provided with the valve which has been fully closed. On the other hand, a large amount of gas is distributed to the accommodation unit provided with the valve which has been fully opened. Therefore, a larger amount of gas can be supplied to the accommodation unit in which the culture solution needs to be

agitated.
[0081] The present embodiment discloses the culture method wherein the opening degree adjustment step is executed when a predetermined condition set in advance is satisfied.
[0082] The present embodiment discloses the culture device wherein the control unit adjusts the opening degree of the at least one of the plurality of valves when a predetermined condition set in advance is satisfied.
[0083] The predetermined condition is, for example, a condition under which microalgae tend to settle. Since the opening degree adjustment is executed when such a situation occurs, it is possible to prevent the microalgae from settling or flocculating.
[0084] Even in a case where a gas sufficient for culturing microalgae is continuously supplied to the accommodation units, there is a tendency for the microalgae to settle over time. In order to avoid such a situation, it is preferable to execute the opening degree adjustment and the second opening degree adjustment when the predetermined time period has elapsed. That is, the present embodiment discloses the culture method wherein the predetermined condition is that the predetermined time period has elapsed.
[0085] The present embodiment discloses the culture device wherein the predetermined condition is elapse of the predetermined time period, and the control unit adjusts the opening degree of the at least one of the plurality of valves when the predetermined time period has elapsed.
[0086] Microalgae also tend to settle when the surrounding environmental temperature decreases. In order to avoid this situation, it is preferable to execute the opening degree adjustment and the second opening degree adjustment when the temperature of the culture solution reaches the allowable lower limit value. That is, the present embodiment discloses the culture method wherein the predetermined condition is that the temperature of the culture solution reaches the threshold temperature or lower.
[0087] The present embodiment discloses the culture device further including the temperature detector (**36***a* to **36***c*) configured to measure the temperature of the culture solution, wherein the predetermined condition is that the temperature reaches the threshold temperature or lower, and the control unit adjusts the opening degree of the at least one of the plurality of valves when the temperature reaches the threshold temperature or lower.
[0088] Microalgae also tend to settle when the amount of light incident on the accommodation units decreases. In order to avoid this situation, it is preferable to execute the opening degree adjustment and the second opening degree adjustment when the amount of light reaches the allowable lower limit value. That is, the present embodiment discloses the culture method wherein the predetermined condition is that the amount of light emitted to each of the plurality of accommodation units reaches the threshold amount of light or less.
[0089] The present embodiment discloses the culture device further including the light amount measurement device (**38***a* to **38***c*) configured to measure the amount of light emitted to each of the plurality of accommodation units, wherein the predetermined condition is that the amount of light reaches the threshold amount of light or less, and the control unit adjusts the opening degree of the at least one of the plurality of valves when the amount of light reaches the threshold amount of light or less.
[0090] The present embodiment discloses the culture method wherein the pump (**16**) is used as the gas supply unit, and the output of the pump is set to be constant both in a case where the opening degree adjustment step is performed and in a case where the general step (S**5**) of supplying the gas to all of the plurality of accommodation units without performing the opening degree adjustment step is performed.
[0091] The present embodiment discloses the culture device wherein the gas supply unit is the pump (**16**), and the pump is operated at a constant output both in a case where adjustment of the opening degree of the at least one of the plurality of valves is performed and in a case where the gas is supplied to all of the plurality of accommodation units without performing the adjustment.

[0092] As described above, according to the present embodiment, even when the gas supply flow rate from the gas supply unit such as a pump is constant, a large amount of carbon dioxide-containing gas can be temporarily supplied to a predetermined accommodation unit. That is, even when a large amount of carbon dioxide-containing gas is supplied to the culture solution in order to agitate the microalgae, the pump can be operated at a constant output.
[0093] In other words, in this case, when a large amount of carbon dioxide-containing gas is temporarily supplied to one accommodation unit, it is not necessary to increase the discharge amount of the pump. Therefore, it is not necessary to select a pump having an excessive capacity for discharging a large amount of carbon dioxide-containing gas. In other words, it is possible to select a pump having an appropriate capacity for discharging a sufficient amount of gas for culturing the microalgae. Therefore, an increase in electric power consumption per unit time period is avoided. This can reduce the running cost in culturing microalgae.
[0094] The present invention is not limited to the above disclosure, and various modifications are possible without departing from the essence and gist of the present invention.
[0095] For example, the number of the accommodation units is not limited to three. The number of the accommodation units may be two or may be four or more. The number of the gas supply lines and the number of the valves are determined according to the number of the accommodation units.
[0096] In the opening degree adjustment step S**3**, it is sufficient that the opening degree of the main target valve is larger than the opening degree of the valve other than the main target valve. In other words, the opening degree of each valve is not particularly limited. For example, the opening degree of the main target valve (the valve whose opening degree is increased) is not limited to full opening. Similarly, the opening degree of the valve other than the main target valve (the valve whose opening degree is reduced) is not limited to full closing. [0097] What is claim is:

Claims

1. A culture method for culturing microalgae in a culture device including a plurality of accommodation units configured to accommodate a culture solution and the microalgae, a gas supply unit configured to supply a gas to the plurality of accommodation units, and a plurality of gas supply lines configured to connect the gas supply unit with the plurality of accommodation units, respectively, wherein the plurality of gas supply lines are provided with a plurality of valves, respectively, the culture method comprising: an opening degree adjustment step of adjusting an opening degree of at least one of the plurality of valves during culturing of the microalgae in the plurality of accommodation units; and an agitation step of culturing the microalgae in a state in which the opening degree of the at least one of the plurality of valves is adjusted, wherein, in the opening degree adjustment step, by adjusting the opening degree of the at least one of the plurality of valves, supply of the gas to at least one accommodation unit of the plurality of accommodation units is stopped or a supply flow rate of the gas supplied to the at least one accommodation unit is decreased, and a supply flow rate of the gas supplied to at least one remaining accommodation unit is increased.
2. The culture method according to claim 1, comprising a plurality of opening degree adjustment steps including the opening degree adjustment step, wherein the supply flow rate of the gas is increased in all of the plurality of accommodation units by performing the plurality of opening degree adjustment steps.
3. The culture method according to claim 2, wherein the plurality of opening degree adjustment steps for the plurality of accommodation units do not overlap each other.
4. The culture method according to claim 1, wherein in the opening degree adjustment step, the opening degree of the at least one of the plurality of valves is set to full opening, and an opening degree of at least one remaining valve is set to full closing.
5. The culture method according to claim 1, wherein the opening degree adjustment step is

executed when a predetermined condition set in advance is satisfied.
6. The culture method according to claim 5, wherein the predetermined condition is that a predetermined time period has elapsed.
7. The culture method according to claim 5, wherein the predetermined condition is that a temperature of the culture solution reaches a threshold temperature or lower.
8. The culture method according to claim 5, wherein the predetermined condition is that an amount of light emitted to each of the plurality of accommodation units reaches a threshold amount of light or less.
9. The culture method according to claim 1, wherein a pump is used as the gas supply unit, and an output of the pump is set to be constant both in a case where the opening degree adjustment step is performed and in a case where a general step of supplying the gas to all of the plurality of accommodation units without performing the opening degree adjustment step is performed.
10. A culture device that cultures microalgae in a culture solution, the culture device comprising: a plurality of accommodation units configured to accommodate the culture solution and the microalgae; a gas supply unit configured to supply a gas to the plurality of accommodation units; a plurality of gas supply lines configured to connect the gas supply unit with the plurality of accommodation units, respectively; a plurality of valves provided in the plurality of gas supply lines, respectively; and a control unit configured to individually adjust an opening degree of each of the plurality of valves, wherein, by adjusting the opening degree of at least one of the plurality of valves during culturing of the microalgae in the plurality of accommodation units, the control unit stops supply of the gas to at least one accommodation unit of the plurality of accommodation units or decreases a supply flow rate of the gas supplied to the at least one accommodation unit, and increases a supply flow rate of the gas supplied to at least one remaining accommodation unit.
11. The culture device according to claim 10, wherein the control unit performs a plurality of times of opening degree adjustments including the adjusting of the opening degree performed on the at least one of the plurality of valves, and the control unit increases the supply flow rate of the gas in all of the plurality of accommodation units by performing the plurality of times of opening degree adjustments.
12. The culture device according to claim 11, wherein the control unit performs the plurality of times of opening degree adjustments for the plurality of accommodation units without causing the opening degree adjustments to overlap each other.
13. The culture device according to claim 10, wherein the control unit sets the opening degree of the at least one of the plurality of valves to full opening, and sets an opening degree of at least one remaining valve to full closing.
14. The culture device according to claim 10, wherein the control unit adjusts the opening degree of the at least one of the plurality of valves when a predetermined condition set in advance is satisfied.
15. The culture device according to claim 14, wherein the predetermined condition is elapse of a predetermined time period, and the control unit adjusts the opening degree of the at least one of the plurality of valves when the predetermined time period has elapsed.
16. The culture device according to claim 14, further comprising a temperature detector configured to measure a temperature of the culture solution, wherein the predetermined condition is that the temperature reaches a threshold temperature or lower, and the control unit adjusts the opening degree of the at least one of the plurality of valves when the temperature reaches the threshold temperature or lower.
17. The culture device according to claim 14, further comprising a light amount measurement device configured to measure an amount of light emitted to each of the plurality of accommodation units, wherein the predetermined condition is that the amount of light reaches a threshold amount of light or less, and the control unit adjusts the opening degree of the at least one of the plurality of valves when the amount of light reaches the threshold amount of light or less.
18. The culture device according to claim 10, wherein the gas supply unit is a pump, and the pump

is operated at a constant output both in a case where adjustment of the opening degree of the at least one of the plurality of valves is performed and in a case where the gas is supplied to all of the plurality of accommodation units without performing the adjustment.