US 20200060108A1

(19) United States
(12) Patent Application Publication
GOLDSMITH et al.
(10) Pub. No.: US 2020/0060108 A1
(43) Pub. Date: Feb. 27, 2020

(54) **INDOOR PROCESS AND SYSTEM FOR CULTIVATING AND HARVESTING DUCKWEED**

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(21) Appl. No.: **16/365,723**

(22) Filed: **Mar. 27, 2019**

Related U.S. Application Data

(60) Provisional application No. 62/648,758, filed on Mar. 27, 2018.

Publication Classification

(51) **Int. Cl.**

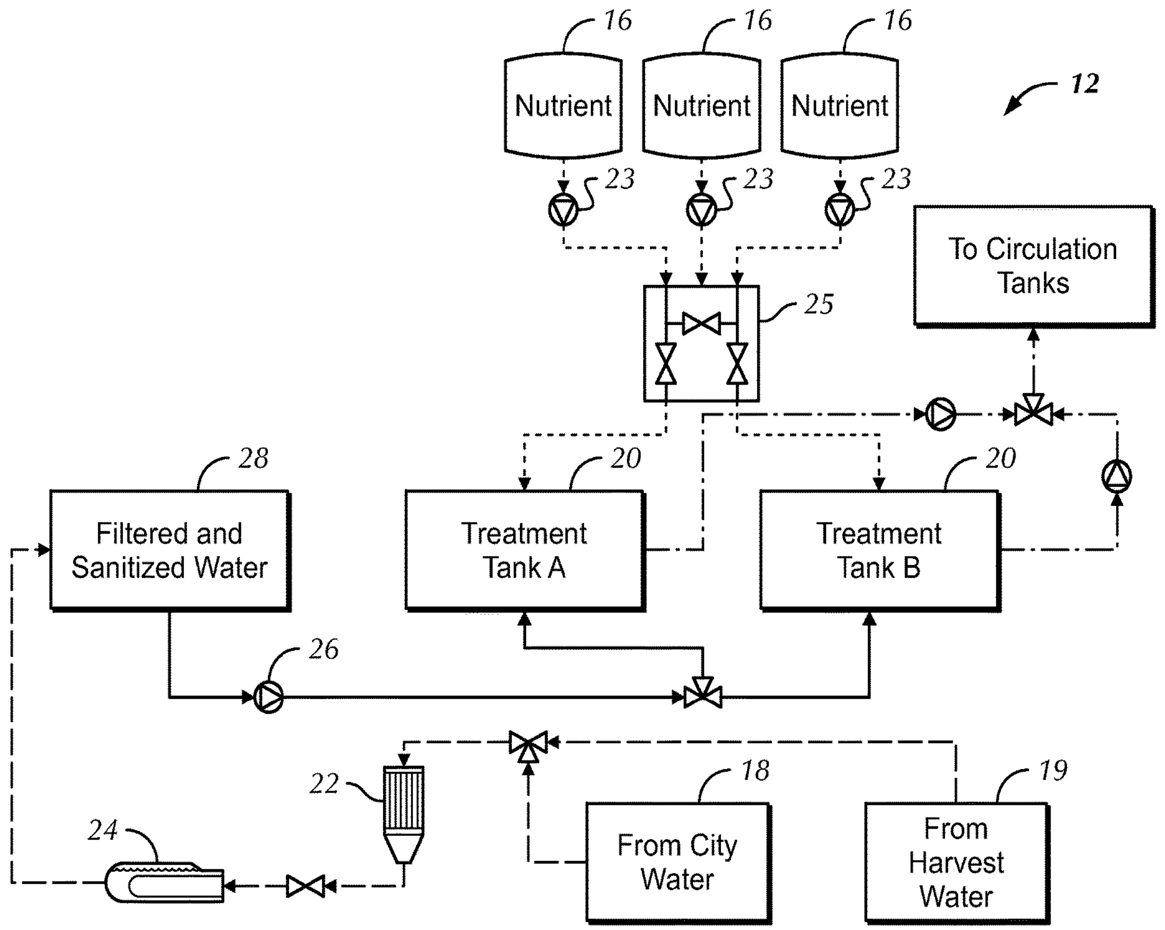
A01G 31/06	(2006.01)
A01G 7/04	(2006.01)
A01G 27/02	(2006.01)
A01G 27/00	(2006.01)

(52) **U.S. Cl.**

CPC ***A01G 31/06*** (2013.01); ***A01G 27/008*** (2013.01); ***A01G 27/02*** (2013.01); ***A01G 7/045*** (2013.01)

(57) **ABSTRACT**

An indoor system and process for cultivating, harvesting, and outputting a culture of aquatic plants, namely duckweed, are provided. The system includes a water treatment system and cultivation and harvesting system. The water treatment system provides for mixing of nutrients and treated water to form a treatment mixture which is supplied to the cultivation and harvesting system for facilitating growth of the duckweed.



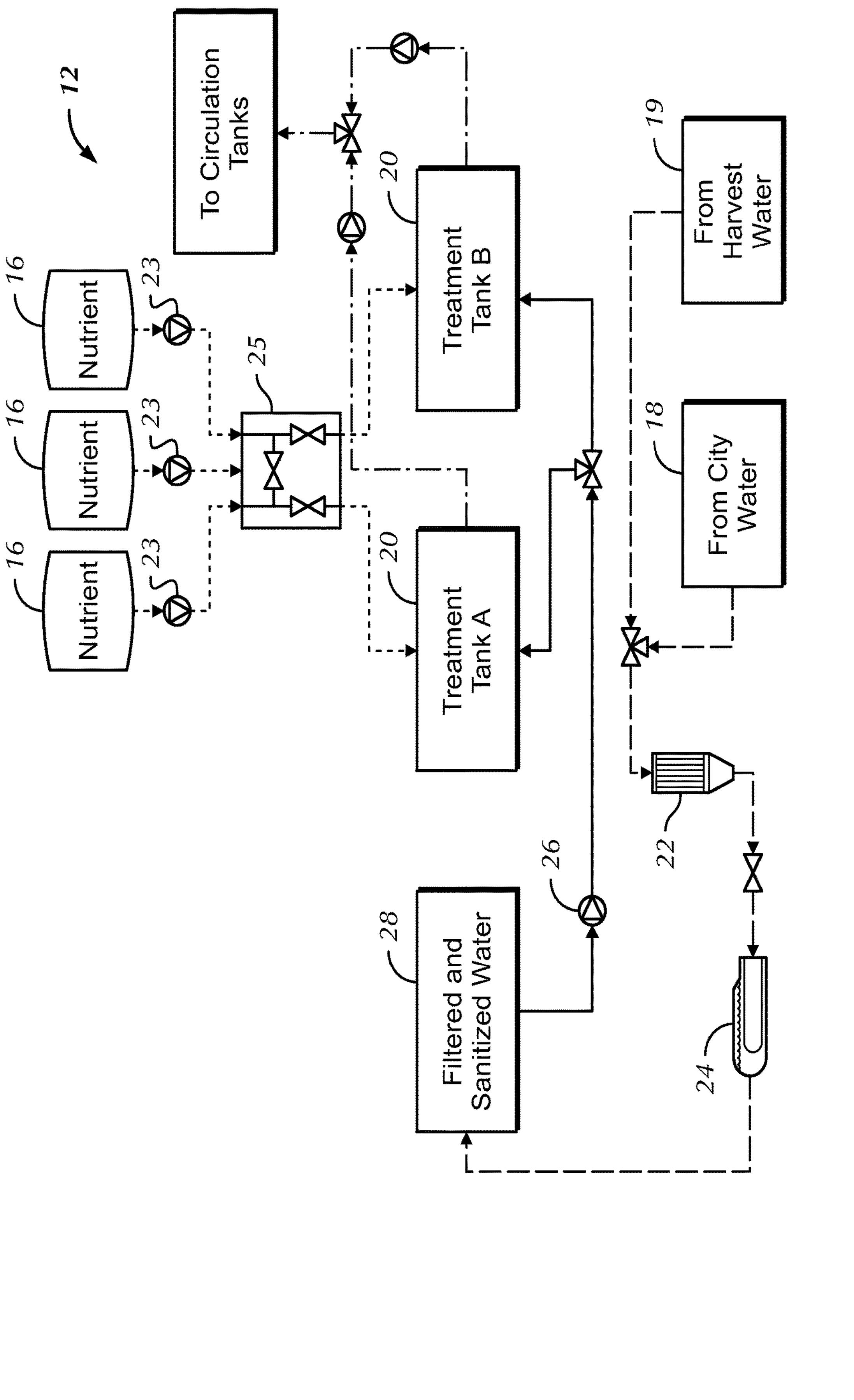

12
16
Nutrient
23
16
Nutrient
23
16
Nutrient
23
25
To Circulation Tanks
20
Treatment Tank B
20
Treatment Tank A
From Harvest Water
19
From City Water
18
22
24
26
28
Filtered and Sanitized Water

FIG. 1

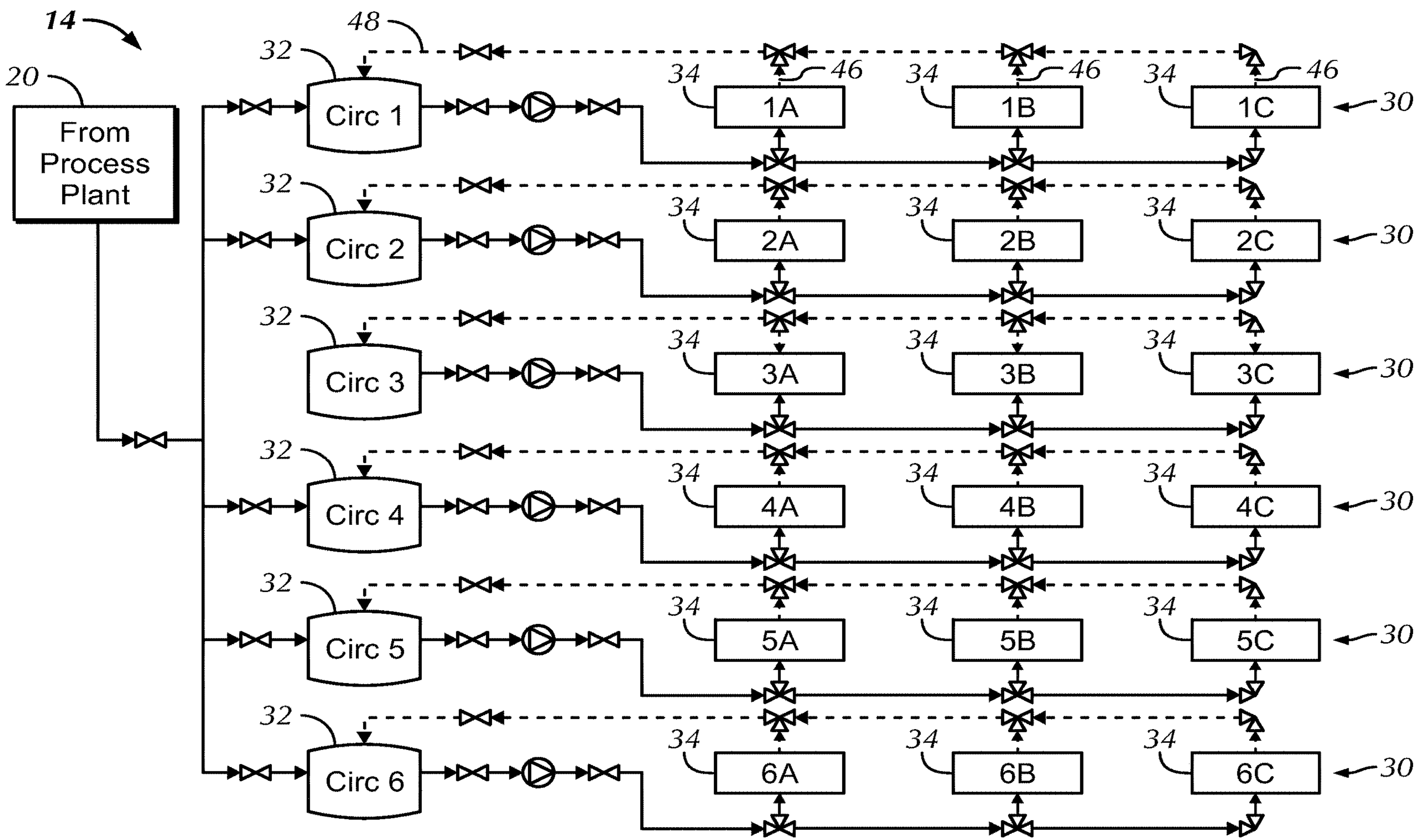

14
20
From Process Plant
48
32
Circ 1
Circ 2
Circ 3
Circ 4
Circ 5
Circ 6
34
46
1A
1B
1C
2A
2B
2C
3A
3B
3C
4A
4B
4C
5A
5B
5C
6A
6B
6C
30

FIG. 2

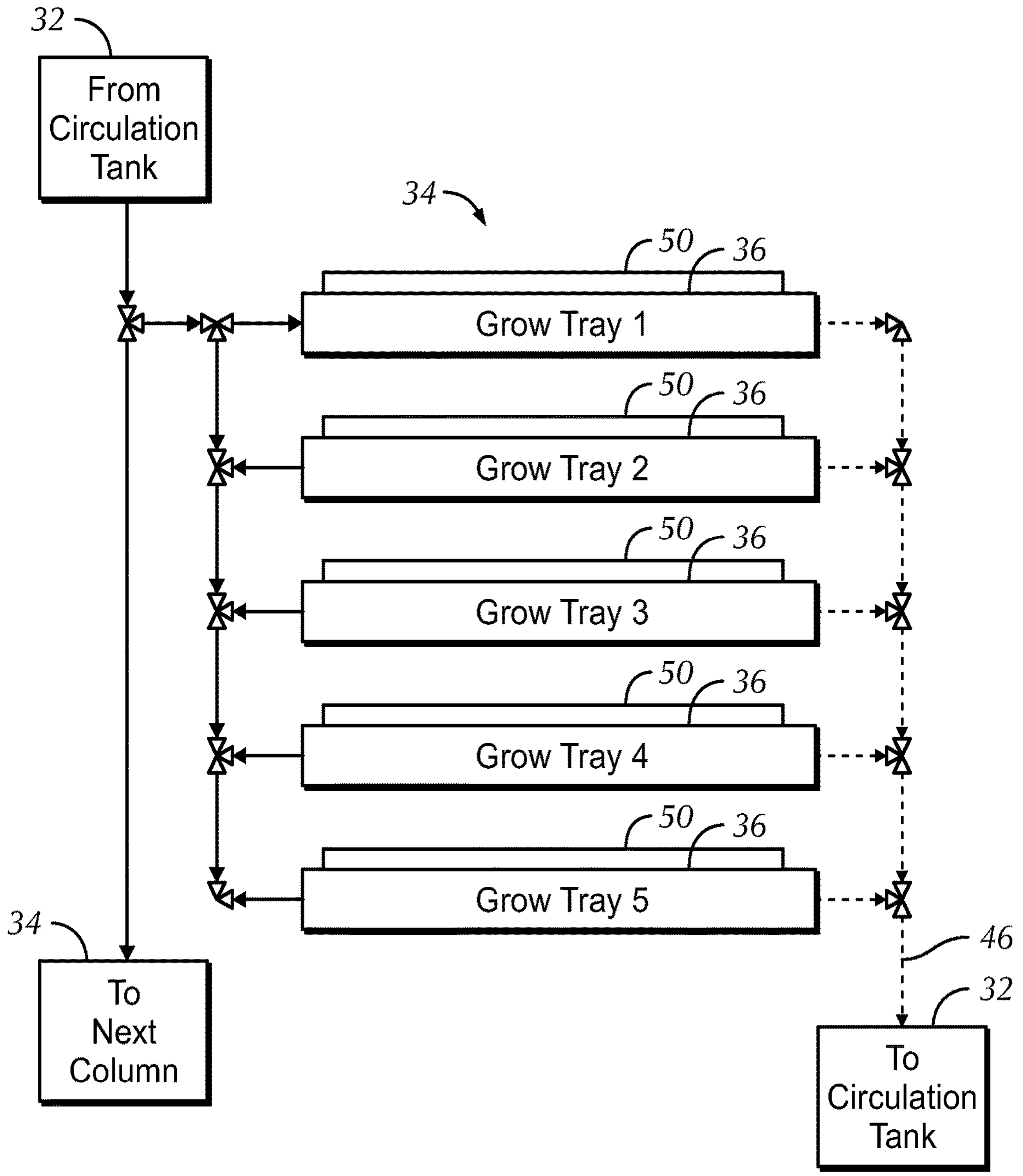

32
From Circulation Tank
34
50
36
Grow Tray 1
Grow Tray 2
Grow Tray 3
Grow Tray 4
Grow Tray 5
34
To Next Column
46
32
To Circulation Tank

FIG. 3

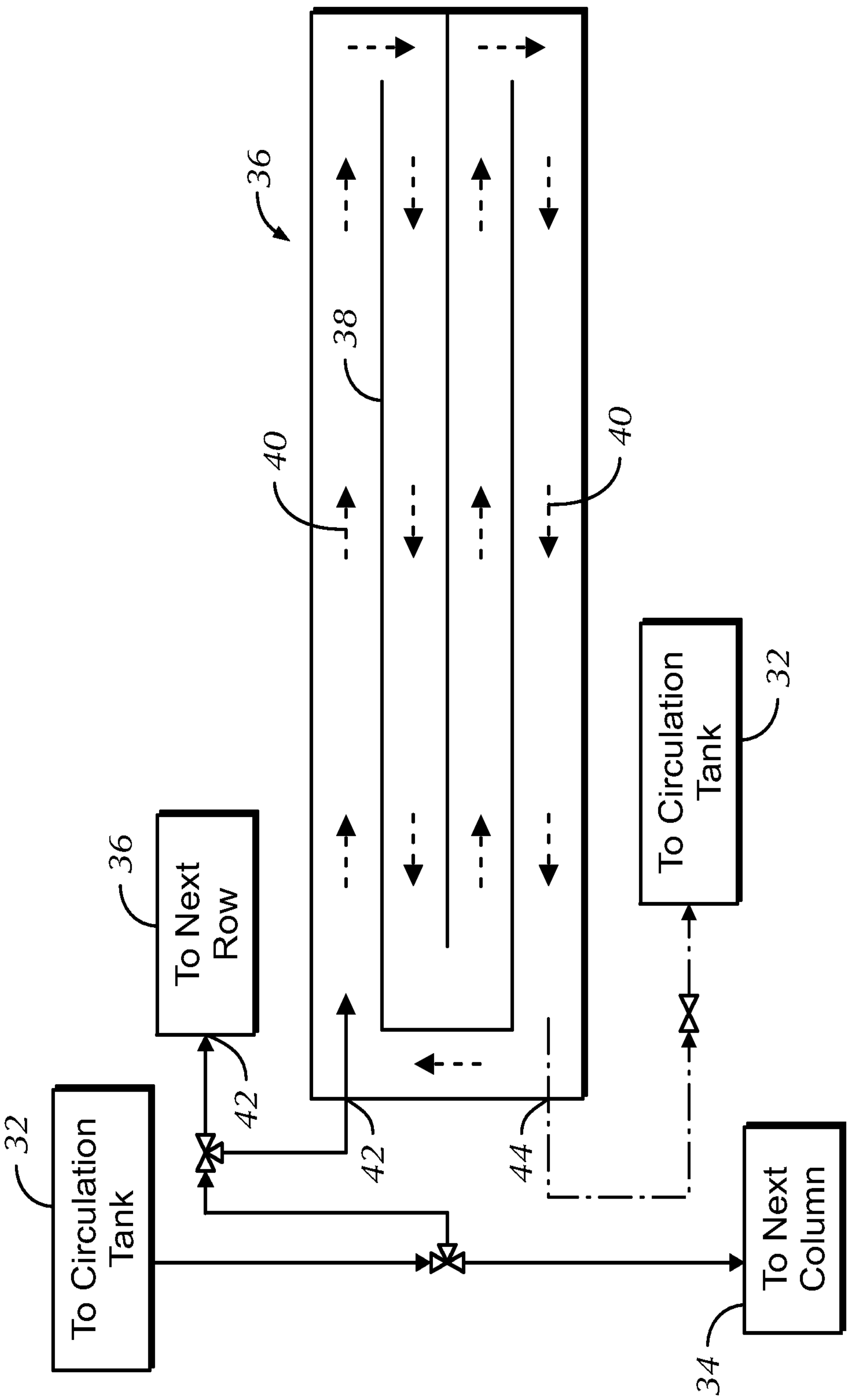

36
38
40
40
To Circulation Tank
32
To Next Row
36
42
42
44
To Circulation Tank
32
To Next Column
34

FIG. 4

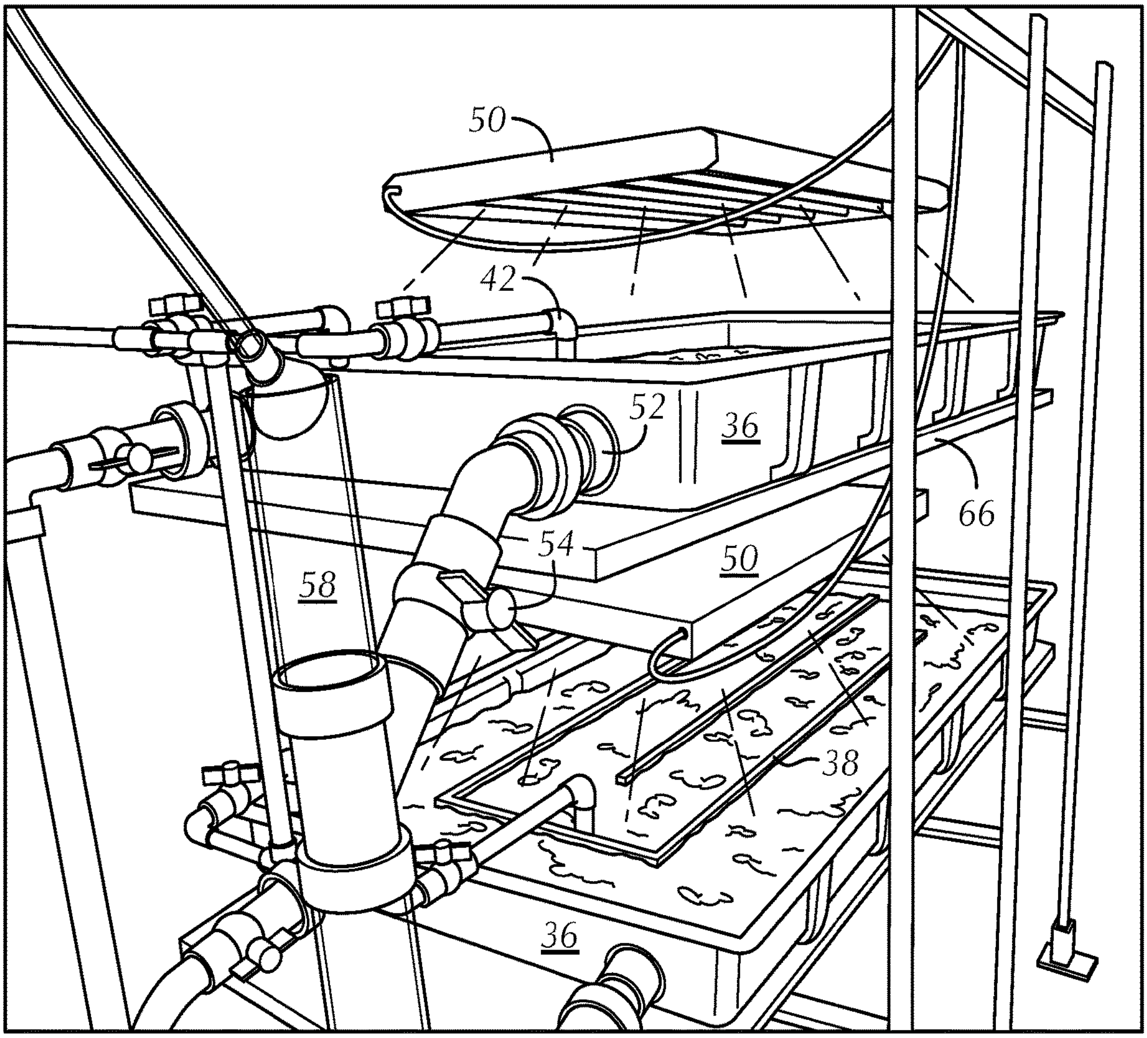


FIG. 5

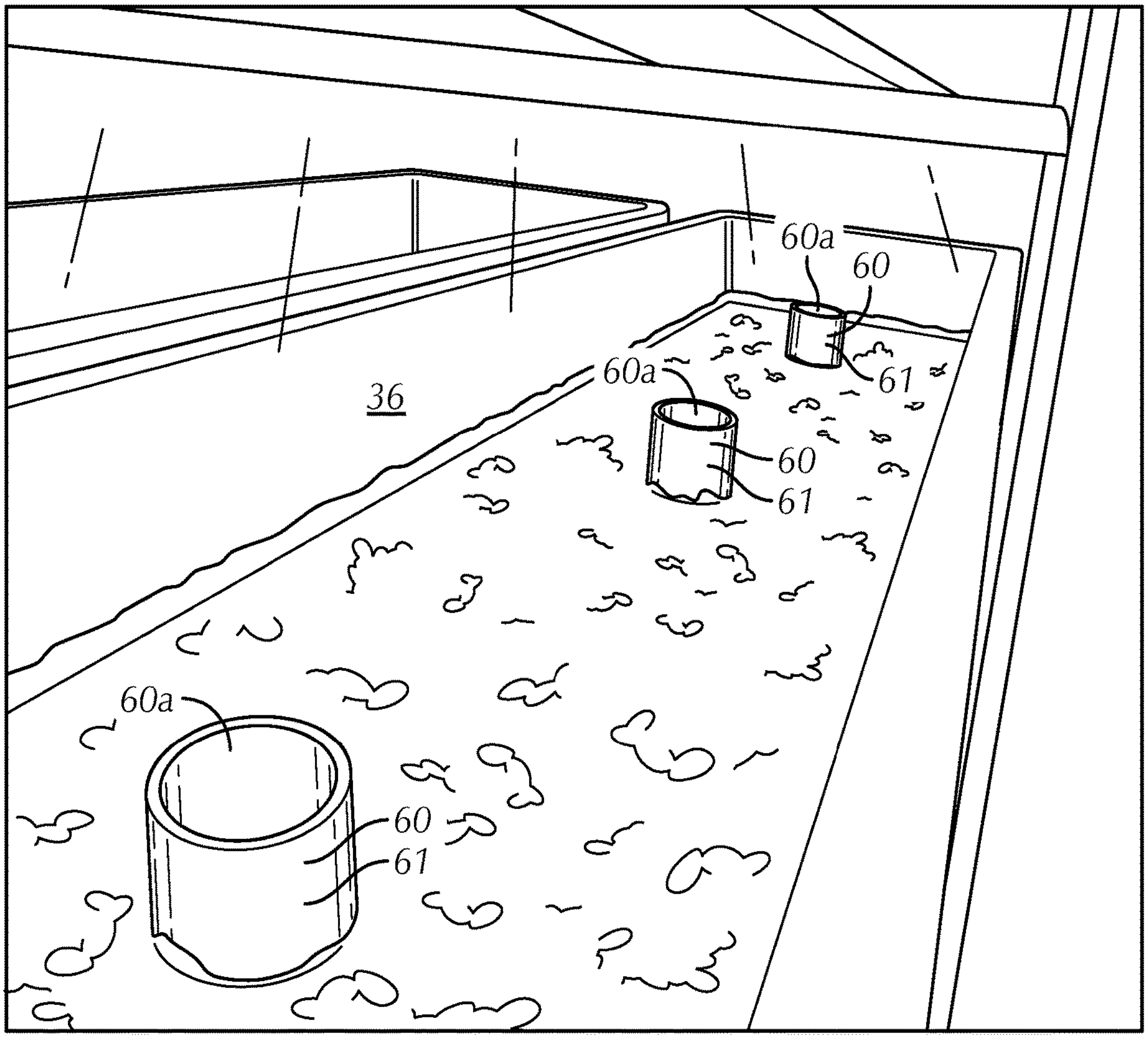


FIG. 6

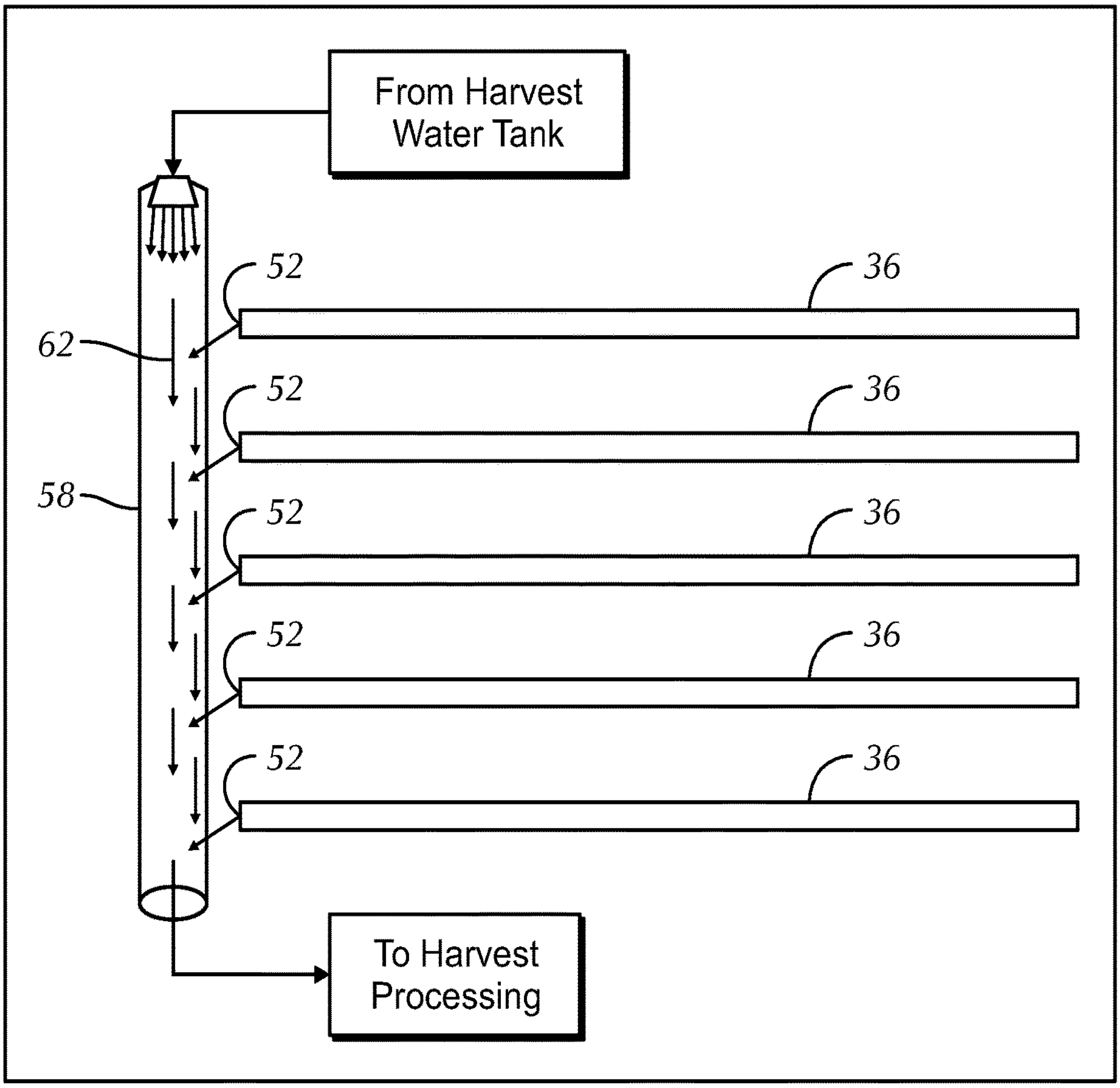

From Harvest Water Tank
52
36
62
52
36
58
52
36
52
36
52
36
To Harvest Processing

FIG. 7

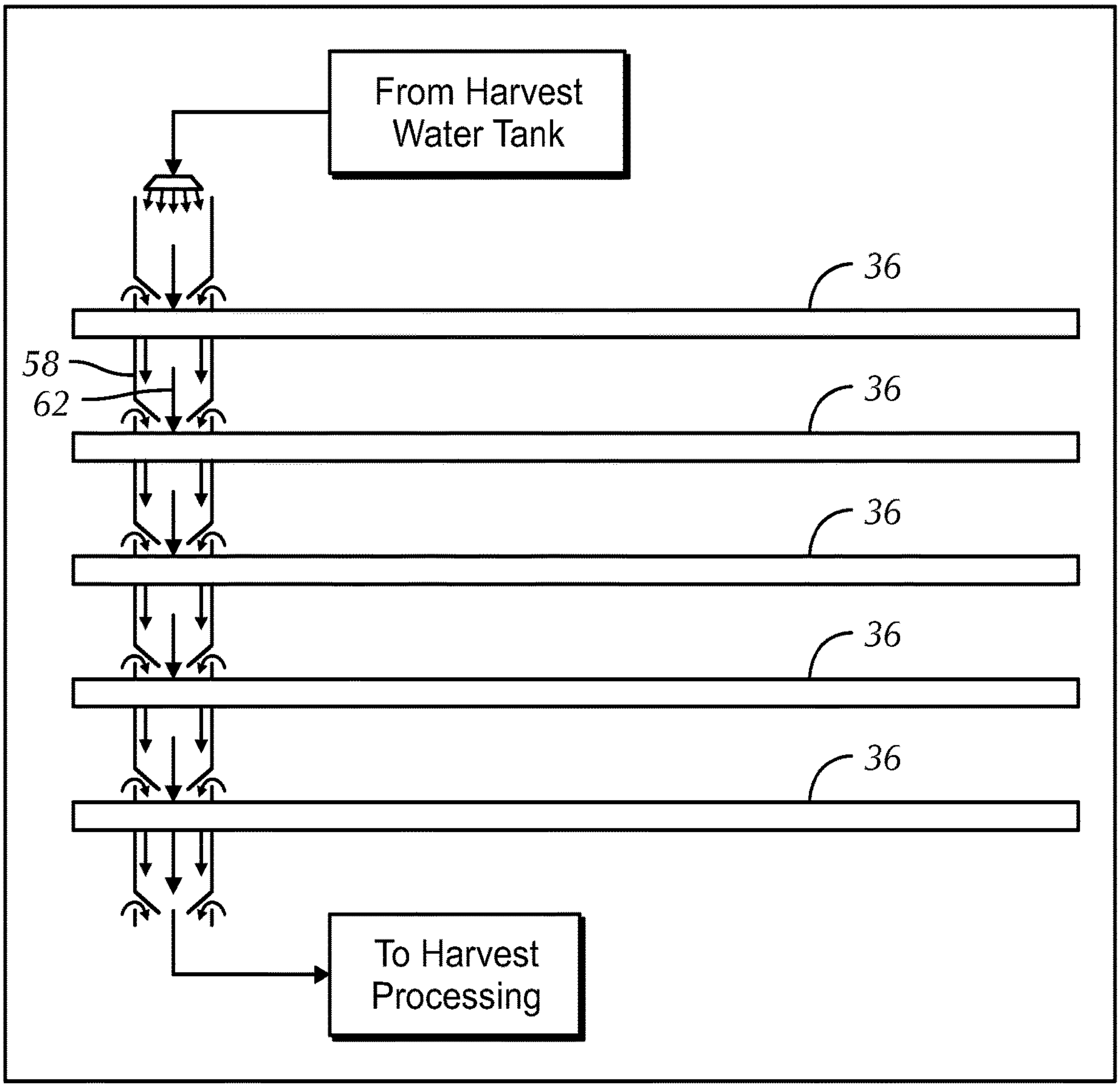

From Harvest Water Tank
36
58
62
36
36
36
36
To Harvest Processing

FIG. 8

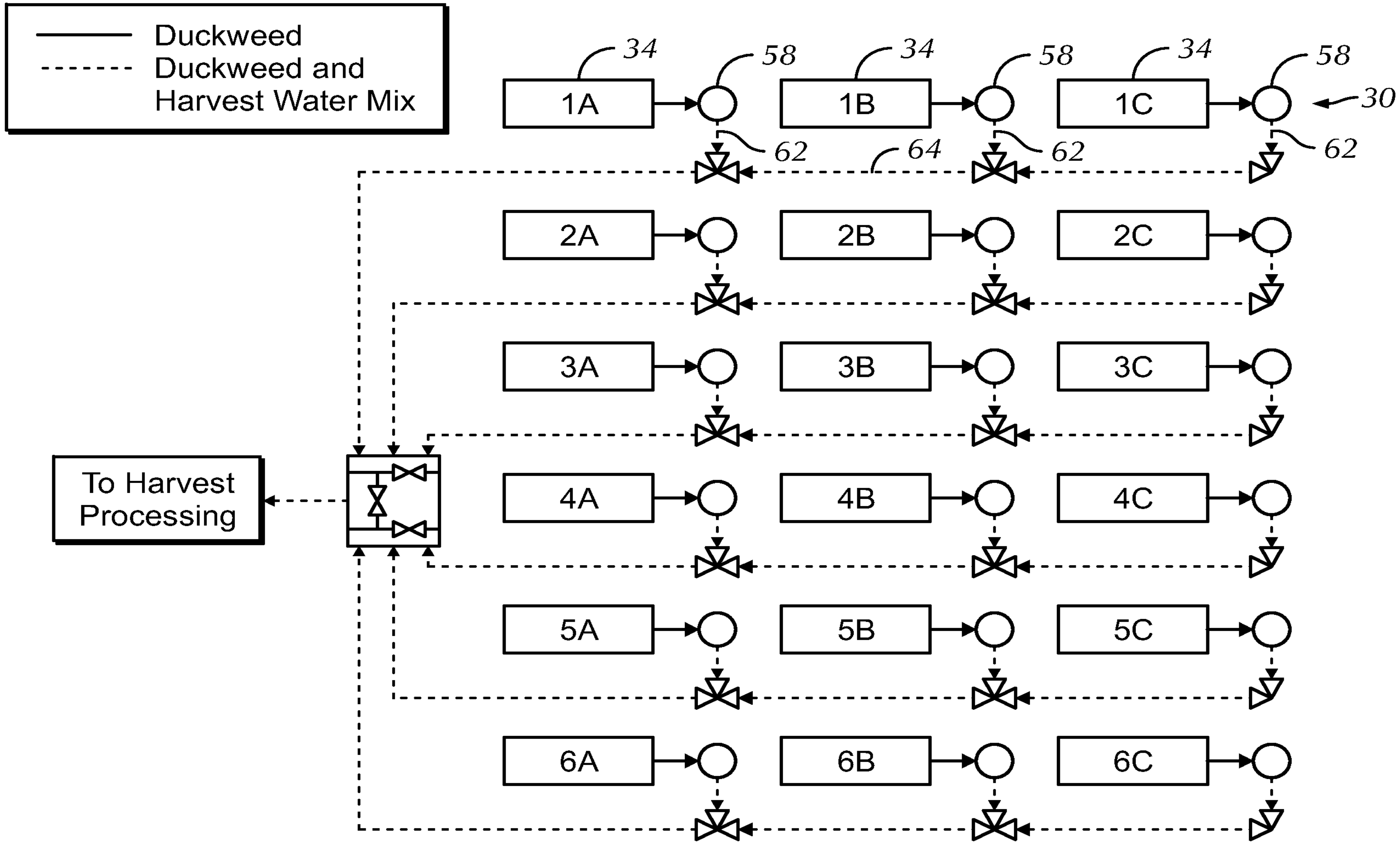

Duckweed
Duckweed and Harvest Water Mix
To Harvest Processing
1A
1B
1C
2A
2B
2C
3A
3B
3C
4A
4B
4C
5A
5B
5C
6A
6B
6C
34
58
62
64
30

FIG. 9

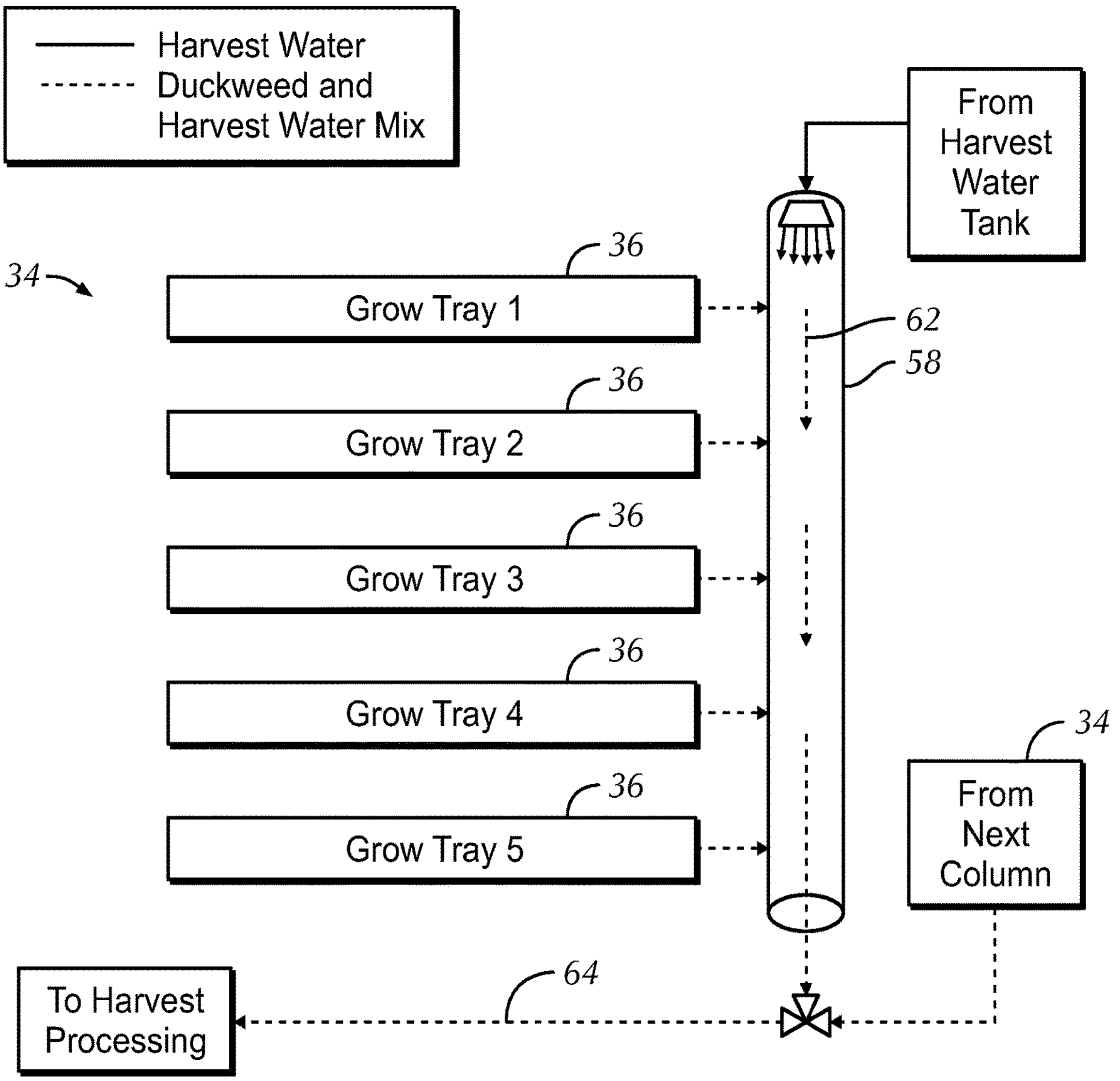

Harvest Water
Duckweed and Harvest Water Mix
From Harvest Water Tank
34
36
Grow Tray 1
62
58
36
Grow Tray 2
36
Grow Tray 3
36
Grow Tray 4
34
From Next Column
36
Grow Tray 5
64
To Harvest Processing

FIG. 10

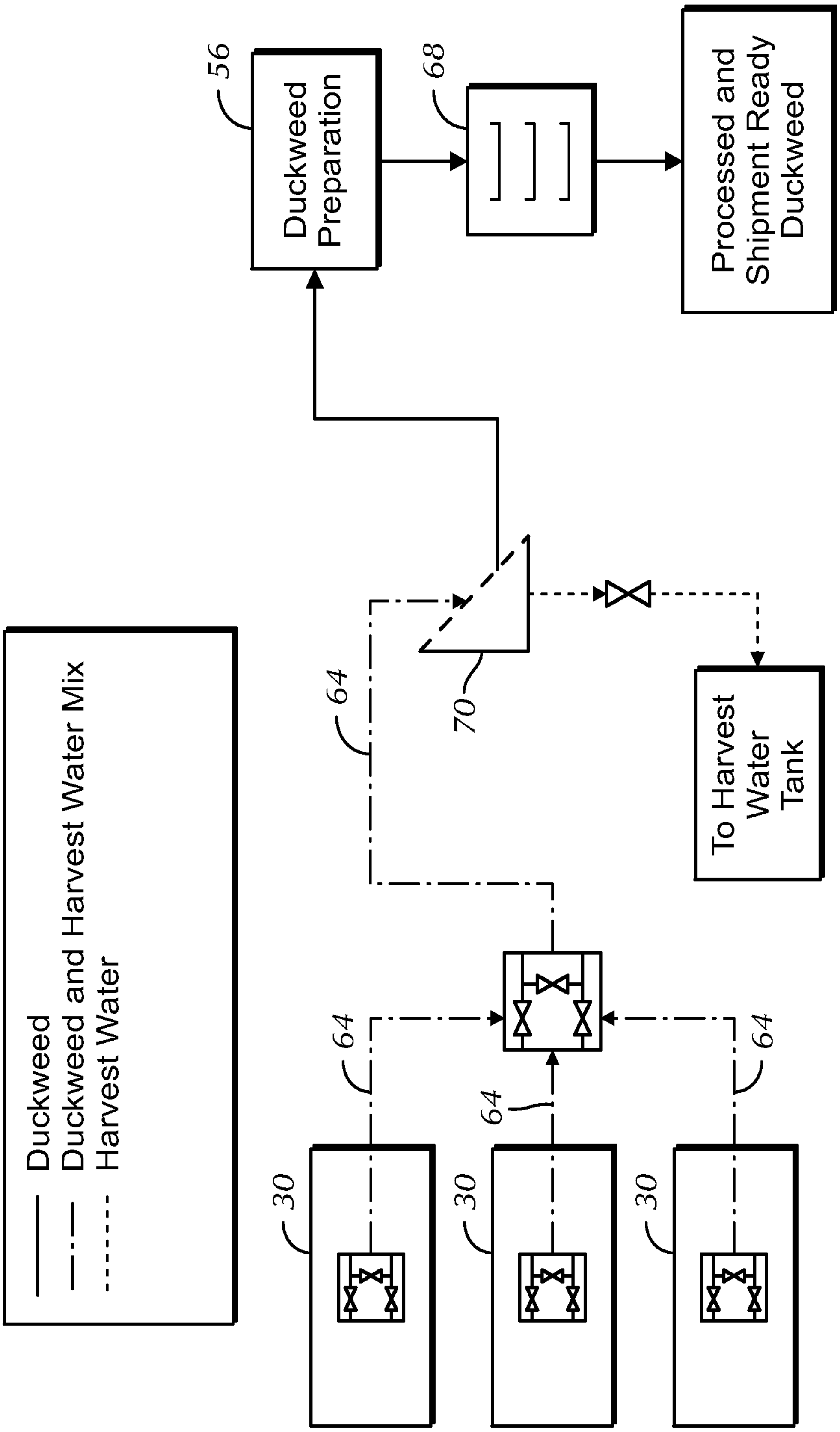

Duckweed
Duckweed and Harvest Water Mix
Harvest Water
Duckweed Preparation
56
68
Processed and Shipment Ready Duckweed
64
70
To Harvest Water Tank
30

FIG. 11

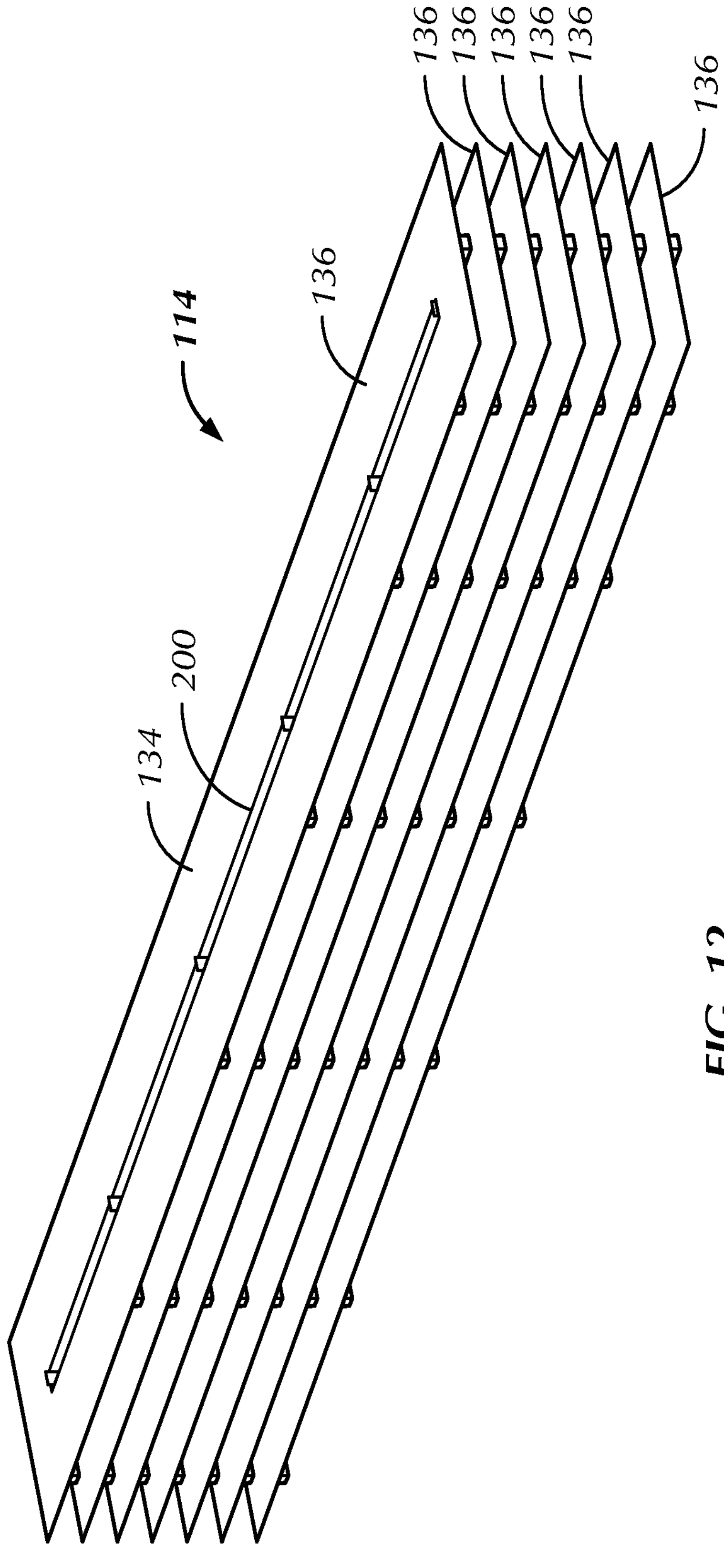


FIG. 12

INDOOR PROCESS AND SYSTEM FOR CULTIVATING AND HARVESTING DUCKWEED

BACKGROUND OF THE INVENTION

[0001] The present invention relates generally to the cultivation and processing of small aquatic photosynthetic organisms such as algae, aquatic species, and the like, including the small aquatic plant floating aquatic species such as duckweeds.

[0002] Lemnaceae is a family of flowering plants, also known as the duckweed family, as it contains the duckweeds or water lentils. Duckweeds include the genera *Spirodela, Landoltia, Lemna, Wolffia*, and *Wolfiella*. Duckweeds are fast-growing and high-pigment-containing monocotyledonous plants and are classified as macrophytes. Recently, some companies have begun analyzing the nutritional value of duckweeds for human consumption, and have found that due to its amino acid composition, duckweed qualifies as a high quality protein source for human nutrition.

[0003] Therefore, it is desirable to provide a system and process for quick, simple and efficient growth and harvesting of duckweed in a reliable manner.

[0004] Conventional duckweed growth and harvesting systems and methods are typically implemented in an outdoor setting. As such, the duckweed is exposed to the surrounding environment and subject to contamination, such as bacteria, from the surrounding environment. Consequently, conventional duckweed growth and harvesting systems typically require a decontamination step before the harvested duckweed is suitable for human or animal consumption. In addition, operation of conventional outdoor duckweed growth and harvesting systems are subject to constraints associated with the seasons and weather.

[0005] Therefore, it would also be desirable to provide a system and process for growth and harvesting of duckweed that is not impacted by the outdoor environment and the associated seasons and weather.

BRIEF SUMMARY OF THE INVENTION

[0006] In one embodiment, the present invention relates to a system and process for cultivating, harvesting, and outputting a culture of aquatic plants, namely duckweed. The system comprises a water treatment system and cultivation and harvesting system. The water treatment system provides for mixing of nutrients and treated water to form a treatment mixture which is supplied to the cultivation and harvesting system for facilitating growth of the duckweed.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0007] The foregoing summary, as well as the following detailed description of the invention, will be better understood when read in conjunction with the appended drawings. For the purpose of illustrating the invention, there are shown in the drawings an embodiment which is presently preferred. It should be understood, however, that the invention is not limited to the precise arrangements and instrumentalities shown.

[0008] In the drawings:

[0009] FIG. **1** is a schematic diagram illustrating a process for producing a treatment mixture in accordance with an embodiment of the present invention;

[0010] FIG. **2** is a top view schematic diagram of a cultivation and harvesting system and process in accordance with an embodiment of the present invention;

[0011] FIG. **3** is a side view schematic diagram of a growing unit in accordance with an embodiment of the present invention;

[0012] FIG. **4** is a top view schematic diagram of the flow surrounding and within a growing vessel according in accordance with an embodiment of the present invention;

[0013] FIG. **5** is a perspective view of a portion of a growing unit in accordance with an embodiment of the present invention;

[0014] FIG. **6** is top perspective view of a growing vessel in accordance with an embodiment of the present invention;

[0015] FIG. **7** is a side view schematic diagram of a harvesting system and process according to the embodiment shown in FIG. **5**;

[0016] FIG. **8** is a side view schematic diagram of a harvesting system and process according to the embodiment shown in FIG. **6**;

[0017] FIG. **9** is a top view schematic diagram of a portion of a harvesting system and process in accordance with an embodiment of the present invention;

[0018] FIG. **10** is a side view schematic diagram of a portion of a harvesting system and process in accordance with an embodiment of the present invention;

[0019] FIG. **11** is a schematic diagram of a portion of a harvesting system and process in accordance with an embodiment of the present invention; and

[0020] FIG. **12** is a side perspective view of a cultivation and harvesting system in accordance with another embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0021] Certain terminology is used in the following description for convenience only and is not limiting. The words "right", "left", "lower" and "upper" designate directions in the drawings to which reference is made. The words "inwardly" and "outwardly" refer to directions toward and away from, respectively, the geometric center of the system and designated parts thereof. Unless specifically set forth herein, the terms "a", "an" and "the" are not limited to one element but instead should be read as meaning "at least one". The terminology includes the words noted above, derivatives thereof and words of similar import.

[0022] As used herein the term "aquatic organism" includes all biological organisms living or growing in, on, or near the water such as, but not limited to, fish, molluscs, crustaceans, echinoderms, other invertebrates and their life-stages, as well as aquatic (e.g., marine and fresh water) plants. Types of aquatic plants include, but are not limited to, a plant from the Lemnaceae family (Duckweed), especially, from the *Spirodela, Landoltia, Lemna, Wolffiella* and *Wolffia* genera, edible micro and macro-algae. While embodiments described herein may refer to "aquatic plants," "an aquatic plant culture," or "culture of aquatic plants" or to duckweed in particular, any of the embodiments descried herein may be used to grow, culture, harvest, etc. any type of "aquatic organism." Preferably, however, the system of the present invention is used to grow, culture and harvest duckweed.

[0023] Referring to FIGS. **1-12**, there are shown a system and process for cultivating, harvesting, and outputting a culture of aquatic plants, namely duckweed, according to embodiments of the present invention. The system preferably comprises a water treatment system **12** and cultivation and harvesting system **14**. The water treatment system **12** provides for mixing of nutrients and treated water to form a treatment mixture which is supplied to the cultivation and harvesting system **14** for facilitating growth of the duckweed.

[0024] The water treatment system **12** comprises at least one nutrient tank or container **16**, and more preferably a plurality of nutrient tanks **16**; a water supply source **18**; and at least one treatment tank or container **20**, and more preferably a plurality of treatment tanks **20**.

[0025] Each nutrient tank **16** comprises at least one nutrient, and more preferably, a mixture of organic nutrients and/or inorganic nutrients. The nutrients facilitate rapid vegetative growth of the duckweed. Examples of some nutrients include, but are not limited to, nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), iron (Fe), magnesium (Mg), boron (B), manganese (Mn), copper (Cu), zinc (Zn), and molybdenum (Mo). For example, the nutrient mixture may be a commercially available mixture, such as General Hydroponics®, MaxiGro™. According to the manufacturer, this solution contains (% by weight) 1.5% Ammoniacal N; 8.5% Nitrate N; 5% Available Phosphate P_2O_5; 14% Soluble Potassium K_2O; 6% Calcium Ca; 2% Soluble Magnesium Mg; 3% Combined Sulfur S; 0.12% Chelated Iron Fe; 0.05% Chelated Manganese Mn; and 0.002% Molybdenum Mo.

[0026] Another known nutrient mixture comprises 210 ppm Nitrogen N; 235 ppm Potassium K; 200 ppm Calcium Ca; 31 ppm Phosphorus P; 64 ppm Sulfur S; 48 ppm Magnesium Mg; 0.5 ppm Boron B; 2.5 ppm Iron Fe; 0.5 ppm Manganese Mn; 0.05 ppm Zinc Zn; 0.02 ppm Copper Cu; and 0.01 ppm Molybdenum Mo.

[0027] Preferably, where a solid nutrient mixture is used, the mixture is solubilized in filtered and sanitized water to create a liquid concentrate, and the liquid concentrate nutrient mixture is then dosed into the treatment tanks **20** at a predetermined dilution. It will be understood by those skilled in the art that any appropriate dilution level may be utilized, depending upon a variety of factors, such as the composition of the solid nutrient mixture, the desired growth rate of the duckweed, and the like.

[0028] Preferably, in the aforementioned nutrient mixtures, the amount of ammoniacal nitrogen is increased and the amount of nitrate nitrogen is decreased, because ammoniacal nitrogen is a preferred nitrogen source by duckweed species. Such an adjustment may be made through the addition of ammonium sulfate and adjustment of the other nutrient concentrations.

[0029] It will be understood by those skilled in the art that any nutrient or mixture of nutrients (organic and/or inorganic) suitable for duckweed growth may be utilized in the present system and method, and more particularly stored in the nutrient tanks **16**.

[0030] In one embodiment, the nutrient tanks **16** are preferably equipped with sensors to monitor one or more factors, such as, but not limited to, nutrient water level, pH, Temperature, Total Dissolved Solids (TDS), Ammonia (NH_4^+), Nitrate (NO_3^-). For preparation of the treatment mixture, the nutrients are pumped (e.g., by dosing pumps **23** in FIG. **1**) from the nutrient tanks **16** via a valve manifold system **25** to the treatment tanks **20**, where the concentrated nutrient solution is introduced into the filtered and sanitized water. The pump rate of the dosing pumps **23** may depend upon a variety of factors, including the size of the tank to be supplied.

[0031] The water source **18** is preferably ground water or surface water, such as city or tap water, or water from an industrial plant with which the water treatment system **12** is being operated in tandem (as described in more detail hereinafter). Another source **19** of water for the water treatment system **12** is water which is recycled from the cultivation and harvesting system **14**, as will be described in greater detail herein. The ground water **18** and recycled water **19** combine to form a stream of untreated water, as represented by a dashed line in FIG. **1**. In the water treatment system **12**, the untreated water first passes through a filter **22** and subsequently through a sanitizer **24**, to form a stream of treated water.

[0032] The filter **22** is preferably used in combination with a UV sanitizer **24** to remove unwanted materials and chemicals from the city make-up water **18** and the recycled harvest water **19**. In one embodiment, the filter **22** is a carbon filter having a pore size of 5-10 microns and is configured to remove chemicals such as, but not limited to, chlorine, benzene, radon, various solvents, volatile organic chemicals such as pesticides and herbicides, iron, hydrogen sulfides, lead and the like from the two water sources **18**, **19**. However, it will be understood that the filter pore size may vary and be selected based on a variety of factors, such as the type of chemical to be removed from the water.

[0033] The filtered water is then pumped through the UV sanitizer **24**. The UV sanitizer **24** kills micro-organisms, such as bacteria, viruses, molds, and other pathogens that may be present in the filtered water. The UV sanitizer **24** preferably utilizes germicidal fluorescent lamps at a wavelength of 250-270 nanometers (nm) to eradicate the organisms. The water flows through a tube that is surrounded with light from the germicidal fluorescent lamps, preferably at a flow rate of less than 40 gallons per minute (gpm). It will be understood by those skilled in the art that the type and operating conditions of the UV sanitizer, as well as the flow rate of the water to be treated, may vary and be selected based on a variety of factors, such as the type of organisms to be removed from the water.

[0034] The water treatment system **12** preferably includes a storage tank **28** for storing the treated water, and more particularly the filtered and sanitized water, until it is needed for preparation of the treatment mixture.

[0035] In one embodiment, the water treatment system **12** is operated in tandem with any industrial plant, such that any/or all emissions from the industrial plant can be conditioned and routed to the water treatment systems **12** for producing the treatment mixture, thereby resulting in a close to zero emissions process for the industrial plant.

[0036] For preparation of the treatment mixture, the treated water is pumped (for example, via a pump **26**) from the storage tank **28** to the treatment tanks **20** at a predetermined flow rate, where it combines with the nutrients supplied from the nutrient tanks **16**, in order to form the treatment mixture. The treatment mixture is then pumped (for example, via respective pumps **25**) from the treatment tanks **20** to the cultivation and harvesting system **14**.

[0037] The treatment tanks **20** are preferably maintained at a temperature between 60° F. and 90° F., and more preferably at a temperature of 75° F. It will be understood that the temperature of the treatment tanks **20** may be set to any appropriate temperate as needed for the system **12**, for example, based on the composition of the treatment mixture stored therein. The treatment tanks **20** are preferably filled with the filtered and sanitized water and dosed with the concentrated nutrient solution until the treatment mixture is at a prescribed dilution. Periodically, as needed, the treatment tanks **20** are preferably replenished with the filtered and sanitized water, and then adjusted to the correct nutrient dilution by dosing with the concentrated nutrient solution.

[0038] In one embodiment, the treatment mixture is preferably enriched with carbon dioxide and/or oxygen for adjustment to and maintenance of the desired pH of the treatment mixture. The pH of the treatment mixture is preferably continuously monitored. More preferably, the pH of the treatment mixture is adjusted to and maintained at a pH suitable for growth of the duckweed into a biomass. Preferably, the pH of the treatment mixture is adjusted to and maintained at a pH of from approximately 4.5 to approximately 8. More preferably, the pH of the treatment mixture is adjusted to and maintained at a pH of 5.5 to 6.5. Adjustment of the pH is preferably carried out within the treatment tanks **20**, prior to the treatment mixture being transferred to the cultivation and harvesting system **14**.

[0039] In one embodiment, each of the inlet and outlet conduits of the water treatment system **12** is equipped with one or more valves, in order to enable accurate control of the water and nutrient flow throughout the water treatment system **12**. It will also be understood that any such valves and the pumps of the water treatment system **12** may be manually operated or may be under automated control responsive to the output of one or more sensors provided throughout the water treatment system **12** and/or the cultivation and harvesting system **14**.

[0040] The cultivation and harvesting system **14** is preferably a completely enclosed system, meaning that it is housed in an indoor facility. As such, operation of the system **14** is not constrained by the seasons and weather. Also, the duckweed to be cultivated by the system **14** is not subject to contamination from the outdoor environment.

[0041] The cultivation and harvesting system **14** comprises at least one growing system **30**, and more preferably a plurality of growing systems **30**. The growing systems **30** are preferably isolated from each other, such that the operation of one system **30** does not affect that of another system **30**. The plurality of growing systems **30** may be housed together in a single indoor facility, or separately from each other in multiple indoor facilities.

[0042] Referring to FIGS. **2-3**, each growing system **30** includes a supply tank **32** and a plurality of growing units **34**. Each supply tank **32** receives and stores the treatment mixture supplied from the treatment tanks **20** of the water treatment system **12**. The supply tanks **32** are preferably maintained at a temperature between 60° F. and 90° F., and more preferably at a temperature of 75° F. It will be understood that the temperature of the supply tanks **32** may be set to any appropriate temperate as needed for the system **14**, for example, based on the composition of the treatment mixture stored therein. The supply tanks **32** are preferably maintained at a pH of 4.5 to 8, and more preferably from 5.5 to 6.5. An ammonia (NH_4^+) concentration within each supply tank **32** is preferably above 2 ppm. A Total Dissolved Solids (TDS) concentration of the contents of each supply tank **32** is preferably below 2,000 ppm. Once the ammonia (NH_4^+) level drops below the prescribed concentration (2 ppm), the supply tanks **32** are preferably emptied to allow for replenishment from the treatment tanks **20**. The drained supply tank treatment mixture is then filtered and sanitized for reuse. Once the TDS levels have surpassed the prescribed concentration (2,000 ppm), the supply tanks **32** and the growing units **34** are preferably drained to allow for refilling of the treatment mixture from the treatment tanks **20**.

[0043] The growing units **34** of each growing system **30** are arranged adjacent to each other in a side-by-side configuration. Each growing unit **34** comprises a plurality of growing vessels **36** adapted to grow the duckweed. It will be understood that while the term vessel is used herein, any structure which can serve to contain a fluid mixture can be used as the growing vessel **36**. The growing vessels **36** are arranged in a vertically-stacked and spaced-apart orientation, as shown in FIG. **3**. Thus, the cultivation and harvesting system **14** has a modular and multi-tiered design which optimizes the square footage of the overall growing area.

[0044] The number of growing vessels **36** included in each growing system **30** is variable dependent upon the particular size of the growing system **30**.

[0045] In a preferred embodiment, each growing vessel **36** has a generally rectangular shape formed by four sidewalls, with an open upper end and an opposing closed bottom end **66**. Each growing vessel **36** preferably has a length of 15 to 45 feet, a width 5 to 15 feet, and a depth of 0.125 to 1 foot, and more preferably a length of 25 to 35 feet, a width of 7.5 to 10 feet, and a depth of 0.25 to 0.5 feet. The growing vessels **36** are preferably maintained at a pH of 4.5 to 8, and more preferably from 5.5 to 6.5. An ammonia (NH_4^+) concentration within each growing vessel **36** is preferably above 2 ppm. A Total Dissolved Solids (TDS) concentration of the contents of each growing vessel is preferably below 2,000 ppm. However, it will be understood by those skilled in the art that the size and shape of the growing vessels **36** may vary in particular applications, depending upon the particular needs of the facility.

[0046] Each growing vessel **36** preferably has a water level ranging from 0.25 to 1 foot, and more preferably a water level of 2 to 3 inches.

[0047] It will be understood by those skilled in the art that the operating conditions of the growing vessels **36**, treatment tanks **20** and supply tanks **32** (for example, the pH, the ammonia (NH_4^+) concentration, the TDS concentration, and the water level) may vary and be set to any value as necessary for achieving optimal conditions for the desired duckweed cultivation rate.

[0048] The treatment mixture in the supply tanks **32** and growing vessels **36** is preferably in a constant circulation, and therefore will have the same water quality conditions.

[0049] The duckweed is preferably introduced into each of the growing vessels **36** through the open end or through an opening in one of the sidewalls. Preferably, the ratio of the weight of duckweed to the area of each growing vessel **36** ranges from 0.25 ounces of duckweed per 1 ft^2 growing area to 1 ounce of duckweed per 1 ft^2 growing area. Such a ratio facilitates rapid vegetative growth of the duckweed, but it will be understood that the ratio may be adjusted (i.e., increased or decreased) as necessary based on process refinement.

[0050] Preferably, CO_2 is introduced into the growing vessels **36** and/or into the supply tanks **32** that pump the treatment mixture to the growing vessels **36**.

[0051] Referring to FIG. **4**, each growing vessel **36** includes one or more interior dividing walls **38** that form a meandering channel **40** that provides a continuous circuit flow system used for mixing the treatment mixture and the aquatic organism (i.e., duckweed). More particularly, the meandering channel **40** extends from a treatment mixture inlet **42** to an outlet **44** of each growing vessel **36**. The treatment mixture stored in the respective supply tank **32** of each growing system **30** is supplied to the inlet **42** of each growing vessel **36** of each growing unit **34** and circulates through the meandering channel **40** for facilitating growth of the aquatic plant. From the inlet **42**, the treatment mixture mixes with the duckweed contained in the growing vessel **36** as it travels through the meandering channel **40** toward the outlet **44**.

[0052] The treatment mixture is pumped into the growing vessel through the inlet **42** at a flow rate of 100 to 500 gallons per hour (gph), and more preferably 250 to 350 gph. It will be understood by those skilled in the art that the flow rate may vary in particular applications, depending upon the particular needs of the facility and the characteristics of the particular aquatic plant being cultivated. In one embodiment, circulation of the treatment mixture within the meandering channel **40** is generated merely by the force with which the treatment mixture is pumped into the growing vessel **36**. In another embodiment, a stirring mechanism (not shown) is used to facilitate the circulation of the treatment mixture through the meandering channel **40**.

[0053] The treatment mixture is preferably circulated throughout each growing vessel **36** in a closed loop system. During circulation within the meandering channel **40**, a portion of the treatment mixture exits a first growing vessel **36** via the outlet **44**, and is combined with the exiting treatment mixture of a second growing vessel **36** which is positioned immediately above and/or below the first growing vessel **36**, thereby forming a combined recirculation stream **46** for each growing unit **34** in a common conduit (see FIG. **3**). The combined recirculation stream **46** of each growing unit **34** is routed to the respective supply tank **32**. More particularly, such a combined recirculation stream **46** is generated for each growing unit **34** of each growing system **30**, and each of the individual combined recirculation streams **46** combine with each other upstream of the supply tank **32** in a common conduit, so as to form a single recirculation stream **48** which is introduced into the supply tank **32** (see FIG. **2**).

[0054] Preferably, there is a constant flow of treatment mixture from the respective supply tank **32** to the growing vessels **36**, as well as a constant flow of treatment mixture from the growing vessels **36** back to the respective supply tank **32**. The rates of both flows are preferably equal going into and exiting out of the growing vessels **36**, such that the water column within each growing vessel **36** is maintained at the desired level (for example, 2 to 3 inches).

[0055] By the continuous and closed loop recirculation of the treatment mixture to the duckweed through the meandering channel **40**, a continuous and rapid growth mode is achieved in each growing system **30**.

[0056] Also, each growing vessel **36** is provided with a respective overhead light source **50** which promotes growth of the aquatic plant contained therein. The light emitted by the overhead light source **50** is preferably in the visible spectrum of approximately 400 nanometers (nm) to approximately 600 nm. The overhead light source **50** also preferably has a color temperature of 6500 Kelvin (K) to mimic natural sunlight. The overhead light source **50** is positioned at a distance of from 3 inches to 6 feet, and preferably 1 to 2 feet, away from, and more particularly above, the top of the water column inside each growing vessel **36**. During a growth cycle, the overhead light sources **50** are preferably operated on a prescribed cycle of periodic on and off periods, such as 18 hours ON, and then 6 hours OFF. This cycle is preferably constantly repeated to create a day and night cycle in order to facilitate rapid vegetative growth of the duckweed.

[0057] It will be understood by those skilled in the art that the necessary light intensity and spectrum, the positioning of the light source, and/or the operating durations and cycle of the light source may vary based on a variety of factors, such as the particular duckweed species utilized and the desired growth/cultivation rate.

[0058] The cultivation or growth phase of the process is continued until a desired quantity of mature duckweed specimens are produced, that is until a sufficient quantity of a duckweed-based biomass, is produced. Cultivation/growth times are determined empirically and vary, depending on numerous factors within the control of the operator including, for example, the identity of the duckweed species, the composition of the treatment mixture, the pH of the treatment mixture, the temperature of the treatment mixture, and the light intensity for each growing vessel **36**. Preferably, the ratio of the weight of duckweed to the area of each growing area **36** ranges from 0.25 ounces of duckweed per 1 ft^2 growing area to 1 ounce of duckweed per 1 ft^2 growing area. Once the preferred ratio is reached, the duckweed is harvested (e.g., once daily, bi-daily, or semi-daily basis, or based on an as-needed basis).

[0059] As the biomass grows, it develops into a floating mass on the surface of the water contained in each growing vessel **36**. The biomass of duckweed is ready for harvesting when the aforementioned preferred ratio of the duckweed weight to growing area is achieved, and more preferably surpassed. Attainment of the ratio may be determined through visual sensor technology, visual observation by those skilled in the art, calculation time periods based on growth, and the like, or a combination of such methods.

[0060] Referring to FIG. **12**, there is shown an alternative embodiment of the cultivation and harvesting system **114**. The system **114** of FIG. **12** is also preferably a completely enclosed system, meaning that it is housed in an indoor facility. However, instead of a plurality of growing units **34** arranged adjacent to each other in a side-by-side configuration, there is one growing unit **134** which comprises a plurality of growing vessels **136** adapted to grow the duckweed. The growing vessels **136** are arranged in a vertically-stacked and spaced-apart orientation. Each growing vessel **136** is of much larger dimensions that than growing vessels **36** of the first embodiment.

[0061] Preferably, each growing vessel **136** has a generally rectangular shape formed by four sidewalls, with an open upper end and an opposing closed bottom end. Each growing vessel **136** preferably has a width of up to 20 feet and a depth of 1 inch to 1 foot, and preferably a depth of between 2 inches to 4 inches. Each growing vessel **136** also preferably has a water level of 2 to 3 inches. This design creates a continuous closed loop circuitous stream of the treatment mixture. By the continuous and closed loop recirculation of the treatment mixture to the duckweed through the design of this embodiment, a continuous and rapid growth mode is achieved in each growing vessel **136** around the central opening **200**. The central opening **200** is provided for engagement with a support frame (not shown), plumbing components (not shown), and electrical components (not shown).

[0062] It will be understood by those skilled in the art that the length of each growing vessel may be set to any desired size based on a variety of factors, such as the dimensions of the building in which the system is housed. The depth and width of each growing vessel and the water column may also vary based on a based on a variety of factors, such as the dimensions of the building in which the system is housed, the desired cultivation/growth rate, and the like.

[0063] The duckweed is preferably introduced into each of the growing vessels **136** through the open end. Preferably, the ratio of the weight of duckweed to the growing vessel **136** area ranges from 0.25 ounces of duckweed per 1 ft^2 growing area to 1 ounce of duckweed per 1 ft^2 growing area, although this ratio may be adjusted based on process optimization.

[0064] Harvesting of the cultivated duckweed can be done in a variety of manners. In one embodiment, as shown in FIGS. **5** and **7**, a sidewall of each growing vessel **36** includes a second outlet conduit **52**, hereinafter referred to a harvest outlet. The harvest outlet **52** is provided at a position corresponding to the water surface level of the growing vessel **36**, such that the harvest outlet **52** is generally aligned with the floating duckweed on the surface of the water contained in each growing vessel **36**. The harvest outlet **52** is preferably equipped with a valve **54**, and more particularly a gate valve, which can be selectively opened or closed to enable or prevent flow through the harvest outlet **52**. When the gate valve **54** is open, the cultivated duckweed at the surface of the growing vessel **36** and a portion of the water contained in the growing vessel **36**, hereinafter referred to as a harvested duckweed mixture, naturally (e.g., by gravity) exits the growing vessel **36** and flows through the harvest outlet **52**, and subsequently to a tank **56** for storing harvested duckweed. It will also be understood that a mechanical device may be utilized to facilitate the flow of the cultivated duckweed toward and/or through the harvest outlet **52**.

[0065] In another embodiment of the harvesting process and system according to the present invention, as shown in FIGS. **6** and **8**, each growing vessel **36** is provided with at least one, and preferably a plurality of, conduits or tubes **60** which extend into the interior of each growing vessel **36** and through the bottom wall **66**. More particularly, each of the tubes **60**, hereinafter referred to as drain tubes **60**, has two opposing open ends. A first open end **60***a* of each drain tube **60** is positioned within the interior of the respective growing vessel **36**, above the normal growth water level (i.e., above the surface of the floating mass of duckweed). The opposing second open end (not shown) of each drain tube **60** is positioned outside of the respective growing vessel **36**, with the tubular sidewall **61** of each drain tube **60** extending through the bottom wall **66** of the growing vessel **36**. In order to harvest the cultivated duckweed from each growing vessel **36**, each growing vessel **36** is flooded with water, for example at a rate of 100 to 500 gallons per hour (gph), and more preferably 250 to 350 gph, such that the water level in the growing vessel **36** is caused to rise, thereby resulting in the contents of the growing vessel **36** overflowing into the open ends **60***a* of the drain tubes **60**. More particularly, the duckweed at the surface of the water level is caused to overflow from the growing vessel **36** and into the drain tubes **60** via the first open ends **60***a*.

[0066] As the harvested duckweed mixture exits a first growing vessel **36** (either via the harvest outlet **52** or the drain tubes **60**), the harvested duckweed mixture of the first growing vessel **36** is combined with the exiting harvested duckweed mixture of a second growing vessel **36** which is positioned immediately above and/or below the first growing vessel **36** within a conduit **58**, thereby forming a combined harvested duckweed mixture stream **62** for each growing unit **34** (see FIGS. **7-8**). The second open end of each drain tube **60** is preferably tapered to allow the harvested duckweed and harvest water to fall into the tube positioned below, without any of the harvested duckweed and harvest water from falling into the growing vessel **36** positioned below. To facilitate movement and complete capture of all of the harvested duckweed mixture flowing through the conduit **58** (i.e., in the combined harvested duckweed mixture stream **62**), a stream of water which is recycled from the harvesting process is provided, preferably continuously, to the conduit **58** at a flow rate of 100 to 500 gallons per hour (gph), and more preferably 250 to 350 gph. It will be understood by those skilled in the art that the water flow rate may vary in particular applications, depending upon the particular needs of the facility and the characteristics of the particular aquatic plant being cultivated.

[0067] Referring to FIGS. **9-10**, the individual combined harvested duckweed mixture streams **62** of each growing unit **34** of each growing system **30** combine with each other upstream of the harvested duckweed mixture storage tank **56**, so as to form a single harvested duckweed mixture stream **64** of each growing system **30** which is introduced into the harvested duckweed storage tank **56** (see FIGS. **9-10**).

[0068] Referring to FIG. **11**, the withdrawn aquatic biomass is then subjected to a collection and separation process. Preferably, before being introduced into the harvested duckweed storage tank **56**, the harvested duckweed mixture passes through a filtration screen **70** to separate the harvested duckweed from the harvest water. The filtration screen **70** preferably has a mesh size of approximately 1,500 to 3,000 microns (i.e., 1/16 to 1/8 inches). However, it will be understood by those skilled in the art that any appropriate mechanical separation process and/or a filtration screen of any mesh size may be utilized, as long as the solid plant particles are sufficiently separated from residual liquids. For example, the collected biomass may be separated into independent lots via an underwater air distribution system (not shown), or may be passed through a polyphasic separator.

[0069] The separated water is recycled to the growing systems **30** during the harvesting process as described above and/or to the water treatment system as described above. The filtered and cultivated duckweed is then stored within the harvested duckweed storage tank **56**. Before final processing, in one embodiment, the cultivated duckweed may pass through a dryer **68** for further drying of the duckweed.

[0070] Finally, the duckweed is packaged for shipping and use as a protein-based product.

[0071] In one embodiment, the duckweed may be washed prior to drying for removal of contaminants. However, because cultivation of the duckweed is carried out in an enclosed setting, a decontamination step is only optional and not necessary.

[0072] It will be appreciated by those skilled in the art that changes could be made to the embodiments described above without departing from the broad inventive concept thereof. It is understood, therefore, that this invention is not limited to the particular embodiments disclosed, but it is intended to cover modifications within the spirit and scope of the present invention.

1. An enclosed system for cultivating and harvesting a duckweed-based biomass, the enclosed system comprising:

a water treatment system including at least one nutrient tank containing at least one nutrient, a treated water and at least one treatment tank containing a treatment mixture; and

a cultivation and harvesting system including a plurality of growing vessels configured to receive duckweek and the treatment mixture for cultivating the duckweek-based biomass, each growing vessel including an associated light source and an outlet for harvesting of the cultivated duckweed-based biomass,

wherein the water treatment system provides for mixing of the at least one nutrient and the treated water to form the treatment mixture which is supplied to the cultivation and harvesting system for facilitating growth of the duckweed-based biomass.

2. The enclosed system according to claim **1**, wherein the at least one nutrient tank contains a mixture of organic nutrients and inorganic nutrients.

3. The enclosed system according to claim **1**, where the at least one nutrient is selected from the group consisting of nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), iron (Fe), magnesium (Mg), boron (B), manganese (Mn), copper (Cu), zinc (Zn) and molybdenum (Mo).

4. The enclosed system according to claim **1**, further comprising a filter and a UV sanitizer, wherein untreated from a water supply source passes through the filter and the UV sanitizer to form the treated water.

5. The enclosed system according to claim **4**, wherein the UV sanitizer utilizes germicidal fluorescent lamps at a wavelength of 250-270 nanometers.

6. The enclosed system according to claim **1**, wherein the treatment mixture is preferably enriched with at least one of carbon dioxide and oxygen.

7. The enclosed system according to claim **1**, wherein the growing vessels are arranged in a vertically-staked and spaced-apart orientation.

8. The enclosed system according to claim **1**, wherein each growing vessel has a water level ranging from 0.25 to 1 foot.

9. The enclosed system according to claim **8**, wherein the water level in each growing vessel ranges from 2 to 3 inches.

10. The enclosed system according to claim **1**, wherein each growing vessel includes an inlet, an outlet and a meandering flow channel extending from the inlet to the outlet, such that the treatment mixture which is supplied to the inlet of each growing vessel mixes with the duckweed as it travels through the meandering flow channel towards the outlet.

11. The enclosed system according to claim **1**, wherein the associated light source of each growing vessel is an overhead light source which emits light in the visible spectrum of approximately 400 nanometers to approximately 600 nanometers.

12. The enclosed system according to claim **1**, wherein a ratio of the weight of duckweed to a growing area within each growing vessel ranges from 0.25 ounces of duckweed per 1 square foot of growing area to 1 ounce of duckweed per 1 square foot of growing area.

13. A method for cultivating and harvesting a duckweed-based biomass in an enclosed environment, the method comprising:

providing a treatment mixture and duckweed to at least one growing vessel having an associated light source, each growing vessel having an inlet, an outlet and a meandering flow channel extending from the inlet to the outlet, the treatment mixture being supplied to the inlet of each growing vessel and mixing with the duckweed as it travels through the meandering flow channel towards the outlet in a closed loop system to form a duckweed-based biomass until a predetermined ratio of the weight of duckweed to a growing area of the at least one growing vessel is achieved; and

harvesting the duckweed-based biomass from the at least one growing vessel.

14. The method according to claim **13**, wherein the treatment mixture includes at least one nutrient selected from the group consisting of nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), iron (Fe), magnesium (Mg), boron (B), manganese (Mn), copper (Cu), zinc (Zn) and molybdenum (Mo).

15. The method according to claim **13**, wherein the predetermined ratio of the weight of duckweed to a growing area within each growing vessel ranges from 0.25 ounces of duckweed per 1 square foot of growing area to 1 ounce of duckweed per 1 square foot of growing area.

16. The method according to claim **13**, wherein the at least one growing vessel includes a harvest outlet at a position corresponding to a water level of the at least one growing vessel, the harvest outlet being equipped with a valve, and wherein the harvesting of the duckweed-based biomass is performed by opening the valve to allow the flow of duckweed through the harvest outlet.

17. The according to claim **16**, wherein the water level is from 0.25 to 1 foot.

18. The method according to claim **13**, wherein the at least one growing vessel includes at least one conduit extending into an interior of the at least one growing vessel through a bottom wall thereof, a first open end of the at least one conduit being positioned above a water level of the at least one growing vessel, and wherein harvesting of the duckweed-based biomass is performed by introducing additional water into the at least one growing vessel until the water level rises and the duckweed-based biomass overflows into the first open end of the at least one conduit.

19. The method according to claim **18**, wherein the water level is from 2 to 3 inches.

20. The method according to claim **13**, wherein the associated light source is an overhead light source which emits light in the visible spectrum of approximately 400 nanometers to approximately 600 nanometers.

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