

MEMBRANE AERATED BIOFILM REACTOR

TECHNOLOGICAL FIELD

This disclosure concerns a membrane aerated biofilm reactor (MABR) water treatment technology.

BACKGROUND ART

5 References considered to be relevant as background to the presently disclosed subject matter are listed below:

- International Patent Application Publication No. WO 2008/130885.

Acknowledgement of the above references herein is not to be inferred as meaning that these are in any way relevant to the patentability of the presently disclosed
10 subject matter.

BACKGROUND

Membrane aerated biofilm reactor (MABR) systems typically utilize microorganisms for removing organic pollutants present in the water to be treated. In some MABR systems, biofilm grows on a gas permeable membrane by supply of
15 oxygen and soluble organic compounds to the biofilm.

WO 2008/130885 describes a membrane supported biofilm apparatus having a plurality of hollow fiber gas permeable membranes in a tank containing water to be treated. The membranes have an outside diameter of about 200 microns or less and occupy between 0.5% and 4% of the tank volume and biofilm is supported on the
20 membranes within the to be treated.

GENERAL DESCRIPTION

The present disclosure relates to a membrane aerated biofilm reactor (MABR) technology. Provided are water treatment modules, reactors, systems and methods embodying this technology.

Biological water treatment systems such as those employing MABR technologies tend to get clogged by the development of excess biofilm on the exterior surface of the membranes during operation, specifically with suspended solids in the water, thus resulting in decline in performance of the water treatment system. One of the beneficial effects of the MABR technology of this disclosure is a reduction in such clogging.

The MABR of this disclosure comprises a bundle of hollow fiber membranes and a gas diffuser configured for discharging gas bubbles that rise through and within confines of a treatment portion of the bundle of hollow fiber membranes.

Accordingly, provided, by one embodiment of this disclosure, is a water treatment module comprising a bundle of hollow fiber membranes that are gas permeable and water impermeable. The bundle of hollow fiber membranes comprises a treatment portion that extends between a bottom end and a top end of the bundle of hollow fiber membranes and comprises at least one gas diffuser. The bundle of hollow fiber membranes are linked, at one or both of their two ends, to a source of a first type of gas which is a gas of a kind that supports biofilm growth and are configured to permit inlet of that first type of gas into the respective end. This gas is supplied into the lumen of the hollow fibers for the purpose of diffusing through the membrane into the water and thereby support biofilm growth. This gas will be referred herein as "biofilm growth-support gas" or in abbreviation as "BGSG".

The at least one gas diffuser is functionally associated with the bottom end of the bundle (for example, may be integrally formed with or placed in the vicinity of) and is configured for discharging gas bubbles within the bundle's confines such that in operation gas bubbles rise through the treatment portion between the fibers. In other words, the gas bubbles discharged out of the at least one diffuser drifts upwardly within the confines of the bundle, at least at the treatment portion thereof and lead to scouring of excess biofilm off the membranes, agitation and mixing of water in the hollow fiber membranes' vicinity. The gas supplied to and discharged out of the at least one diffuser will be referred to herein as "auxiliary gas" or in abbreviation as "AG". As will also be noted below, the BGSG and the AG may be the same or may be different gasses.

Provided by another aspect of the present disclosure is a water treatment reactor that comprises one or more modules of this disclosure.

Provided by a further aspect of the present disclosure is a water treatment system that comprises one or more water treatment tanks, one or more water treatment modules
5 within each of the tanks, and one or more gas conduit arrangements. Each of the one or more water treatment modules may be that described above and comprises a bundle of hollow fiber membranes that are gas permeable and water impermeable. Within the system, each of the bundles has a general vertical orientation with a treatment portion extending between a bottom end and top end of the bundle. At least one gas diffuser is
10 functionally associated with the bottom end of the bundle and is configured for discharging bubbles of an AG within the bundle's confines such that these gas bubbles rise through the treatment portion between the hollow fibers. At least one of the one or more gas conduit arrangements is configured for supply of BGSG to one end of the fibers to permit gas inlet into the lumen of the hollow fibers. The gas conduit
15 arrangement is also configured for supply AG to the at least one diffuser. In some embodiments, the conduit arrangement for supply of the AG and for supply of the BGSG will be different, even where the AG and the BGSG are the same gas, as the supply regiment may usually be different.

The gas conduit arrangement for the AG will be referred to herein as the "AG
20 conduit arrangement" and that of the BGSG as the "BGSG conduit arrangement" and the respective gas sources will be referred to as "AG source" and "BGSG source"). The AG source and the BGSG source may be pressurized gas tanks, may be gas pumps or their combinations. The AG and BGSG conduits arrangements may include also gas pressure regulators, valves, other flow regulators, etc., to properly control gas flow rate,
25 pressure and supply schedule, as needed.

The BGSG is selected according to the type of biofilm to be grown on the membranes, which in turn depends on the type of pollutants in the water to be treated. Specifically, the gas can be air, air enriched with oxygen or air supplemented with methane, pure oxygen, pure methane or any methane- or oxygen-containing gas. For
30 example, where the water to be treated comprises organic matter and/or ammonium compounds, the water-treatment gas is typically one that is rich in oxygen. Where the

water to be treated comprises nitrogen oxides containing compounds (e.g. nitrate), the water-treatment gas can be also one that is rich in methane.

By a yet further aspect, this disclosure provides a water treatment method that comprise treating water in a membrane aerated biofilm reactor, and discharging gas
5 bubbles such that the bubbles rise through and within confines of a treatment portion of a bundle of hollow fiber membranes of the reactor.

According to one embodiment of this method water to be treated is brought into contact with one or more treatment modules, of the kind described herein. The BGSG is introduced into the lumen of the hollow fibers (typically passed therethrough from one
10 end to the other) and the AG is caused to discharge out of the diffusers such that gas bubbles rise through the treatment portion within the confines of the bundle and between the fibers.

By one embodiment, the fibers are held together tightly in at least one of the bottom end and top end of the bundle. This tight holding may be by means of potting
15 element fitted at one or both of the bottom or top ends of the bundle. The AG gas diffuser may, by some embodiments, be integral with the potting element at the bottom end of the bundle. The potting element may be a cast element; e.g. cast over the end portions of the fibers.

By one embodiment, the at least one gas diffuser comprises a gas outlet that are
20 positioned within the confines of the bundle's bottom end.

By other embodiments, the at least one gas diffuser comprises gas outlets positioned outside the confines of the bundle's bottom end portion. The module in this embodiment also comprises a channeling element for directing/forcing the discharged gas bubbles to flow into the confines of the bundle and thereby through the hollow
25 fibers of the bundle. Such a channeling element may be in the form of a sleeve element enveloping a least the bottom end of the bundle, and the majority of the treatment portion. In some embodiments, the channeling element envelops the bottom end and the treatment portion of the bundle of hollow fibers.

The discharge of the gas bubbles from the at least one diffuser may be
30 continuous, by some embodiments, and intermittent by others.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to better understand the subject matter that is disclosed herein and to exemplify how it may be carried out in practice, embodiments will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in
5 which:

Figures 1A, 1B and 1C are schematic illustrations of a water treatment module in accordance with an embodiment of the present disclosure, including a perspective view (**Figure 1A**), an exploded view of this module (**Figure 1B**) and a cross-sectional view of a bottom portion with some of the central fibers not shown for the purpose of
10 illustration (**Figure 1C**).

Figures 2A and 2B are schematic perspective views of a group of water treatment modules of the kind shown in Figures 1A-1C (**Figure 2A**) and an enlarged partial side view of the stack (**Figure 2B**).

Figures 3A, 3B and 3C are schematic illustrations of another embodiment of a
15 water treatment module of this disclosure including a side perspective view (**Figure 3A**), a bottom perspective view (**Figure 3B**) and a longitudinal perspective cross-sectional view with some of the central fibers not shown for the purpose of illustration (**Figure 3C**).

Figure 4 is a schematic, perspective cross-sectional view of a bottom portion of
20 a module with some of the central fibers not shown for the purpose of illustration according to another embodiment of this disclosure.

Figure 5 is a schematic partial cross-section illustration of a water treatment tank including modules of the kind illustrated in **Figures 1A-1C and 2A-2B**.

Figures 6A, 6B, 6C and 6D are schematic illustrations of a water treatment
25 module in accordance with an embodiment of the present disclosure, including a perspective view (**Figure 6A**), an exploded view (**Figure 6B**), a perspective longitudinal cross-sectional view of the bottom portion with some of the central fibers not shown for the purpose of illustration (**Figure 6C**) and a perspective horizontal cross-sectional view of the bottom end portion with the central fibers not shown for the
30 purpose of illustration (**Figure 6D**).

Figure 7 is a schematic representation of a water treatment system according to an embodiment of this disclosure.

DETAILED DESCRIPTION

The present disclosure will now be elaborated upon with reference to some
5 specific embodiments, schematically illustrated in the attached Figures. Among others, it is to be noted that the dimensions of structural elements in the Figures are not to scale with respect to one another.

As will readily be appreciated, the illustrated embodiments are intended as examples of the general teaching including the modules, reactors, systems and methods
10 of this disclosure. As will also be appreciated, the current disclosure is by no means limited to these specific embodiments.

A module of a membrane aerated biofilm reactor (MABR), according to an embodiment of this disclosure, is shown in **Figures 1A-1C** as element **100**. A group of such modules is shown in **Figures 2A-2B**. In **Figure 2B** one of the sleeves (discussed
15 below) is removed from one of the modules for illustrative purposes.

The module is the basic operational unit of a reactor of this disclosure. Some reactors and systems embodying the principles of this disclosure may include a single module; while in other embodiments, a plurality of modules may be included in a reactor and system. The modules may be arranged in groups, for example, configured
20 into a linear array of the kind illustrated in **Figures 2A-2B** or into a 2-dimensional array. An MABR tank according to this disclosure may include one or a plurality of such arrays.

The module **100** seen in **Figures 1A-1C** includes a bundle **102** of hollow fiber membranes (with some of the central fibers not shown for the purpose of illustration).
25 The membrane may be made from a variety of gas permeable and water impermeable polymers. The polymers may, for example, be selected from polydimethylsiloxane (PDMS), polymethylpentene (PMP), polyvinylidene fluoride (PVDF) and polysulfone. Specific examples of such polymers include: TPX, marketed by Mitsui Chemicals, Japan; PDMS (silicone rubber), marketed by Dow Corning, USA; Kynar (PVDF),
30 marketed by Arkema, USA.

The bundles of hollow fibers may, for example, be modules of the kind which is commercially available, including: ZeeWeed™ (GE Water, USA); Puron® (Koch, USA); MemPulse® MBR (Evoqua, USA).

The module **100** is typically entirely submerged in the water to be treated. The bundle **102** has a treatment portion **104** extending between bottom end **106** and top end **108**. The bottom end **106** and top end **108** of the bundle **102** are held by respective top potting element **112** and bottom potting element **110** that are illustrated as cast elements (that are cast over the end portions of the hollow fibers). The hollow fibers in the bundle **100** are held tightly together at their two ends **106** and **108** by the potting elements **110** and **112**, respectively and are more loosely packed throughout the treatment portion **104**. The bundle **100**, which is generally cylindrically shaped (e.g., having an essentially circular cross-section), is enveloped by a sleeve **114** that, among others, serves the function of confining gas bubbles emitted by the diffusers (discussed below) to the treatment portion **104** during their upward rise. Sleeve **114** may be supported in position by a supporting structure, for example by hooks or cables extending from a top support rack; by bottom support rack or legs; or by resting on the BGSG supply pipe, as shown in the exemplary embodiment of **Figures 3A-3C**.

As will be further illustrated below, the module **100** having a generally cylindrical cross-section is but an example and, in other embodiments, the modules disclosed herein may be configured to have a cylindrical oval cross-section or may have a generally prismatic structure, e.g. of the kind illustrated in **Figures 5A-5D** described below.

The potting elements **110, 112** are fitted into respective bottom fitting **116** and top fitting **118** formed at an end of respective connecting tubes **120, 122** linked to and extending from respective gas lines **124, 126** that are linked to a BGSG conduit arrangement (not shown). The potting elements **110, 112** are configured, in a manner as known *per se*, to enable gas inflow or outflow into or out of the hollow fibers. Thus, through this arrangement there is gas communication between gas lines **124, 126** through the lumens of the hollow fibers.

In one embodiment, the BGSG is supplied by line **124** from a BGSG source (not shown) and is then discharged by line **126** that ducts excess BGSG to circulate it, for

example, back to the BGSg source or to duct it to an exhaust outlet, from where it may be released into the atmosphere. This flow direction is represented by arrows **A1** and **A2** in **Figures 2A-2B**. As will be appreciated, this, of course, is but an example and BGSg conduit arrangement may be configured for an opposite direction of flow, thus switching the roles of lines **124**, **126**. In some embodiments the BGSg may also be provided through both lines and is then discharged only through the membrane into the water to be treated.

The BGSg is supplied to the hollow fibers and permeates/diffuses through the fibers' membranes into the water surrounding the hollow fibers. As a result, biofilm growth takes place along the fibers' exterior surface, i.e. the fibers' surface facing the water.

The BGSg is selected so as to be biofilm supportive in line with the nature of the contaminants/pollutants in the water to be treated. The BGSg, as known *per se*, may be oxygen, methane, air, etc.

The modules **100** also include diffusers **130** fitted around the periphery of the bottom end **106** and potting element **110** but below sleeve **114** and within the confines of an area defined by the sleeve **114**. There are four diffusers in this specific embodiment for each module but this too, as can also be appreciated, is but an example and any reasonable number of diffusers (e.g. 2, 3, 5, 6) may be included in a module of this disclosure.

Furthermore, whereas in this embodiment the diffusers **130** are arranged around the periphery of the module's bottom end **106**, in other embodiments, as will be exemplified below, one or more diffusers may also be included within the bottom end of the bundle, in addition or in the alternative to peripherally positioned diffusers of the kind included in the embodiments of **Figures 1A-2B**.

Figures 1A-1C and **2A-2B** also illustrate AG supply line **132** which are part of an AG conduit arrangement (not illustrated). The gas diffusers **130**, are fitted on the AG supply lines **132**, that are linked to and configured to supply gas from an AG source (not shown). Diffusers **130** are configured for discharging gas bubbles into the water volume of module **100**. The AG may be the same as or different than the BGSg. A specific example of AG is air.

Given the relative position, bottom end of sleeve **114** serves as a channeling element for channeling the AG bubbles into the confines of the bundle **102** during their upward rise, after their discharge by the diffusers **130**. The relatively loose packing of the bundles throughout the treatment portion **104** permits distribution of the AG bubbles
5 throughout the bundles.

The confined rising path of the discharged AG bubbles within the bundle of fibers results in scouring of excess biofilm off the outer surface of the hollow fibers' membrane as well as the agitation and mixing of water confined within the sleeve. As a result, there is relatively low level of clogging between the hollow fibers (typically
10 occurring from biomass over accumulation on the exterior surface of hollow fiber membranes in MABR systems) and the fibers are generally maintained free from each other at the treatment portion of the module. In addition to reducing overall clogging, and hence lessening of maintenance efforts, the water turbulence by the gas bubbles also improves efficiency of water treatment by homogenizing water and suspended
15 solids.

The AG conduit arrangement may be designed for continuous or intermittent gas discharge. For example, the AG discharged out of the diffusers may be designed to occur for a few seconds once every few minutes (e.g. 10-30 seconds every 5-20 minutes) or for a few minutes once every few hours (e.g. 1-10 minutes once or twice a
20 day), etc. As can be appreciated, the AG discharge may be designed to occur both for a few seconds every few minutes, for mixing, and for a few minutes every few hours, for scouring. In addition, the AG delivery schedule may be adapted for modification as needed, either automatically or manually.

As shown in **Figures 2A-2B**, the modules **100** in this embodiment are arranged
25 in a group of four. However, as noted above, this is but an example and such a group can include any number of modules based on a variety of engineering considerations as well as on the basis of available commercial elements of the system.

Figures 3A-3C show another embodiment of a module of this disclosure, which is a modification of the Figures 1A-1C. In Figures 3A-3C, like elements are indicated
30 with the same reference numeral shifted by **100**. Thus, for example, sleeve **214** serves the same function as sleeve **114** of the above embodiment. The differences in the

embodiment of Figures 3A-3C from that of Figures 1A-1C is two basic features. First, as can be seen, sleeve **214** rests on and is supported in position by the BSG line **224**. Furthermore, the AG supply line **232** with the associated diffusers **230** is positioned at a level below line **224**. Otherwise the function of this element is similar to that of the
5 embodiment of Figures 1A-1C.

Figure 4 is a schematic perspective cross-section of the bottom end of a module of another embodiment. In this figure like elements to those of the embodiments illustrated in **Figures 1A-2B** have been given like reference numerals shifted by **200**. Thus, for example, connecting tube **320** serves the same function as connecting tube
10 **120** of the described embodiment. The reader is referred to the description of **Figures 1A-2B** for understanding the function of these elements.

The module of this embodiment, generally designated **300**, has an overall very similar structure to that of module **100** and, among others, may include a sleeve surrounding the treatment portion (shown in **Figure 4** is an embodiment that is devoid
15 of a sleeve). The distinction between module **300** and module **100** resides in the diffuser arrangement. In the embodiment of **Figure 3**, rather than a number of diffusers positioned peripheral to the bottom end of the bundle, a diffuser is configured as a nozzle **333** integrally formed within potting element **310** and centrally positioned within the bottom end **306** of the bundle of fibers. Nozzle **333** is linked by conduit or tube **335**,
20 also integrally formed within potting element **310** through coupling element **337** projecting from the side of potting element **310**, to an AG supply line **332**.

In other embodiments, the diffuser arrangement may include several diffuser nozzles formed in the potting element; for example, one at the center and several more peripherally positioned.

25 Diffusers configured to discharge gas bubbles within the bundles may also be such that are not integrally formed within the potting element. In addition, as also noted above, by some embodiments the diffuser arrangement may include a combination of diffusers configured to discharge AG bubbles within the bundles bottom end portion, integrally formed in the potting element or not, and diffusers configured for discharging
30 gas peripherally to the bottom end portion of the bundle, e.g. of a kind shown in **Figures 1A-2B**.

A water treatment tank **440**, in partial schematic cross-section, according to an embodiment of this disclosure, is illustrated in **Figure 5**. Tank **440** includes a water inlet **442** linked to a source (not shown) of water to be treated and a water outlet **444** that discharges treated water out of the tank, for example, to a treated water reservoir or a secondary clarifier (not shown). Tank **440** is illustrated as holding a group **446** of four modules as illustrated in **Figure 2A**, but similarly may house a plurality of groups **446** of modules, which may be of the kind illustrated herein.

In some embodiments that tank is an open tank. In other embodiments the tank has a top cover.

The tank **440** has also a BGSG inlet **448** linked, via BGSG supply line **450** to a BGSG source **452**; and an AG inlet **454** linked, via an AG supply line **456** to an AG source **458**. BGSG line of groups **446** may also have an exhaust outlet line **426** for discharging excess BGSG from the modules of groups **446**.

As noted above, an MABR module having a generally cylindrical cross section configuration is exemplary; and by other exemplary embodiments, the general configuration may be prismatic, e.g. rectangular prismatic configuration of the kind shown in **Figures 6A-6D**.

The module **500** seen in **Figures 6A-6D** includes a bundle **502** of hollow fiber membranes (with some of the central fibers not shown for the purpose of illustration) with a treatment portion **504** extending between bottom end **506** and top end **508**. Bottom and top ends **506**, **508** are fitted in and held by respective cast potting elements **510**, **512**. A cuboid sleeve **514** or a sleeve that is differently shaped (e.g. a generally cuboid shape with rounded corners, one with an elliptical or oval cross-section) is fitted over and surrounds the bundles' treatment portion **504**. Potting elements **510** and **512**, which have a generally rectangular cross section, are fitted into the corresponding bottom and top rectangular fittings **516**, **518** that are linked to BGSG conduit arrangement through respective gas lines **524**, **526**. Gas line **524** is linked to a BGSG source (not shown). Gas flows in gas line **524** in the general direction represented by arrow **A3**, then through the fibers and into line **526** where gas flows in the direction represented by arrow **A4**. The fibers which are gas permeable and water impermeable

may be made out of any one of the polymers noted above in the description of embodiments of **Figures 1A-2B**.

The module **500** includes a dual diffuser arrangement with a set of peripheral diffusers **530** formed on a first AG supply line **532** surrounding the bundle's bottom end
5 **506** and another set of diffusers formed within the confines of the bundle, and are constituted by nozzles **533** integrally formed in the potting element **510** and linked to AG supply line **532A** through a conduit **535**.

Accordingly, in a module of this embodiment, gas either continuously or intermittently flows out of the two sets of diffusers - out of diffusers **530** around the
10 bundles' periphery and out of nozzles **533** within the confines of the bundle. For the peripheral diffusers **530**, the sleeve **514** serves as a channeling element to guide the AG bubbles discharge by the peripheral diffusers **530** into the confines of the bundle **502** in their upward rise.

Sleeve **514** may structurally be supported in any of the manners described
15 above. Also, in a manner analogous to that shown in **Figures 3A-3C**, the diffusers **530** may be located at a level below that of the BGSG line.

As appreciated, a module disclosed herein can, by other embodiments, have only gas diffusers outside the confines of the bundle of hollow fiber membrane, such as diffusers **530** in **Figure 6D**, functionally operating with sleeve **514** to ensure that the
20 bubbles of the discharged gas rise within the confines of the bundle of hollow fiber membranes; or only gas diffusers having gas discharging nozzles within the confines of the bundle of hollow fiber membranes, such as nozzles **533** in **Figure 6C**; or combinations similar to those described above or others.

A system according to any embodiment of this disclosure is schematically
25 illustrated in **Figure 7**. This system includes one or more water treatment tanks **640** incorporating one or a plurality of MABR modules **600** according to this disclosure comprising AG diffusers **630**. The tank **640** includes a water inlet **642** linked to a water source **641** of water to be treated. The system also includes a BGSG source **652** and an AG source **658** as well as respective BGSG and AG conduit arrangements **650**, **656**
30 linked to module **600** and diffusers **630** respectively. The BGSG and the AG may be the

same or different, as discussed above. In one embodiment, the BGS and AG are both air, provided at, respective, lower and a higher pressure.

The water treatment in the system of the invention may be performed, by some embodiments, in a batch-wise manner; or may be carried out in a continuous operational
5 mode.

In one embodiment, treated water discharge **644** ensuing from tank **640** is directed to a secondary clarifier (not shown). Water to be treated from source **641** may be first mixed with activated sludge from the bottom of the clarifier before being fed into tank **640**.

CLAIMS:

1. A water treatment module comprising
a bundle of hollow fiber membranes that comprises a treatment portion
extending between bottom and top ends and comprising at least one gas diffuser, the
5 membranes being gas permeable and water impermeable;
at least in one end of the hollow fiber membranes being linked to a source of
biofilm growth-supporting gas (BGSG) and configured to permit inlet of said BGSG
into the hollow fiber membranes; and
the at least one gas diffuser being associated with the bundle's bottom end and
10 configured for discharging gas bubbles within the bundle's confines such that gas
bubbles rise through the treatment portion between the fibers.
2. The water treatment module of claim 1, wherein the fibers in at least one of the
bottom and top ends are held tightly together.
3. The water treatment module of claim 1 or 2, comprising one or two potting
15 elements associated, each, with an end of the bundle.
4. The water treatment module of claim 3, wherein the gas diffuser is integral with
the bottom potting element.
5. The water treatment module of claim 3 or 4, wherein the potting elements are
cast elements.
- 20 6. The water treatment module of claim 3, 4 or 5, wherein the potting elements are
cast over the end portions of the fibers.
7. The water treatment module of any one of the preceding claims, wherein the gas
diffuser comprises gas outlets positioned within the confines of the bundle's bottom end
portion.
- 25 8. The water treatment module of any one of claims 1-6, wherein the gas diffuser
comprises gas outlets positioned outside the confines of the bundle's bottom end
portion.

9. The water treatment module of any one of the preceding claims, comprising a channeling element for channeling discharged gas bubbles into the confines of the bundle.

10. The water treatment module of claim 9, wherein said channeling element is a sleeve element enveloping a least the bottom end portion of the bundle.

11. The water treatment module of any one of the preceding claims, comprising a sleeve element enveloping at least the majority of the treatment portion.

12. A water treatment device comprising one or more modules of any one of the preceding claims.

13. A water treatment system comprising

one or more water treatment tanks, one or more water treatment modules within each of the tanks, a BGSG conduit arrangement for a biofilm growth-supporting gas (BGSG), a BGSG source linked thereto, an AG conduit arrangement for an auxiliary gas (AG) and an AG source linked thereto; the AG being the same or a different gas than the BGSG;

one or more of the treatment modules comprises

a bundle of hollow fiber membranes that comprises a treatment portion extending between bottom and top ends, the membranes being gas permeable and water impermeable, and

a gas diffuser associated with the bottom end and configured for discharging AG bubbles within the bundle's confines such that gas bubbles rise through the treatment portion between the fibers;

the BGSG conduit arrangement being configured for supplying BGSG to the fibers in said bundle, and the AG conduit arrangement being configured for supplying AG to said diffuser.

14. The water treatment system of claim 13, wherein said water treatment tank comprises a plurality of said modules.

15. The water treatment system of claim 13 or 14, comprising one or more modules of any one of claims 2-12.

16. A water treatment method comprising

permitting water to come into contact with one or more treatment modules, each comprises a bundle of hollow fiber membranes, the membranes being gas permeable and water impermeable, the bundles having a treatment portion extending between a
5 bottom end and a top end;

introducing a biofilm growth-supporting gas (BGSG) into the hollow fiber membranes; and

permitting an auxiliary gas (AG), which may be the same or different than said BGSG, to discharge gas AG bubbles such that they rise through the treatment portion
10 within the confines of the bundle and between the fibers.

17. The water treatment method of claim 16, comprising intermittently discharging or releasing said AG.

18. The method of claim 16 or 17, carried out by the use of the modules of any one of claims 1-12 or the system of claim 13, 14 or 15.

15 **19.** A method comprising

treating water in a membrane aerated biofilm reactor, and

discharging gas bubbles such that the bubbles rise through and within confines of a treatment portion of a bundle of hollow fiber membranes of the reactor.

20. A membrane aerated biofilm reactor comprising a gas diffuser configured for
20 discharging gas bubbles that rise through and within confines of a treatment portion of a bundle of hollow fiber membranes of the reactor.