SYSTEMS AND APPARATUS FOR SEAWATER ORGANICS REMOVAL

[0001] Biofouling causes severe problems to ships' hulls, coastal structures, industrial cooling towers and drinking water delivery systems. Use of the term "biofouling" herein refers to a build-up of biological organisms or a biofilm of such organisms on a surface such that the surface becomes encumbered and may even be degraded with respect to the useful purpose of the surface or structure. This problem occurs when biological organisms naturally present in the fluid source are entrained in the fluid taken into a filtration system inlet or intake. The build-up of a biofilm layer due to microbial growth, deposition of colloidal matter and adsorption of organics on reverse osmosis (RO), nanofiltration (NF) and ultrafiltration (UF) membrane surfaces leads to the deterioration of filtration efficiency and eventually the need to replace the membranes. Due to the foregoing, minimizing biofilm development and accumulation is a major concern in the desalination and water treatment industries.

[0002] Phytoplankton, diatoms, and other organic species in the oceans are a source of biofouling and need to be mediated to minimize problems with downstream filtration systems. Extracellular polysaccharide secretions (EPS) serve as the precursor for the production of transparent exopolymeric particles (TEP) which play a decisive role in macro-aggregation processes. These gel-like particles appear in many forms; amorphous blobs, clouds, sheets, filaments or clumps, ranging in size from ~2 to ~200 μm. TEP are mostly polysaccharide, negatively charged, very sticky and are frequently colonized by bacteria. These aggregates foul membrane systems and serve as nutrients for biofilm growth.

[0003] Another problem for water and particularly seawater treatment systems is a seasonal event such as that known as "red tide", which is an algae infestation, or a harmful algae bloom (HAB). An occurrence, or harmful algae bloom, is generally defined as an occurrence having algae micro-organisms in an amount of 10^6 cells/L or greater.

[0004] In one aspect of the presently described embodiments, the system comprises a non-filtration hydrodynamic seawater pretreatment system and method for the removal of bio-organisms, and particularly algae using the same, the system comprising an inlet in operative connection with a source of raw seawater, and a membrane-less hydrodynamic separator unit including at least one separator module for removing bio-organic material from raw seawater, the separator module having a curved configuration leading to a bifurcated outlet operative for passing pre-treated effluent to a downstream filtration system and for the removal of waste fluid. In at least one aspect of the foregoing, the pre-treated effluent stream contains less than 10% of the amount of bio-organic material contained in the raw seawater without the use of a coagulant and/or flocculant. With the use of a coagulant and/or flocculant, the residual bio-organic matter is less than 1%.

[0005] In another aspect of the presently described embodiments, there is provided a non-filtration hydrodynamic pre-treatment separator unit suitable for use in the pre-treatment of intake fluid to remove algae and other particulate matter there from prior to the fluid allowing the waste to be disposed off directly in the ocean rather than bringing them on-land to be treated and later disposed of.

[0006] In another aspect of the presently described embodiments, there is provided a non-filtration hydrodynamic

pre-treatment separator unit suitable for use in the pre-treatment of intake fluid to remove algae and other particulate matter there from prior to the fluid being treated by a conventional RO or other water treatment system.

[0007] In another aspect of the presently described embodiments, there is provided a non-filtration hydrodynamic seawater pretreatment system, including a membrane-less hydrodynamic separator unit including at least one separator module for removing bio-organic material from raw seawater and suitable for implementation as a precursor to or a part of an off-shore or on-shore filtration system, wherein the system provides for pre-treating raw seawater to remove organics, i.e. algae, TEP, phytoplankton, diatoms, and other bio-organisms, without using a filtration barrier.

[0008] In another aspect of the presently described embodiments, the system provides a mechanism to minimize the impingement phenomenon that results when marine organisms are trapped against a conventional intake screen by the velocity and force of the fluid flow, causing cell rupture and releasing undesirable toxins or by-products to the environment.

[0009] In another aspect of the presently described embodiments, the system provides a rapid process for the removal of bio-organisms without the need for extended flocculation and/or sedimentation/floatation processes.

[0010] In another aspect of the presently described embodiments, the system provides an ecologically safe mechanism for maintaining the environmental balance of the source water while still removing potentially harmful algae from pre-treated seawater and returning the same intact to the environment.

[0011] In another aspect of the presently described embodiments, the non-filtration hydrodynamic seawater pretreatment system comprises a unit including a plurality of curved particle separation modules stacked such that the modules are parallel to one another and all of the modules are operatively connected to the inlet.

[0012] In another aspect of the presently described embodiments, the curved particle separation module(s) comprise curved portions that span between 180 degrees and 360 degrees of angular distance along a diameter thereof.

[0013] In another aspect of the presently described embodiments, the system comprises at least a second plurality of stacked curved particle separation modules arranged in parallel with the plurality of stacked curved particle separation modules.

[0014] In another aspect of the presently described embodiments, the system provides clean seawater such that filtration systems downstream of the pretreatment system suffer less clogging and require less maintenance.

[0015] In another aspect of the presently described embodiments, the system effectively and efficiently removes bio-organisms and nutrients (TEP), and thereby reduces bio-film formation and the associated affects thereof on costly membranes.

[0016] In another aspect of the presently described embodiments, minute bio-organisms that by-pass pre-filtration devices are prevented from entering the primary filtration device and fouling the same.

[0017] FIGURE 1 is a bar graph showing efficiency of conventional pretreatment system for bacteria and other organics removal;

[0018] FIGURE 2 is a graph showing results for removal of algae using the pretreatment device in a form of the presently described embodiments;

[0019] FIGURE 3 is a graph showing efficiency of a pretreatment device in a form of the presently described embodiments;

[0020] FIGURE 4 illustrates a general form of the presently described embodiment that does not use a coagulant and/or flocculant;

[0021] FIGURE 5 illustrates a general form of the presently described embodiment that uses a coagulant and/or flocculant;

[0022] FIGURE 6 illustrates a form of the presently described embodiments;

[0023] FIGURE 7 illustrates a form of the presently described embodiments;

[0024] FIGURE 8 illustrates a form of the presently described embodiments;

[0025] FIGURE 9 illustrates a form of the presently described embodiments;

[0026] FIGURE 10 illustrates a form of the presently described embodiments;

[0027] FIGURE 11 illustrates a form of the presently described embodiments;

[0028] FIGURES 12(a)-12(b) illustrate a form of the presently described embodiments; and

[0029] FIGURES 13(a)-13(e) illustrate a form of the presently described embodiments.

[0030] The presently described embodiments relate to various fluidic structures, implementations and selected fabrication techniques to realize construction of systems including membrane-less hydrodynamic pre-treatment separation units for the pre-treatment of raw seawater to remove bio-organic matter therefrom, and for returning the same, unruptured, to the raw seawater source without disturbing the ecological balance thereof. These contemplated systems provide for efficient input of fluid to be processed, and improved throughput. As used herein, the term "hydrodynamic pre-treatment separator" refers to the use of the hydrostatic force of the seawater environment, as well as gravitational force, to propel the seawater through the hydrodynamic pre-treatment separation system, including the hydrodynamic separator unit, without the need for using an external power source. However, this does not preclude the use of a pump for the device to operate.

[0031] It will be understood that variations of these systems and units may be realized based on dimensional scale and channel architecture. However, it is contemplated that the embodiments described herein will be highly scalable to span macro-scale (1-10 L/min) single-channel flow rates.

[0032] Planar embodiments utilizing convenient stacking techniques are contemplated. In this regard, hydrodynamic separator units having at least one module defining an arc in the range of 180 to 360 degrees allow for sequential stages of transverse flow pattern development, attainment of steady state flow velocity, and time for several circulatory passes to sweep particles to a desired position in the fluid flow. Other planar embodiments described herein include helical spirals.

[0033] The presently contemplated embodiments may be fabricated from inexpensive materials such as inexpensive plastics, or other suitable materials required for the treatment process.

[0034] In addition, a stacked parallel multi-channel embodiment provides for quick assembly and disassembly. Notable features of such a contemplated unit include convenient inlet manifolds and outlet manifolds that include a bifurcating mechanism or splitter to split the fluid into particulate or waste and effluent fluid streams. The contemplated embodiments also allow for a multiple stage device operative to output an extremely narrow band of particulates for further disposal or processing. Other parallel configuration embodiments and fabrication techniques therefore are contemplated.

[0035] Further, the membrane-less hydrodynamic pre-treatment separation units and configurations thereof provide for the introduction of coagulating or flocculating agents as part of the pre-treatment system, though the same are not required, and for the maintenance of the system, including a cleaning cycle. Also, a feedback and/or control system may be implemented with any of the presently described embodiments.

[0036] As has been noted above, the minimizing of bio-fouling, and particularly of bio-film development and accumulation is a major concern in the desalination and seawater treatment industries. The build-up of a bio-film layer due to microbial growth, deposition of colloidal matter, and adsorption of organics onto conventional filtration devices, such as RO, NF, and UF membrane surfaces, leads to deterioration of filtration efficiency and eventually to the need to replace fouled membranes.

[0037] One type of bio-fouling is that commonly referred to as "red tide". This phenomenon occurs, for example, in the South China Sea coastal waters, where in 1985 over 100 species of harmful algae were identified, and in 1993, 61 species of dinoflagellates, most commonly *Alexandrium tamarensis Balech, Ceratium furca, Gonyaulux polyhedral, Noctiluca scintillans,* and *Prorocentrum minimum* were identified (http://www.red-tide.org/new). For example, identified harmful algae include: in Malaysia, *Pyrodinium bahamense* var. *compressum;* in the Philippines, *Pyrodinium bahamense* var. *compressum, Gymnodinium catenatum, Alexandrium tamiyavanichii;* in Thailand, *Noctiluca scintillans, Ceratium furca, Trichodesmium erythraeum, Chaetoceros, Cosinodiscusss, Skeletonema, Mesodinium rubrum, Cochlodinium* sp.; in Vietnam, *Phaeocystis globosa;* and in Indonesia, *Skeletonema costatum, Chaetoceros, Bacterisastrum, Thalassothrix, Thalassionema, Rhizosolenia, Pseudonitszchia, Prorocentrum minimum, Gonyaulax* sp., *Trichodesmium erythraeum.*

[0038] While in some locations the red tide affect is periodical, in other areas harmful algae bloom (HAB) is present year-round. A HAB event is generally defined as an occurrence having algae micro-organisms in an amount of 10^6 cells/L or greater. Micro-organisms sometimes provide needed food or stimulate growth of other plant or animal life, thereby contributing to the food chain of the habitat. Other micro-organisms remove harmful or toxic matter from the habitat, resulting in the micro-organisms themselves becoming toxic. It may be necessary to remove such algae in order to eliminate them as a source of poison for other marine life, such as, for example, shell fish. Doing so without rupturing the cells of the

micro-organisms becomes increasingly critical so as to avoid the release of toxins or other harmful matter that may contaminate the downstream filtration system, require special handling and/or disposal, and possibly contaminate the seawater habitat if the waste is to be returned to the source.

[0039] Shear rate represents another concern with regard to the removal of micro-organisms that may be toxic or harmful. Of specific concern is the shear caused by passage of intake fluid through conventional membranes. The growth, reproduction and/or metabolism of the bio-organisms are known to be limited by turbulence. For example, it is known that *Protoceratium reticulatum* experience a reduced growth rate under turbulent conditions as compared to static conditions. At bulk average shear of 0.3/s over a 24 hour period, elevated production of chlorophyll, peridinin, and dinoxanthin, all antioxidants presumably generated to repair cell damage from shear, was noted and the growth rate was reduced. In addition to the strong inhibitory affects on cell culture rates of even low level shear, it may also fragment cell chains.

[0040] Shear rate during operation of some filtration systems may cause the rupture of bio-organism cell walls. This can be problematic in several ways. First, it may cause the release of toxic or infectious matter into the influent water. Also, the cellular matter causes further fouling of membranes and contact fluid surfaces, and again the cellular matter may be toxic or infectious, thus contaminating the fluid passing through the system. It is known that pressure drops of up to 200psi may rupture algae cells. Therefore, it is important that shear rate be controlled at a level below typical filtration operation shear rates, and specifically below that known to rupture algae so as not to cause the noted problems. Cell structures are different

for different species, and thus shear rates should be sufficiently low for all. For example, diatoms (e.g. *Chaetoceros* and *Skeletonema*) generally have glassy silicates in their rigid cell walls, cyanobacteria and dinoflagellates (e.g. *Pyrodinium, Noctiluca,* and *Alexandrium*) have more cellulosic cell walls, and those known as "oilgae", or producers of oil, have very robust cell structures and require extreme compaction methods, such as pressure drop of about 150 psig, to extract the oil.

[0041] The membrane-less hydrodynamic pre-treatment separator system and units provided herein, however, operates in the shear rate range of 100/s to 1500/s, which is a couple of magnitudes lower than that necessary to rupture algae cell walls of any of the foregoing types or bio-organisms and most others that are similar. Therefore, the hydrodynamic pre-treatment separator system provided herein represents an acceptable alternative to conventional membrane filtration systems with regard to the problems caused by excessive shear.

[0042] Bio-organisms can vary in size and shape. For example, Table 1 set forth representative size and shape data for some of the bio-organisms noted herein. Of course, this data is provided as merely informative with regard to the type of bio-matter that the hydrodynamic pre-treatment separator system in accord herewith is intended to remove.

TABLE 1

MICRO-ORGANISM	SHAPE	AVERAGE SIZE
Pyrodinium bahamense var. *compressum*	spherical	41.9µm long and 43.8µm wide
Gymnodinium catenatum	(a)circular or squarish cells; (b)spherical cysts;	(a)38-53µm long and 33-45µm wide; (b) 45-50µm;

	(c)chains	(c)32-64 cells/ chain
Skeletonema costatum	tube-like cell chain	2-21μm
Trichodesmium erythraeum	cells that form colonies that appear as bundles of filaments	2-3 mm thick
Noctiluca scintillans	spherical	200μm to about 2mm diameter
Chaetoceros gracilis	tube-like cells	200-900μm long

[0043] The bio-organisms may represent a danger to marine life. For example, *Chaetoceros debilis* has silica cell walls and has a loosely spiraled appearance. This bio-organism becomes entrapped in the gill tissue of fish, causing the generation of copious amounts of mucous which eventually suffocate the affected fish.

[0044] In light of the foregoing, there is an obvious need to prevent harmful algae blooms from occurring and for the removal of harmful bio-organisms from sources of seawater. Attempts have included minimizing runoff from agricultural areas and fertilized fields, decreasing exposure to light, dosing infested water with gypsum or alum, pretreatment of the water source with algaecide, and treatment of ballast water to prevent cyst transplantation of new algal species. In addition, it is known to treat filtered water prior to use by the addition of a flocculating agent such as clay, i.e. montmorillonite, kaolinite, or yellow loess. This treatment, however, tends to increase the cell mortality rate. With regard to larger infestations, for example coastal red tide blooms, the most commonly used treatment is unfortunately no treatment at all, i.e. the bloom is left to disappear on its own. This results in expensive repair and

maintenance that may lead to extended downtime of seawater filtration systems.

[0045] Extracellular polysaccharide secretions (EPS) serve as the precursor for the production of transparent exopolymeric particles (TEP), which include the foregoing examples and many other species, and which play a decisive role in macro-aggregation processes. These gel-like particles appear in many forms, including amorphous blobs, clouds, sheets, filaments or clumps, ranging in size from ~2 to ~200 μm. TEP are mostly polysaccharide, negatively charged, very sticky and are frequently colonized by bacteria. These aggregates foul membrane systems and serve as nutrients for bio-film growth.

[0046] Conventional membrane filtration devices, at normal operating flow rates, are likely to deform or shred the TEP into smaller fragments, but are unlikely to readily remove the TEP. Thus, it remains as a basis for further growth of the bio-film. Similarly, the use of sediment traps causes the TEP, which is mucous-like, to accumulate with sediments as a viscous sludge that complicates handling and disposal. Notwithstanding the foregoing, there is a need to return bio-organisms to the source water unaltered, based on the fact that the TEP represent a food source for small filter-feeding protozoans (e.g. *Appendicularia* and *Euphausia pacifica*), and for larval stage organisms, copepods, and some fish. Finally, due to the fact that certain bacteria may preferentially feed on and degrade TEP that contain more mannose or galactose, the concentration, removal and return of this type of TEP represents a potential ecological shift in the environmental. The release of hazardous or nuisance grade byproduct gases may also become problematic in this situation. Therefore, there is an obvious need to balance the removal of harmful algae with

the need to return bio-organisms to the source seawater unaltered.

[0047] In one aspect of the current invention there is provided a membrane-less hydrodynamic pre-treatment separator system, suitable for implementation in an off-shore or on-shore environment, for pre-treating seawater to remove bio-organics, i.e. algae, TEP, phytoplankton, diatoms, and other bio-organisms, without using a filtration barrier. Removed bio-organic material may be returned to the source water or may be disposed of as needed. The membrane-less hydrodynamic pre-treatment separator system provided is ecologically friendly in several regards, i.e., it does not require the use of toxic or harmful chemicals or release the same to the environment; it provides for the return of waste cleaned from the raw seawater to the shore for disposal or further treatment, to the intake source for further treatment, or back to the source water; it operates on hydrodynamic force generated by the fluid flow through the system; and, if necessary, it provides for the use of a biocompatible and biodegradable organic flocculent, such as chitosan, made from the chitan of shells, as a separation enhancer.

[0048] In another aspect of the current invention there is provided a membrane-less hydrodynamic pre-treatment separator system that effectively and efficiently removes bio-organisms and nutrients (TEP), and thereby reduces bio-film formation and the associated affects thereof on costly membranes of downstream filtration systems. In this regard, use of the pre-treatment system provided results of at least an 80% reduction in bio-organics and TEP in the intake fluid, and preferably of at least a 90% reduction, thus providing for a five-fold increase in the useful life of downstream membrane and

RO systems prior to cleaning and even longer to eventual replacement. Due to the high efficiency of the pretreatment system with regard to particulate removal, i.e. on the order of 95%, the intake fluid fed to downstream desalination or other operations is of a higher quality, thus enhancing the performance and efficiency thereof.

[0049] Figure 1 is a bar graph showing the amount of bacteria, clumped particulates, and other particulates in raw seawater, and in post-treatment effluent treated by conventional filtering devices, including UV irradiation, MMF and CF, conventional filtering mesh and RO. No treatment method tested provided a noticeable reduction in bacteria, which includes the bio-organisms that are the focus of the current system.

[0050] In contrast, Figure 2 provides a graph showing the concentration in ppm (parts/million) of algae greater than 6 µm in diameter in raw seawater, in the waste stream and in the effluent stream of a membrane-less hydrodynamic pre-treatment separator system in accord with at least one aspect of the current invention. Figure 3 further details the effectiveness of the current system in a graph showing the system to operate with 95% efficiency with regard to the removal of algae having a diameter of greater than about 6 µm.

[0051] In the following discussion, in which various embodiments are discussed with respect to the Figures, it is understood that like numbers may be used to refer to like components or portions of the Figures. Further, it is understood that though a certain size or type of device may be shown, unless otherwise stated other similar devices or features may be substituted so long as the intended result of the operating system is achieved.

[0052] With reference now to Figure 4, a general embodiment to pre-treat raw seawater for desalination is shown for cut-off size separation. With this type of pre-treatment, particulate matter having a certain particle size or larger is removed by the separator. Shown then is seawater treatment system 10 having raw seawater intake 12 passing fluid to a spiral separation unit. Separator 14 includes a bifurcated outlet (not shown) having an effluent stream 16 operatively connected to effluent water tank 20 and waste stream 18, laden with removed particulate matter, which transports the waste stream for disposal or storage (not shown). Optional filter 22 may be added to fine filter the effluent stream. In system 10, pre-treatment filter 24 is an 80 mesh screen filter, though any suitable screen filter is contemplated as part of this system.

[0053] Figure 5 provides another general embodiment to pre-treat raw seawater for desalination 10, including raw water inlet 12 through mesh screen filter 24, spiral separator 14, and then through either effluent stream 16 and optional filter 22 to effluent tank 20 or through waste stream 18 to storage or disposal (not shown). In addition, in this embodiment there is provided coagulant and/or flocculant injection device 26, spiral mixer 28 to facilitate aggregation of the coagulant and/or flocculant and particulate matter remaining in the rough filtered seawater, and aggregation tank 30 where the coagulated particulate matter is further combined with a flocculating agent. The addition of these latter units is intended to aid in removal of particulate matter by creating larger particles that are more easily removed by spiral separator 14.

[0054] In at least one aspect of the current invention, there is provided a simplified non-filtration hydrodynamic pre-treatment separator system for the pre-treatment of raw seawater, for

example as set forth in Figure 6, that avoids the problems presented by source water containing large amounts of harmful algae and other bio-organisms. In the hydrodynamic pre-treatment separator system 40 shown in Figure 6, raw seawater 41 enters and passes through inlet screen 42 by gravitational force. Screen 42 removes larger particulate matter, for example having a size of about 2 to 3 mm and above. Raw screened seawater 43 then flows toward hydrodynamic separator unit 50 through channel 44, which has segments 44(a) and 44(b). Fluid first enters and moves through segment 44(a) until it is filled, at which time it spills over into segment 44(b). Screened seawater 43 is driven through channel 44 by hydrostatic forces, which further force the screened raw seawater into and through hydrodynamic separator unit 50, which includes at least one non-filtration, membrane-less separator module in accord with that shown in, for example, Figure 10 or 11 hereof, or as shown in any of the embodiments of the applications to our common assignee which have been incorporated by reference above. The hydrodynamic separator module functions to remove bio-organisms from the screened raw seawater in advance of the further filtration thereof by downstream filtration operations or systems.

[0055] Fluid flow through the hydrodynamic pre-treatment separator system 40 is in this and some other embodiments maintained by eductor pump 56. Eductor pump 56, in operative communication with check valve 58, receives effluent from effluent line 52 through line 60. As effluent from line 60 enters eductor pump 56 it creates a vacuum, drawing screened raw seawater into separator unit 50 and waste there from through check valve 58. This vacuum offsets the drop in pressure from separator unit inlet side in channel 44(b) and outlet side where

effluent line 52 emerges, and maintains the flow of raw screened seawater into and removal of effluent from separator unit 50.

[0056] Seawater that has been pre-treated for removal of bio-organics that cause bio-fouling of downstream membranes exits hydrodynamic separator unit 50 as a bifurcated outlet stream, including effluent stream 52 and waste stream 54. Effluent stream 52 may be transported by an appropriate means, at low pressure, for further filtration in a downstream filtration operation on-shore or off-shore. Alternatively, depending on the end use requirements, effluent stream 52 may be used as is or contained for subsequent use. Optionally, submersible pump 62 may be employed to facilitate pumping effluent stream 52. Check valve 58 in operative communication with hydrodynamic separator unit 50 releases larger algae, such as those types consistent with red tide events, and other larger particulate matter as part of waste stream 54. The waste product from waste stream 54 may be returned to the ocean so as not to upset the ecological balance, or may be disposed of in an appropriate manner, as disclosed herein.

[0057] Figure 7 presents another aspect in accord with the current disclosure, wherein a coagulant and/or flocculant is added to maximize the efficiency of the waste removal process when the size of the algae to be removed is known to be very small, for example on the order of less than about 5 μm. In this instance it may be desirable to enhance the efficiency of the hydrodynamic pre-treatment separator system by the addition of a coagulating agent. In this embodiment, raw seawater 41 enters hydrodynamic pre-treatment separator system 70 through inlet screen 42 by gravitational force. The raw screened seawater 43 then flows toward hydrodynamic separator unit 50

through channel 44, which has segments 44(a) and 44(b). Fluid first enters and moves through segment 44(a) until it is filled, at which time it spills over into segment 44(b). Sufficient detention time is allowed for coagulation and/or flocculation prior to feeding into the hydrodynamic separator. The raw screened seawater 43 is driven through channel 44 by hydrostatic forces, which further force the screened seawater into and through hydrodynamic separator unit 50, which includes at least one non-filtration, membrane-less separator module in accord with that shown in, for example, Figure 10 or 11 hereof, or as shown in any of the embodiments of the applications to our common assignee which have been incorporated by reference above. The hydrodynamic separator functions to remove bio-organisms from the screened seawater in advance of the further filtration thereof by downstream filtration operations or systems.

[0058] At this point, coagulant and/or flocculant 72, such as chitosan, is added to screened seawater 43 in channel 44 by any suitable means for doing so. Chitosan, comprising crushed shells, is exemplified here as an appropriate coagulant and/or flocculant because it maintains the environmentally friendly aspect of the system. Of course, any appropriate coagulant and/or flocculant may be used. The coagulated screened seawater is circulated through hydrodynamic separator unit 50 by hydrodynamic force. The fluid stream is bifurcated before exiting separator 50 into effluent stream 52 and waste stream 54. In this embodiment, waste stream 54 is removed through check valve 58, which is in operative communication with separator unit 50 through waste line 54, and can then be returned to channel 44(a) for combination with raw screened seawater 43 to assist in increasing the particle size of the bio-organisms that the pre-treatment is intended to remove, along

with coagulant and/or flocculant 66. In the alternative, if it contains larger size waste it can be removed to shore for disposal or containment. Pump 64 may optionally be added to the system to assist with moving waste stream 54. Effluent stream 52 is transported by an appropriate means at low pressure for further filtration in a downstream filtration operation on-shore or off-shore. Alternatively, depending on the end use requirements of the cleaned seawater, effluent stream 52 may be used or contained for subsequent use. Optionally, a submersible pump 62 may be employed to facilitate pumping effluent stream 52.

[0059] In another aspect in according with the current disclosure, the hydrodynamic pre-treatment separator system 80 includes a forced air cleaning cycle. With regard to Figure 8, raw seawater 41 enters hydrodynamic pre-treatment separator system 80 through inlet screen 42 by gravitational force, and travels through channel 44 to hydrodynamic separator 50 in accord with the disclosure provided above. The fluid stream is bifurcated before exiting separator 50 into effluent stream 52 and waste stream 54. In this embodiment, as hydrodynamic separator 50 becomes fouled, system 80 may be shut down briefly, and air forced into hydrodynamic separator unit 50 through waste stream line 54 positioned upstream of check valve 58. Air stream 72 enters hydrodynamic separator unit 50 through waste stream 54 by the force of a blower or other such device connected to an air supply (not shown), dislodging scrubbed solids/waste from hydrodynamic separator unit 50, the dislodged solids/waste accumulating above separator 50 in head space 82 of channel segment 44(b). In that scenario where hydrodynamic separator unit 50 includes a plurality of stacked modules, as shown for example in Figure 11, the air

scouring will be done sequentially. As such, each module will include an air inlet and an on-off valve to control the sequential cleaning of the modules. As each module is cleaned, dislodged solids/waste will accumulate in head space 82.

[0060] Once hydrodynamic separator unit 50 is clean, air stream 72 is turned off, and system 80 is once again subject to the hydrodynamic force of the seawater in the system, which causes raw seawater 41 to again flow through screen 42, through channel 44 and into hydrodynamic separator unit 50. As the screened seawater moves through channel 44, the dislodged solids are picked up and carried back into hydrodynamic separator unit 50 for removal as part of waste stream 54. Loop seal 74 is in this scenario a portion of effluent stream line 52 and is operatively associated with hydrodynamic separator unit 50 to prevent air from the cleaning cycle from exiting effluent stream 52. As such, loop valve 74 is positioned below the water line and includes air vent 88 for the discharge of accumulated air above sea level. Waste stream 54 is removed through check valve 58 and disposed of or re-used in accord with any of the foregoing embodiments. Similarly, effluent stream 52 is transported by an appropriate means at low pressure for further filtration in a downstream filtration operation on-shore or off-shore, or for use or storage in accord with any other embodiment hereof.

[0061] In an alternative to the foregoing air cleaning cycle, a chemical cleaning cycle may be used with the hydrodynamic pre-treatment separator system disclosed in any of the embodiments provided herein. Figure 9 provides an example of such a cleaning cycle. In this embodiment, hydrodynamic pre-treatment separator system 90 receives raw seawater 41 through inlet screen 42 by gravitational force. The screened

seawater 43 then flows through channel 44 (a) and (b) to hydrodynamic separator unit 50, where the hydrodynamic force of screened seawater 43 moves the fluid through the non-filtration, membrane-less separator unit 50 for the removal of bio-organisms, in accord with any of the foregoing aspects. Stream 43 is circulated through hydrodynamic separator unit 50 where bio-organisms are removed and the stream is bifurcated before exiting hydrodynamic separator unit 50 into effluent stream 52 and waste stream 54.

[0062] In this aspect, as the hydrodynamic separator unit 50 becomes fouled, system 90 may be shut down briefly for a cleaning cycle. Upon shut down, weir gates 84 and 86 on weir overflows (not shown) drop to prevent the ingress of raw seawater or clean effluent into the hydrodynamic separator unit 50. Cleaning fluid, charged to hydrodynamic separator unit 50 by any suitable means for doing so, is recirculated through hydrodynamic separator unit 50 by pump 82 through line 76. For example, cleaning fluid might be pumped from a fluid storage tank or other containment on-shore, or may be stored on support mechanism housing/supporting system 90, for example a platform. In either instance, it may be fed to system 90 by, for example, gravity, and recirculated by dedicated pump 82. Weir gates 84 and 86 prevent the cleaning fluid circulating through hydrodynamic separator unit 50 from escaping into either effluent line 52 or into channel 44(b). Once the cleaning cycle is complete, a valve (not shown) may be used to close off the cleaning fluid inlet and force spent fluid out through line 78 for disposal, for example on-shore.

[0063] Optionally, the cleaning fluid may be supplemented by an air stream, such as that shown in Figure 8. In one alternative, aeration alone is used to recirculate the cleaning

fluid through hydrodynamic separator unit 50. The cleaning fluid is prevented from entering the source water and seawater is prevented from back-flowing into hydrodynamic separator unit 50 during the cleaning cycle by the hydraulic head differential between the screened seawater 43 in channel 44(a) on the intake side of weir gate 84 and that in channel 44(b) on the opposite side of weir gate 84 where fluid enters hydrodynamic separator unit 50. During cleaning, check valve 58 functions to assist in retaining the cleaning fluid within hydrodynamic separator unit 50 and keeping it from exiting the system through waste stream 54.

[0064] Upon completion of the cleaning cycle, pump 82 is stopped and system 90 is re-activated. At this time, weir gates 84 and 86 are raised and fluid again moves through hydrodynamic pre-treatment separator system 90, and waste stream 54 is removed through check valve 58 and disposed of or re-used in accord with any of the foregoing embodiments. Similarly, effluent stream 52 is transported by an appropriate means at low pressure for further filtration in a downstream filtration operation on-shore or off-shore, or for use or storage in accord with any other embodiment hereof.

[0065] Membrane-less hydrodynamic separator unit 50 contemplated for use herein may take the form of any separator disclosed in those disclosures to our common assignee incorporated herein by reference. For example, though not intended to be in any way limiting, Figure 10 provides a representation of an example hydrodynamic separator unit suitable for use herein. Figure 10, then, sets forth an example of a suitable hydrodynamic separator unit 50, in keeping with the definition provided above, having inlet 102 (which may include an inlet coupler for stacked arrangements), curved

portion 104, and at least one bifurcated outlet 106 defining effluent stream 52 and waste stream 54. As shown, there may be provided an additional outlet 108 for selected particles such as particles of a particular size or density (e.g. buoyant particles). Outlet 108 is positioned midway around curve portion 104 between inlet 102 and outlet 106. As above, at least one outlet coupler may also be utilized. Depending on the seawater water quality, i.e. particulate concentration and size distribution, hydrodynamic separator unit 50 will collect all of the particulates into a band of different widths. In order to allow optimization of the efficiency of the hydrodynamic separator in real time, it is desirable to have an adjustable stream splitter (not shown). It is understood that hydrodynamic separator unit 50, as shown in this Figure 10 may be a single module or a plurality of parallel stacked modules, as shown in more detail in Figure 11.

[0066] Figure 11 provides a representation of a stacked arrangement including a plurality of modules 100 in hydrodynamic separator unit 50, for example of the type shown in Figure 10. With reference to Figure 11, a stacked hydrodynamic separator unit 50 comprises multiple planar hydrodynamic separator modules 100 (e.g. fractional arc segments) that are vertically stacked as parallel channels to increase throughput. These hydrodynamic separator modules do not complete a loop for any one module 100, although the characteristics and functions of a spiral device will nonetheless apply to these stacked separator modules in this case. Hydrodynamic separator modules 100 each comprise inlet 102, curved or arc section 104 and an outlet 106. Also shown in Figure 11 is an inlet coupler 112 that allows for an inlet of seawater from a common source to each hydrodynamic

separator module 100 shown. It should be appreciated that the inlet coupler may take a variety of forms. In one form, the inlet coupler is a cylinder and has perforations or a continuous slot corresponding to the inlet of each hydrodynamic separator. Hydrodynamic separator unit 50 provides for increased throughput for fluid particle separation. At least one outlet coupler (not shown) may also be implemented. The outlet coupler(s) could resemble the inlet coupler, for example.

[0067] Figures 12(a) - (b) illustrate a further embodiment of the presently described embodiments. As shown in Figure 12(a), hydrodynamic separator unit 200 includes eight parallel hydrodynamic separator modules in a helical spiral arrangement. This embodiment provides for improved throughput due to the compact configuration, as shown in the exploded view of Figure 12(b).

[0068] In operation, raw seawater enters hydrodynamic separator unit 200 through inlet 202 and exits (separated) through outlet paths 204 and 206. Upper fluidic manifold 210 feeds the eight separate hydrodynamic separator modules 217 through the respective radially skewed slots 214 on end cap 212. Lower end cap 216 has slots corresponding to each hydrodynamic separator module as well. Outlet manifold 218 includes inner ring 219 which acts as the bifurcator to split the separated fluid into waste and effluent streams, 204 and 206. The helical spiral structure formed by hydrodynamic separator modules 217 fits within external protective sleeve 220. Each individual hydrodynamic separator module may optionally have individual flow control at inlet or outlet to stop the flow.

[0069] Any of the foregoing embodiments may be used alone or as part of a stacked and/or packed arrangement. By this is meant that the hydrodynamic separator unit 50/200 may include

a plurality of hydrodynamic separator modules arranged in parallel, planar fashion using convenient stacking techniques, for example creating a tower. Similarly, the unit may include multiple stacks or towers packed together using convenient packing techniques.

[0070] Figure 13(a)–(e) provide an illustration depicting how the throughput and separation capacity of the disclosed aspects may be amplified. For example, Figure 13(a) represents a single hydrodynamic separator module that may be used to pre-treat raw seawater, prior to conventional filtration, in accord with any of the foregoing aspects. It is anticipated that one such module may treat 40,000 gallons of raw seawater per day. As shown in Figure 11, a plurality of modules may be stacked in planar relationship, and form a tower such as that depicted in Figure 13(b). In Figure 13(b), the tower includes 6 modules. This is merely exemplary, however, and more or less may be used. Using 6 modules, of the type shown in Figure 13(a), the hydrodynamic pretreatment separator system may clean, for example, a throughput of 240,000 gallons per day. Figure 13(c) contemplates the positioning of 4 towers of the type shown in Figure 13(b) within a single, closely packed arrangement, i.e. a 1 MGD hydrodynamic separator unit, for example retained or positioned on a skid or other base support. In such an arrangement, for example, each tower may have a diameter of about 2 feet. In this exemplary arrangement, each tower includes 6 stacked modules, wherein each module has a flow throughput of 100 liters per minute. Based on this, the skid, having an overall footprint of only 5 feet by 5 feet, has a throughput capacity of 1 million gallons per day (MGD). Finally, Figure 13(d) provides a schematic for an assembly including 16 such units or skids, and thus representing a cleaning capacity of

16 MGD. Figure 13(e) expands upon this further, including 32 units and having a separation capacity of 32 MGD. In Figure 13(e), raw seawater 41 passes through inlet screens 42 on either side of 32 unit system. The screened seawater then circulates through hydrodynamic separator units 50, generating effluent and waste streams that are combined such that effluent stream 52 and waste stream 54 exit on opposite sides. In one embodiment, a common area may be included, for example to house various pumps, cleaning devices, mechanical equipment, and valves in accord with any of the aspects disclosed herein.

CLAIMS:

1. A seawater pretreatment system for the removal of bio-organic material from a source of raw seawater, the system comprising:

at least one inlet for receiving raw seawater; and

a membrane-less hydrodynamic separator unit including at least one separator module for removing bio-organic material from the raw seawater, the separator module having a curved configuration leading to a bifurcated outlet operative for passing treated effluent to a downstream filtration system and for the removal of waste fluid;

wherein the pre-treated effluent stream contains less than 10% of the amount of bio-organic material contained in the raw seawater without the use of a coagulant and/or flocculant.

2. The system as set forth in claim 1 wherein the system further includes a source of at least one of a coagulant and a flocculant, and the treated effluent stream contains less than 1% residual bio-organic material.

3. The system as set forth in claim 1 wherein the bio-organic material comprises phytoplankton, algae, diatoms, seawater organisms, and TEP.

4. The system as set forth in claim 1 wherein the separator module curved configuration comprises at least one curved portion that spans between 180 degrees and 360 degrees of angular distance along a diameter thereof.

5. The system as set forth in claim 1 wherein the hydrodynamic separator unit includes a plurality of curved particle separation modules stacked such that the modules are parallel to one another and all of the modules are operatively connected to the inlet.

6. The system as set forth in claim 1 wherein the system can be implemented as a pretreatment system for an on-shore or an off-shore filtration system.

7. A method for prolonging the useful life of a seawater filtration system comprising:

providing a hydrodynamic pretreatment separation system for the removal of bio-organisms from a source of raw seawater;

circulating the raw seawater through the hydrodynamic pretreatment separation system to render an effluent stream and a waste stream;

passing the effluent stream to the seawater filtration system which is downstream of the hydrodynamic pretreatment separation system; and

filtering the effluent stream to remove remaining waste;

wherein the hydrodynamic pretreatment separation system removes at least 90% of bio-organisms entrained in the raw seawater prior to passing the effluent to the seawater filtration system, such hydrodynamic pretreatment separation system including:

at least one inlet for receiving raw seawater; and

a membrane-less hydrodynamic separator unit for removing bio-organic material from the raw seawater, the separator unit including at least one module having a curved configuration leading to a bifurcated outlet for rendering the effluent stream and the waste stream.

8. The method as set forth in claim 7, wherein micro-organisms removed by the hydrodynamic pretreatment separation system do not undergo cell rupture and are returned to the source of raw seawater intact and functional.

9. A mechanism to minimize the impingement phenomenon that results when marine organisms are trapped against a conventional intake screen by the velocity and force of the fluid flow, the mechanism comprising a non-filtration hydrodynamic pretreatment separation system including at least one inlet for receiving raw seawater, and a non-filtration barrier hydrodynamic separator unit for removing bio-organic material from raw seawater based on fluid flow dynamics, the separator unit including at least one module having a curved configuration that causes marine organisms to be concentrated into bands within the module prior to being removed from the system as part of a waste stream, thereby eliminating cell rupture and the release of undesirable toxins or by-products to the raw seawater environment.

10. The mechanism as set forth in claim 9 wherein the bands within the separator unit include at least effluent stream which, upon removal from the separator unit, contains less than 10% of the amount of bio-organic material contained in the raw seawater without the use of a coagulant and/or flocculant.