

FEED DIFFUSING SYSTEM AND METHOD FOR REDUCING MEMBRANE FOULING

FIELD OF THE INVENTION

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The present invention relates generally to the field of water treatment. More particularly, the present invention relates to a feed diffusing system and a method for reducing membrane fouling in membrane-based water treatment systems.

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BACKGROUND OF THE INVENTION

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There is a need for availability and sustainable management of water and sanitation globally. However, increased pollution of existing water sources and high energy cost of conventional membrane-based water treatment systems are key challenges that impede sustainable water management practices.

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Membrane based water treatment systems such as submerged membrane systems combine various treatment processes with membrane filtration to purify wastewater. Submerged membrane systems such as membrane bioreactors (MBRs) comprise closely spaced membranes. Such a tightly packed configuration creates regions of low shear stress and poor hydrodynamics lead to a range of fouling mechanisms, including cake layer formation, pore blocking, and biofilm development. The fouling mechanisms negatively impact water quality, shorten membrane lifespan, and increase operational and maintenance costs.

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Aeration has been utilized as a preventive strategy against membrane fouling in these systems. The basic idea is to introduce air bubbles near the membrane surface, which generate shear forces as they ascend through the water column. These forces have the potential to dislodge particulate matter and inhibit biofilm formation, thus reducing the tendency for fouling. However, implementing this principle effectively in tightly packed configurations like those found in MBRs is challenging, which leads to the limitations of existing aeration methods.

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If the submerged membrane system is used for water treatment as opposed to wastewater treatment, excessive aeration is not recommended, as it will resuspend solids that have settled onto the bottom of the tank. Therefore, aeration needs to be optimized so as to reduce the resuspension of solids.

Further, current aeration techniques have considerable drawbacks, especially in submerged membrane systems. They are typically energy-intensive, requiring substantial

volumes of air or other gases to be pumped through the system. This not only drives up operational costs but also raises environmental sustainability concerns. Furthermore, traditional aeration approaches often produce strong turbulent forces or uneven airflow patterns, which can result in mechanical stresses that lead to fiber breakages, compromising the integrity of the membrane modules. Therefore, there remains a need for a simple and cost-effective system and method for reducing membrane fouling.

SUMMARY OF THE INVENTION

The present invention relates to a feed diffusing system for reducing membrane fouling in a membrane module disposed in an environment. The system comprises:

a feed inlet for receiving a feed mixture;

one or more feed outlets in fluid communication with the feed inlet;

wherein the one or more feed outlets is arranged adjacent to a membrane in a membrane module so as to enable diffusion of the feed mixture through the one or more feed outlets at an average feed outlet velocity, v greater than or equal to 1 m/s.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a front schematic view of a feed diffuser system for reducing membrane fouling in a membrane module according to the invention;

FIG. 2 is a front schematic view of an alternative design of a feed diffusing system for reducing membrane fouling according to the invention;

FIG. 3 is a bottom view of the feed diffusing system of FIG. 2;

FIG. 4 is a side schematic view of the feed diffusing system of FIG. 2 in a membrane module according to the invention;

FIG. 5 is a front perspective schematic view of an alternative design of a feed diffusing system for reducing membrane fouling according to the invention;

FIG. 6 is a cross section schematic view of the feed diffusing system of FIG. 5;

FIG. 7 is a front perspective view of the feed diffusing system of FIG. 5 in a membrane module according to the invention without a pump;

FIG. 8 is a side schematic view of the feed diffusing system of FIG. 5 in a membrane module according to the invention with a pump;

FIG. 9 is a front schematic drawing of a membrane module according to the present invention;

FIG. 10 is a front schematic drawing of an alternative design of a membrane module according to the present invention;

FIG. 11 is a schematic drawing of a test set-up for evaluating Examples;

FIG. 12 is a graph plotting a method of providing pulsed feed water to a membrane according to the present invention;

FIG. 13 is a graph plotting normalized permeability of feed mixture in a membrane module with no feed diffusing system (Comparative Sample 1), a membrane module having a feed diffusing system according to FIG. 1 with angled feed outlets (Inventive Sample A) and a membrane module having a feed diffusing system according to FIG. 1 with straight feed outlets (Inventive Sample B) as a function of elapsed time;

FIG. 14 is a graph plotting a permeability drop of feed mixture in a membrane module with no feed diffusing system (Comparative Sample 2), and permeability drop in different membrane modules having a feed diffusing system according to FIG. 1 with angled feed outlets at different velocities (Inventive Samples C, D, E);

FIG. 15 is a graph plotting a permeability drop of feed mixture in a membrane module with no feed diffusing system (Comparative Sample 3), and permeability drop in different membrane modules having a feed diffusing system according to FIG. 1 with angled feed outlets with different jetting intervals of the feed mixture through the feed inlet (Inventive Samples F, G, H);

FIG. 16 is a graph plotting the permeability drop for the membrane module of FIG. 9 and the membrane module of FIG. 10;

FIG. 17 is a graph plotting a stress distribution of feed outlets with a uniform feed outlet cross sectional area in a feed diffusing device according to the present invention with distribution of feed outlets, each having an uniform feed outlet cross sectional area (Inventive Sample K);

FIG. 18 is a graph plotting a stress distribution of feed outlets with a uniform feed outlet cross sectional area in a feed diffusing system according to the present invention with distribution of feed outlets with distribution of feed outlets of different feed outlet cross sectional areas according to the present invention (Inventive Sample L);

FIG. 19 is a graph plotting a stress distribution of a feed diffuser system having four feed diffusing devices according to the present invention;

FIG. 20 is a histogram graph illustrating the shear stress distribution on a membrane curtain in a water treatment system comprising two feed diffusing systems according to the present invention, based on a volumetric flow rate of 70 litres per minute in the system;

FIG. 21 is a histogram graph illustrating the shear stress distribution on a membrane curtain in a water treatment system comprising two feed diffusing devices according to the present invention, based on a volumetric flow rate of 140 litres per minute in the system; and

FIG. 22 is a histogram graph illustrating the shear stress distribution on a membrane curtain in a water treatment system comprising four feed diffusing devices according to the present invention, based on a volumetric flow rate of 140 litres per minute in the system.

DETAILED DESCRIPTION

The present invention relates to a feed diffusing system for reducing membrane fouling in a membrane disposed in an environment. The system comprises a feed inlet for receiving a feed mixture, and one or more feed outlets in fluid communication with the feed inlet. The one or more feed outlets is arranged adjacent to a membrane in a membrane module so as to enable diffusion of the feed mixture through the one or more feed outlets at an average feed outlet velocity, v greater than or equal to 1 m/s.

In current membrane filtration systems such as for example, submerged membrane filtration systems, the feed mixture is often fed into the tank from the top of the tank. However, this often results in the concentration of foulant increasing near the surface of the membranes and at the bottom of the feed tank as the filtration process progresses, thereby increasing the possibility of fouling of the membrane. Specifically, as the feed water is pushed through the membrane, due to phase separation, foulant accumulates at the surface of the membrane. Over time, the accumulation of foulant reduces the amount of feed water that can be pushed into the membrane pores, therefore reducing the amount of clean water output. The typical way of feeding feed water into the tank from the top does not help to reduce the accumulation of foulant at the surface of the membrane.

Applying a feed diffusing system according to the present invention allows feed mixture to be introduced into the feed tank at strategic locations adjacent to the membrane at an average feed outlet velocity, v greater than or equal to 1 m/s. A technical effect of diffusing feed mixture at an average feed outlet velocity, v greater than or equal to 1 m/s is that this enables a lower drop in loss in permeability (also known as permeability drop) that is lower relative to a water treatment system without the feed diffusing system according to the invention. In other words, regardless of the type of feed mixtures, as long as the feed diffusing system is designed to diffuse the feed mixture at an average feed outlet velocity, v greater than

or equal to 1 m/s, it enables a lower loss in permeability of the membrane over time. It will be appreciated that different feed mixtures would result in different baselines of the loss of permeability. Hence, the baseline could be 3.6 LMBH/H for a certain type of feed or 10 LMBH/H for another type of feed mixture. By baseline, it means that there is no feed diffusing system applied to the membrane. This is supported by data shown hereinafter in the Examples.

Without wishing to be bound by theory, a lower drop in the loss in permeability of the membrane is desired because it means that there is less fouling of the membrane and its surfaces. In contrast, a higher drop in the loss in permeability of the membrane means a higher concentration of particulates/solids on the surface on the membrane, and thereby the membrane has a higher degree of fouling. Therefore, use of a feed diffusing system according to the present system reduces the stagnated locations near the membrane surface and at the bottom of the feed tank and helps to reduce fouling on the membrane.

Further, a feed diffusing system according to the present invention can have dual uses. For example, a process of cleaning a feed tank includes the steps of:

- (a) draining out used feed water (feed water at a higher concentration level);
- (b) removing solids accumulated in the feed tank; and
- (c) adding dilute feed water (dilute feed water at a lower concentration level relative to used feed water) to refill the tank.

After steps (a) and (b) are completed, the dilute feed water is diffused through the one or more feed outlets hits the membrane in the form of water jets, and the water jetting action aids in removing any residual solids stuck on the membrane, thereby achieving a dual purpose of refilling the feed tank while cleaning residual dirt from the membrane. Moreover, the concentration of solids within the feed tank may be more evenly distributed when the system is used because dilute feed water is introduced at different parts of the feed tank, and the system will be more efficient. In conventional feed water refiling methods, dilute feed water is introduced at the top of the tank, the feed water is dilute at the top, with increasing solids concentration as we move down the tank. This means that the membranes near the top of the tank will experience a higher solids concentration than membranes near the bottom of the tank.

Prior to describing the present invention in detail, the following terms are defined and terms not defined should be given their ordinary meaning as understood by a skilled person in the relevant art.

“Feed water” as used herein, refers to raw water before any treatment. Raw water may include but is not limited to raw water from natural water sources or industry water sources.

“Low pressure membrane filtration system” as used herein, operates at a transmembrane pressure of between 0 to 3 bar and removes contaminants larger than 0.05 micrometers in size.

“Membrane” as used herein, refers to a semi-permeable material which allows some component of matter to pass through but stops other component.

- 5 “Membrane fouling” as used herein, refers to a process by which the particles, colloidal particles, or solute macromolecules are deposited or adsorbed onto the membrane pores or onto a membrane surface by physical and chemical interactions or mechanical action, which results in smaller or blocked membrane pores.

For the purposes of illustrating the present invention in detail, the invention is described
 10 below as a feed diffusing system separate from the membrane module. However, it will be appreciated that the feed diffusing system may be configured to be integral with the membrane module. Further, the system is specifically designed for submerged membrane systems. However, it may be configured for use in other membrane systems such as pressurized modules, including but not limited to low pressure membrane filtration systems. Further, the
 15 membrane module according to the present invention described below is a membrane module for treating water. However, it will be appreciated that the membrane module may be configured for use in a variety of application including treating wastewater.

FIG. 1 is a front schematic view of a feed diffusing system 10 for reducing membrane fouling in a membrane module 100 according to the invention. The membrane module 100
 20 comprises a membrane 110 disposed in a feed tank 120. The system 10 comprises a feed inlet 11 and a plurality of feed outlets 12, 14 arranged in a spaced apart arrangement adjacent to the membrane 110 based on a membrane surface area of the membrane 110. The feed inlet 11 may be operably coupled to a pump 1 for pumping feed water to the feed inlet 11, wherein the feed inlet 11 is in fluid communication with the plurality of feed outlets 12, 14.
 25 The plurality of feed outlets 12, 14 comprises a first nozzle 12 and a second nozzle 14. The first and second nozzles 12, 14 may be linearly adjustable in x and y directions relative to a surface area of the membrane 110. It will be appreciated that a number of feed outlets and its distribution is configurable based on the membrane surface area in order for the feed water to reach a membrane surface area for cleaning, and in view of an amount of energy required to
 30 pump the feed water to each of the feed outlets. For example, the feed diffusing system 10 may comprise a predetermined number of nozzles per unit area of the membrane.

The feed diffusing system 10 according to the present invention directs the feedwater into the feed tank through the one or more feed outlets 12, 14. The feedwater that comes out of the feed outlets 12, 14 at an average feed outlet velocity v greater than or equal to 1 m/s will result in shear stress on the membrane 110 that can dislodge the foulant and reduce the accumulation of foulant on the membrane 110.

Further, the system 10 may comprise a body 16 configured for positioning the first nozzle 12 and/or the second nozzle 14 adjacent to surfaces of the membrane 110. The body 16 may be configured for releasably attaching the first and second nozzles 12, 14. In addition, the body 16 may be configured to be slidable along a support 18 disposed in the feed tank 120 to position the first and second nozzles 12, 14 at opposite sides of the membrane 110, and different locations along a length of the membrane 110 in the y direction. It will be appreciated the support 18 may be characterized by any length such as for example equivalent to the length of the membrane 110 in the y direction, as long as it can enable the positioning of the first and second nozzles 12, 14 along the length of the membrane 110.

An advantage of the system 10 according to the present invention is that it enables optimized liquid flow patterns based on an arrangement of the feed outlets 12, 14 at locations determined based on a size of the membrane or a membrane surface area. Table 1 below shows the correlation between the location of the feed outlets 12, 14 relative to the membrane 110 based on the feed diffusing system 10.

Table 1

Feed Diffusing System	FIG. 1
Membrane Specifications	Polypropylene Ultrafiltration
Membrane Dimensions	0.45 millimetres (Outer Diameter)
Membrane Surface Area	8 square meters
Membrane Length	40 centimetres
Distance of Feed Outlet 12, 14 from Top of the Membrane	41 millimetres
Feed outlet opening dimensions	Width = 2 millimetres Length = 18.9 millimetres

In particular, applying feed water at a feed outlet velocity greater than or equal to 1 m/s improves hydrodynamics and solids distribution in the area surrounding the tightly packed

membranes in a membrane module or a membrane system. The average feed outlet velocity, v may be in the range of 1 m/s to from 100 m/s, preferably from 1 m/s to 50 m/s, more preferably from 1 m/s to 10 m/s. A technical effect of limiting an upper limit of the average feed outlet velocity, v is to optimize a shear stress on the membrane for cleaning while minimizing the risks of membrane damage.

As such, the system 10 according to the present invention mitigates fouling effectively without the problems of high energy consumption and risk of membrane damage associated with existing aeration practices. Consequently, the system 10 offers a more efficient, durable, and cost-effective solution, making it beneficial for applications like industrial and municipal wastewater treatment where such submerged membrane systems are prevalently used but such use is often hindered by fouling-related challenges.

The feed diffusing system may comprise one or more feed outlets, wherein each one of the one or more feed outlets may be arranged at a tilting angle relative to a surface of the membrane, wherein the tilting angle is in a range from 0 to 180 degrees.

A technical effect of having the one or more feed outlets arranged at a tilting angle is demonstrated in the Examples with reference to FIG. 13 described hereinafter.

FIG. 2 is a front schematic view of an alternative design of a feed diffusing system 20 for reducing membrane fouling according to the invention. FIG. 3 is a bottom view of the feed diffusing system 20. The system 20 comprises a feed inlet 22 and a feed outlet 26 and differs from the system 10 in that the system 20 comprises a body 24 wherein the feed inlet 22 and the feed outlet 26 are integral with the body 24. In particular, the body 24 comprises an open end defining the feed inlet 22, and a closed end 23 opposite to the feed inlet 22. The feed outlet 26 is disposed along the length of the body 24 on a side 27 of the body 24.

FIG. 4 is a side schematic view of the feed diffusing system 20 in a membrane module 200 according to the invention. The membrane module 200 comprises a membrane 210 disposed in a feed tank 220. The system 20 is disposed above the membrane 110 such that the feed outlet 26 is arranged adjacent to the top of the membrane 210 and proximate to a membrane surface 211 of the membrane 210. Upon pumping of the feed water through a pump 2 to the feed diffusing system 20, the feed water is diffused through the feed outlet 26 and sprayed to at least a part of the membrane surface 211 in the form of a jet curtain or in a direction as illustrated by the arrows.

FIG. 5 is a front perspective schematic view of an alternative design of a feed diffusing system 30 for reducing membrane fouling according to the invention. The feed diffusing system 30 comprises a body 34 having a longitudinal axis 31, wherein one end of the body 34

comprises an opening defining a feed inlet 32, and an opposite end of the body 34 is a closed end. The feed diffusing system 30 further comprises a plurality of feed outlets 36, 38 disposed in a spaced apart arrangement on the body 34 along the longitudinal axis 31. The plurality of feed outlets 36, 38 may be arranged in a spaced apart arrangement adjacent to the membrane in the membrane module based on a membrane area.

Without wishing to be bound by theory, the distance between the feed outlets may be configured by determining an optimum number of feed outlets based on the membrane area. In particular, if the feed outlets are spaced too far apart, a cleaning effect may be reduced as too much of the membrane area will not be cleaned because the water cannot reach it. In contrast, if the feed outlets are too close together, too energy required to pump water to each of the feed outlets.

The feed inlet 32 may be characterized by an inlet cross sectional area (A_{in}), and each of the plurality of feed outlets 36, 38 may be characterized by an outlet cross sectional area (A_{out}) wherein A_{in} is greater than or equal to A_{out} . As shown in FIG. 5, the first feed outlet 36 is proximal to the feed inlet 32 and the second feed outlet 38 is distal from the feed inlet 32. The first feed outlet 36 may be characterized by a first feed outlet cross sectional area, A_{out1} , and the second feed outlet 38 may be characterized by a second feed outlet cross sectional area, A_{out2} , wherein A_{out1} is greater than or equal to A_{out2} . A technical effect of having A_{out1} is greater than or equal to A_{out2} is, when the feed diffusing system 30 is used in a membrane module comprising a plurality of membranes such as for example, membrane curtains, having a plurality of feed outlets of different cross sectional areas enable more even distribution of flow of the feed mixture to the membranes.

FIG. 6 is a cross section schematic view of the feed diffusing system 30. Specifically, the first feed outlet 36 includes a first feed outlet transverse axis 37 and the second feed outlet 38 includes a second feed outlet transverse axis 39. The feed diffusing system 30 has a center plane CP and the longitudinal axis 31 in the center plane CP. An angle between the center plane CP and one of the first feed outlet transverse axis 37 and the second feed outlet transverse axis 39 may be from 1 degrees to 90 degrees, preferably from 10 degrees to 80 degrees, more preferably from 20 degrees to 60 degrees.

FIG. 7 is a front perspective view of a plurality of feed diffusing systems 30 disposed in a membrane module 300 according to the invention. The membrane module 300 comprises a feed tank 301 and a membrane 302 disposed in the feed tank 301. Two feed diffusing systems 30 are arranged on one side of the membrane 302, and another two feed diffusing systems 30

are arranged on the opposite side of the membrane 302. This enables the membrane surfaces on both sides of the membrane 302 to be cleaned simultaneously.

FIG. 8 is a side schematic view of a plurality of feed diffusing systems 30 as shown in FIG. 7 in the membrane module 300. The membrane module 300 is connected to a pump 50 operably connected to each of the feed diffusing systems 30 and a feed tank 60 comprising a feed mixture 62. In use, the pump 50 pumps the feed mixture 62 to the feed diffusing systems 30 so as to diffuse the feed mixture 62 to the membrane 302 in the form of jets as illustrated by the arrows.

A membrane module according to the present invention may comprise a hybrid operation of both aerating and feed diffusing functions as described hereinafter. In particular, a membrane module may consist of a feed diffusing system for reducing membrane fouling. Preferably, the feed diffusing system may be placed at the bottom of a membrane tank of the membrane module and adjacent to the bottom of the membrane. Without wishing to be bound by theory, such placement of the feed diffusing system may increase the jetting velocity and provide more cleaning effect.

Alternatively, a membrane module may comprise a feed diffusing system and an aerator to define a hybrid system for reducing membrane fouling. Preferably, the aerator comprising aeration nozzles may be placed at the bottom of the membrane tank so that air rises upwards in water. Preferably, the feed diffusing system may be placed at the top of the membrane and the feed outlets are arranged in an opposed direction to the aeration nozzles to allow the feed outlets to diffuse the feed water in the form of jets downwards to the bottom of the membrane. This is to provide an optimal cleaning effect.

FIG. 9 is a front schematic drawing of a membrane module 400 according to the present invention comprising a membrane 401 disposed in a feed tank 402 and a feed diffusing system 40. The feed diffusing system 40 is similar in design to the feed diffusing system 10 and differs in that first and second feed outlets 42, 44 are disposed adjacent to the bottom 403 of the membrane 401. An aerator 404 is disposed at the bottom of the feed tank 402 adjacent to the first and second feed outlets 42, 44. The membrane 401 and feed outlets 42, 44 are arranged such that the first and second feed outlets 42, 44 are spaced apart by the membrane 401. Specifically, the first feed outlet 42 is positioned proximal to a side 401A of the membrane 401 whereas the second feed outlet 44 is positioned on an opposite side 401B of the membrane 401.

FIG. 10 is a front schematic drawing of an alternative design of a membrane module 500 according to the present invention comprising a membrane 501 disposed in a feed tank 502 and a feed diffusing system 50. The feed diffusing system 50 is similar in design to the feed

diffusing system 40 and differs in that the feed outlets 52, 54 are disposed adjacent to the top 503 of the membrane 501 and an aerator 504 is adjacent to the bottom of the membrane 501 and opposite to the feed outlets 52, 54.

The present invention relates to a membrane module for two-phase separation of a feed mixture, wherein the module comprises:

a reservoir;

a header;

a membrane (50) disposed in the reservoir, wherein the membrane is releasably attached to the header at the top of the membrane, and the membrane comprises a bottom;

at least one feed diffusing system according to any one of claims 1 to 6 arranged in the reservoir in fluid communication with the membrane,

wherein each of one or more the feed outlets is proximal to at least one membrane surface.

The membrane module may further comprise a pump; and a programmable logic controller (PLC) operably connected to the pump. The feed inlet is connected to the pump. The PLC may be configured to provide a pulsed feed mixture flow in the reservoir through the feed inlet to the one or more feed outlets, such that the pulsed feed mixture flow moves past the at least one membrane surface to dislodge fouling materials therefrom.

The present invention relates to a method of reducing membrane fouling in a membrane system for phase separation of a feed mixture. The method comprises:

(a) providing a membrane system in an environment, wherein at least one surface of the membrane comprises fouling material disposed thereon;

(b) providing a feed mixture into the environment through a feed inlet; and

(c) diffusing the feed mixture through one or more feed outlets to the membrane system for reducing membrane fouling from at least one membrane surface of a membrane in the membrane system, at an average feed outlet velocity, v , of 1 m/s to 100 m/s.

Step (b) may comprises providing a pulsed feed mixture in the reservoir according to the Pulsed Test Method specified within. Specifically, where a membrane module is used in a water treatment system, if the membrane module comprises a plurality of membrane curtains, turbidity in between curtains may be high without implementing the above method according to the present invention. In contrast, when the above method is applied in a water treatment system, the turbidity will be lower.

It will be appreciated that for a feed diffusing system, a membrane module and method according to the present invention, the feed mixture may be selected from the group consisting of: a solid-liquid phase system, a liquid-gas phase system, a liquid-liquid system.

5 The following examples are intended to more fully illustrate the present invention and are not to be construed as limitations of the present invention since many variations thereof are possible without departing from the scope of the present invention. All parts, percentages and ratios used herein are expressed as percent weight unless otherwise specified.

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TEST EQUIPMENT/MATERIALS

Equipment and materials used for each of the Examples set forth herein are listed in Table 2 below and described hereinafter with reference to FIG. 11. Comparative and Inventive Samples used for testing in the Examples are described under the respective Examples.

Table 2 – Specifications of Test Equipment/Materials

Equipment/Materials	Technical Specifications
Membrane tank	38 cm (B) X 17 cm (W) x 80 cm (H)
Membrane module	polypropylene (PP) hollow fiber membranes, 600 Fibres, 40 cm long Total membrane area = 0.34 m ²
Feed water	Bentonite solution at turbidity of 100 +/- 20 NTU
Feed diffuser system (FIG. 5)	Diameter = 28 mm Length = 470 mm Size of Feed inlet = 28 mm Number of Feed outlets = 4 per feeder. Size of Feed outlets = 14, 12.5, 11.5, 10.5mm Pump inlet pressure to the feeders = 1 bar
Feed diffuser system (FIG. 1)	Slit nozzle size = 2mm by 18.9 mm Nozzle position = top of the membrane, angled 0 to 50 deg to the membrane Number of nozzles = 2 Flow rate tested per nozzle = 200 to 400 LPH

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EXPERIMENTAL SET-UP

An experimental setup 130 for conducting experiments for the Examples is detailed in Figure 11. The experimental set-up comprises six acrylic tanks 131, each tank 131 having a length (L), width (W), and height (H) of 38 cm x 17cm x 80 cm, L x W x H. Feed water is provided to the tanks 131 via a central feed water reservoir 133 having a depth, D of 44cm and a height, H of 68cm. A circulating over-head loop pipe system 132 withdraws feed water from the central feed water reservoir 133, circulates it and discharges it back to the central feed water reservoir 133. Above each of the six tanks 131, there is an outlet from the circulating over-head loop pipe system 132 for discharging water to the respective tank via a 2-way normally-closed solenoid On/Off valve (Brand: Airtac Model: 2P0250-08, hereinafter “solenoid valve”, not shown) which receives its signal from an electronic water level sensor (not shown) installed at the bottom of the feed tank 131.

When the water level sensor reads a present value (PV) less than the set value (SV), a Proportional-Integral-Derivative (PID) controller 139 gives a signal to the solenoid valve located overhead of the tank 131 to open, discharging feed water into the tank 131 until the PV reaches the SV, then the PID will turn off the solenoid valve. This allows the feed water level to be maintained at a prescribed SV, allowing the pressure acting on a membrane system to be maintained throughout the test.

The tanks 131 may be equipped with an air injection system 137 and a feed diffusing system 138 according to the present invention. Aeration is achieved via two compressors that deliver compressed air to three-pressure vessels 134 with a preset value of 1 bar gage adjusted via pressure relief valves installed at each vessel. Pressurised air flows via pipes to two air injection systems 137 (one for each tank) which consist of a manifold that distributes air to five flexible 4mm ID rubber hoses/tubing, where the compressed air flow rate is controlled via five mass flow controllers (Brand: ASERT MFC Model: AST10-ABCM with a maximum flow of 50 SLM). The feed diffusing system 138 may be driven by separate pumps to each diffuser nozzle, capable of providing maximum of 400 to 600 LPH of feed water flow rate depending on nozzle configuration.

A membrane bundle 140 may be mounted vertically within the tank 131. Due to hydrostatic pressure from the weight of water, a pressure gradient is created across the length of the membrane, resulting in membrane filtration and permeate water to flow out through a permeate outlet 136.

To measure the permeate, weighing scales 135 (Brand: WANT, Model: WT60001KFP with precision of 0.1 g and maximum allowable weight of 6 kg) are arranged below the tanks 131. Permeate flows from the lower part of the membrane 140 and drops into the collecting containers, placed on the weighing scales 135, via 4mm ID rubber tubing. On each permeate line, a solenoid On/Off valve is installed which can be manually turned On/Off or automatically during the preset cycle.

LabVIEW software (commercially available from National Instruments) is used for controlling all parameters such as water level in the tanks, air flow rate through each nozzle, cycle time, as well as for data acquisition. Water flow rate to each feed diffuser nozzle is controlled by a manual water flow valve integrated with a flow meter.

In the experiments for all the Examples except for Example VII, fine particulate bentonite is used as the water pollutant for testing the hollow-fibre membrane bundles instead of using actual surface water feed for the sake of experimental consistency.

An infrared turbidity meter (Brand: Lovibond Model: TB211 IR Portable Turbidimeter, Range: 0.01 - 1100 NTU) is used for measuring the turbidity of the feed water at the start of each test and the permeate turbidity during permeate collection.

TEST METHODS/CALCULATIONS

A. CONTINUOUS TEST METHOD

A continuous test method for evaluating a technical effect of diffusing feed mixture to the membrane is performed according to the following steps:

1. Raw feed water from a nearby river with turbidity level of 30 to 300 NTU is collected into the membrane tank. The membrane is connected to a low pressure pump at 0.05 to 0.3 bar to increase the outflow rate.
2. The feed diffusing pipe is then positioned around the membranes with the outlet pointed towards the membrane. A pump is used to pump feed water through the feed diffusing system at a fixed flow rate through the experiment.
3. The amount of collected permeate is weighed and recorded every hour.
4. A typical experiment is set to run for 3 hours.

B. PULSED TEST METHOD

This test method is to evaluate a technical effect of diffusing a pulsed feed mixture to the membrane. The steps for performing the above test method are:

1. 16.3 g of finely ground bentonite is mixed with water in each tank separately to the target contamination/concentration level range of 120 ± 10 NTU or 0.4 g/L. Water level is set to a height of 70 cm.
2. The operation regime is set in LabVIEW where permeate is turned ON for x minutes and relaxed (termed relaxation protocol) for y min (where the permeate solenoid valve turned off), where simultaneously aeration will also then run during this y-minute period. The simultaneous operation of relaxation and aeration protocols enables optimized efficiency as the combined relaxation and shearing effects can remove foulant more effectively relative to when the relaxation protocol and the aeration protocol are individually employed. This is because foulants are loosened from the membrane during relaxation, enabling shearing forces (when the to remove these foulants from the membrane surface more effectively.
3. At the end of each hour, the collected permeate is weighed and recorded. The permeate turbidity is measured to ensure that the turbidity is less than 1 NTU to ensure no leakages in any of the membrane fibres.
4. A typical experiment is set to run for 6 hours.

An application of the Pulsed Test Method is illustrated in FIG. 12 for the case of x=55min and y=5min, wherein the permeate is turned ON for 55 minutes (x) and turned off for 5 minutes (y).

To measure the membrane performance, permeability (K) is calculated using Equation 1 to Equation 3. Membrane performance is measured in terms of permeability drop (ΔK) of the membrane per hour of operation, given by Equation 4.

$$K = \frac{V_{Permeate}}{A_{membrane} \times t \times TMP}$$

Equation 1

$$A_{membrane} = N_{Fibres} \times \pi \times D \times L$$

Equation 2

$$TMP = \rho_{liquid} \times g \times \Delta H \times 10^{-5}$$

Equation 3

$$\Delta K = \frac{K_{start} - K_{end}}{Total\ elapsed\ time}$$

Equation 4

The abbreviations used in the equations are described in Table

Table 3 - Abbreviations used in above Equations 1 to 4

Symbol/abbreviation	Quantity	Unit
K	Permeability	$\frac{L}{m^2 \cdot hr \cdot bar} (LMBH)$
$V_{Permeate}$	Volume of collected permeate	L
$A_{membrane}$	Membrane total surface area	m^2
t	Time interval	Hr
TMP	Transmembrane pressure	Bar
N_{Fibres}	Total number of fibre strands in a membrane bundle	—
D	Diameter of one fibre (0.45 mm)	mm
L	Full length of a fibre (40cm)	cm
ρ_{liquid}	Bentonite-water equivalent density (approximately $1005 \frac{kg}{m^3}$)	$\frac{kg}{m^3}$
g	Acceleration due to gravity ($9.81 \frac{m}{s^2}$)	$\frac{m}{s^2}$
ΔH	Elevation difference between water level in the tank and the permeate tubing outlet (1.2m in our experimental setup)	m
ΔK	Permeability drop	$LMBH/H$
K_{start}	Permeability measured at the start of the experiment	$LMBH$
K_{end}	Permeability measured at the end of the experiment	$LMBH$

EXAMPLES

The following Examples are conducted according to standard techniques and methods used in fluid and hydrodynamics measurements known to a person skilled in the art and/or the Test Methods/Calculations described hereinbefore to illustrate the embodiments of the present invention.

EXAMPLE I

The following samples in Table 4 are evaluated according to the Pulsed Test Method described hereinbefore. FIG. 13 is a graph plotting the normalized permeability against elapsed time for a feed diffusing system according to FIG. 1 with feed outlets mounted at a tilting angle and a feed diffusing system according to FIG. 1 with feed outlets that are not mounted at an angle. The normalized permeability data is summarised in Table 4 below.

Table 4 – Normalized Permeability Data

Sample	Feed Tank	Permeability Drop (LMBH/H)	Count (No. of times experiment is repeated)	Std (Standard Deviation of Permeability Drop)
Comparative Sample 1	Base line – no feed diffusing system	3.62	11	1.94
Inventive Sample A	With feed diffusing system of FIG. 1 (feed diffusing outlets at a tilting angle of 50 degrees)	0.66	3	0.45
Inventive Sample B	With feed diffusing system of FIG. 1 (feed outlets are configured in a straight)	0.66	3	0.34

Sample	Feed Tank	Permeability Drop (LMBH/H)	Count (No. of times experiment is repeated)	Std (Standard Deviation of Permeability Drop)
	orientation, i.e. tilting angle = 0 degrees)			

The data for Inventive Samples A and B show that the permeability drop over time is lower (only 0.66 LPBH per hour) when jetting is activated at a mass flow rate of 400 LPH for both nozzles at a feed outlet velocity of 3.7 m/s. In contrast, Comparative Sample 1 has a permeability drop of 3.62 LMBH per hour. The data also shows that the feed outlets can be mounted in a straight or angled orientation to obtain similar effects of the reduction in fouling.

EXAMPLE II

The following samples in Table 5 are evaluated according to the Pulsed Test Method. FIG. 14 is a graph plotting a permeability drop of feed mixture in a membrane module with no feed diffusing system (Comparative Sample 1), and permeability drop in a membrane module having a feed diffusing system according to FIG. 1 with angled feed outlets at different mass flow rates (Inventive Samples C, D, E). Table 5 below contains the data used to plot the graph of FIG. 14.

Table 5

Sample	Feed Tank	Mass Flow Rate, Q, LPH	Feed Outlet Velocity, v (m/s)	Jetting and Aeration Interval	Permeability Drop (LMBH/H)
Comparative Sample 1	Base line – no feed diffusing system	NA	NA	None	3.6
Inventive Sample C	With feed diffusing system of FIG.	400	3.7	Every 55 minutes, for 5 mins	0.66

Sample	Feed Tank	Mass Flow Rate, Q, LPH	Feed Outlet Velocity, v (m/s)	Jetting and Aeration Interval	Permeability Drop (LMBH/H)
	1 (each of the feed diffusing outlets having a size of 2 mm)				
Inventive Sample D	With feed diffusing system of FIG. 1 (each of the feed diffusing outlets having a size of 2 mm)	300	2.8	Every 57 mins, for 3 minutes	0.94
Inventive Sample E	With feed diffusing system of FIG. 1 (each of the feed diffusing outlets having a size of 2 mm)	200	1.9	Every 59 minutes, for 1 minute	1.90

In particular, the data in Table 5 illustrates that increasing outlet mass flow rate or velocity at the one or more feed outlets of the feed diffusing system results in a lower permeability drop in the membrane. In particular, a permeability drop for each of the Inventive Samples C, D, E is lower (ranging from 0.66 to 1.90 LMBH/H) compared to Comparative Sample 2 which has a higher permeability drop of 3.6 LMBH/H.

EXAMPLE III

The following samples in Table 6 are evaluated according to the Pulsed Test Method. The results in Table 6 below and FIG. 15 are based on diffusing feed water into the membrane module in the form of water jets which are activated for a predetermined interval after a fixed

period of low pressure filtration. Specifically, FIG. 15 is a graph plotting a permeability drop of feed mixture in a membrane module with no feed diffusing system (Comparative Sample 1), and permeability drop in three different membrane modules, each having a feed diffusing system according to FIG. 1 with angled feed outlets with different jetting intervals of the feed mixture through the feed inlet (Inventive Sample F, G, H).

An aerator is provided at the bottom of the membrane in the membrane module for each of the Inventive Samples F, G, H to provide aeration at an hourly frequency. Table 6 below contains the data used to plot the graph of FIG. 15 wherein the total duration of experiments for Inventive Samples F, G, H is 5 hours.

Table 6

Sample	Feed Tank	Mass Flow Rate, Q, LPH	Feed Outlet Velocity, v (m/s)	Jetting and Aeration Interval	Permeability Drop (LMBH/H)
Comparative Sample 1	Base line – no feed diffusing system			None	3.6
Inventive Sample F	With feed diffusing system of FIG. 1 (each of the feed diffusing outlets mounted at a tilting angle of 50 deg, and having a size of 2 mm)	200 LPH for water jet and 1 LPM for air nozzle	1.9	Every 55 minutes, for 5 mins	1.03

Sample	Feed Tank	Mass Flow Rate, Q, LPH	Feed Outlet Velocity, v (m/s)	Jetting and Aeration Interval	Permeability Drop (LMBH/H)
Inventive Sample G	With feed diffusing system of FIG. 1 (each of the feed diffusing outlets mounted at a tilting angle of 50 deg, and having a size of 2 mm)	200 LPH for water jet and 1 LPM for air nozzle	1.9	Every 57 mins, for 3 minutes	0.42
Inventive Sample H	With feed diffusing system of FIG. 1 (each of the feed diffusing outlets mounted at a tilting angle of 50 deg, and having a size of 2 mm)	200 LPH for water jet and 1 LPM for air nozzle	1.9	Every 59 minutes, for 1 minute	1.20

The above results show that there is a change in permeability drop when pulsed feed water is directed to the membrane at different intermittent jetting durations.

EXAMPLE IV

The following samples in Table 7 are evaluated according to the Pulsed Test Method. A membrane module according to the present invention may comprise a hybrid operation of both aerating and feed diffusing functions as described hereinafter.

- 5 Table 7 below sets out the parameters and results of Comparative Sample 4 and Inventive Samples I and J. FIG. 16 is a corresponding graph of Table 7 plotting the permeability drop for Inventive Sample I and Inventive Sample J. Inventive Sample I is designed based on the membrane module of FIG. 9 and Inventive Sample J is designed based on the membrane module of FIG. 10. The jetting and aeration intervals of Inventive Samples I and J as described
- 10 in Table 7 below is illustrated in FIG. 12 for the case of $x=55\text{min}$ and $y=5\text{min}$.

Table 7

Sample	Feed Tank	Mass Flow Rate, Q, LPH	Feed Outlet Velocity, v (m/s)	Orientation of Feed Outlets	Jetting and Aeration Interval	Permeability Drop (LMBH/H)
Comparative Sample 4	Base line – no feed diffusing system			NA	NA	3.6
Inventive Sample I	FIG. 9	200 LPH for water jet and 1 LPM for air nozzle	1.9	50 deg	x = 55 minutes, y = 5 mins	1.03
Inventive Sample J	FIG. 10	200 LPH for water jet and 1 LPM for air nozzle	1.9	50 deg	x = 55 minutes, y = 5 mins	0.74

As shown in FIG. 16, the configuration of Inventive Sample O, i.e. having a feed diffusing system opposed to an aerator enables a lower reduction of loss of permeability relative to Inventive Sample N.

EXAMPLE V

5 Inventive Sample K is evaluated according to standard computational fluid dynamics (CFD) computation methods. FIG. 17 is a graph plotting a stress distribution of feed outlets of a feed diffusing system according to the present invention (Inventive Sample K). Inventive Sample K is a feed diffusing system 70 having a substantially similar design to the feed diffusing system 30, i.e. having a feed inlet 72 and a plurality of feed outlets 73, 74, 75, 76
10 integral in a body 78.

Inventive Sample K differs from the feed diffusing system 30 in that Inventive Sample K comprises each of the feed outlets 73, 74, 75, 76 is characterized by a feed outlet cross sectional area and a wall shear contour force illustrated in Table 8 below.

Table 8

Feed Outlet #	Shape	Diameter (millimetres)	Wall Shear Contour Shear Stress (Pa)
73	Circle	12	50
74	Circle	12	59
75	Circle	12	65
76	Circle	12	79

15

As shown in FIG. 17, the feed outlets 76 further from the feed inlet 72 have a higher wall shear contour shear stress relative to the feed outlets 73 nearer to the feed inlet 72.

EXAMPLE VI

20 FIG. 18 is a graph plotting a stress distribution of feed outlets of a feed diffusing system according to the present invention according to the present invention (Inventive Sample L). Inventive Sample L is a feed diffusing system 80 having a substantially similar design to the feed diffusing system 30. In particular, the feed diffusing system 80 comprises a feed inlet 82 and a plurality of feed outlets 83, 84, 85, 86 disposed on a body 88. Each of feed outlets is

characterized by a different feed outlet cross sectional area and a wall shear contour force illustrated in Table 9 below.

Table 9

Feed Outlet #	Shape	Diameter (millimetres)	Wall Shear Contour Shear Stress (Pa)
83	Circle	14	65
84	Circle	12.5	70
85	Circle	11.5	70
86	Circle	10.5	70

Table 9 shows that a feed outlet 83 of a larger diameter closer to the feed inlet 82 relative to a diameter of the feed outlet 86 further from the feed inlet 82 creates a more uniform distribution of the flow velocities out of the feed outlets 83, 84, 85, 86 thereby resulting in a more uniform stress distribution of feed water surrounding the membrane.

EXAMPLE VII

Inventive Samples M-O below are evaluated using river feed water having a turbidity of 300 to 400 NTU. The following samples are evaluated to determine a cleaning efficacy:

1. Membrane module comprising two feed diffusing systems (Inventive Sample M) at a mass flow rate, Q1 of 140 LPM
2. Membrane module comprising two feed diffusing systems (Inventive Sample N) at a mass flow rate, Q2 of 70 LPM
3. Membrane module comprising four feed diffusing systems (Inventive Sample O) at a mass flow rate, Q3 of 140 LPM.

Each of the feed diffusing systems is substantially similar in design to the feed diffusing system 30 of FIG. 5. The configuration of Inventive Sample O is based on FIG. 7.

FIG. 19 is a graph plotting a stress distribution of a membrane module comprising four feed diffusing systems according to the present invention. As shown in FIG. 19, use of four feed diffusing systems in a membrane module based on Inventive Sample O generates a more uniform shear stress distribution relative to two feed diffusing systems in a membrane module at the same mass flow rate of 140 LPM.

FIGS. 20 to 22 are histogram graphs illustrating the shear stress distribution on a membrane curtain in a water treatment system comprising Inventive Sample M, a water treatment system comprising Inventive Sample N, and a water treatment system comprising Inventive Sample O. Based on FIGS. 20 and 22, the differences in shear stress distribution on different positions on the membrane curtain is less in Inventive Sample O relative to Inventive Sample M. As such, use of Inventive Sample O demonstrates a more uniform shear stress distribution on the membrane curtain and consequently enables effective cleaning of the membrane curtain. A cleaning efficacy is demonstrated through comparing a drop in the permeability for each of the Inventive Samples M, N and O. Table 10 below summarizes the correlation between the drop in the permeability and shear stress data for Inventive Samples M, N and O which are obtained according to the Continuous Test Method.

Table 10 – Summary of Shear Stress Statistics

Parameters	Inventive Sample M Q1 = 140 LPM	Inventive Sample N Q2 = 70 LPM	Inventive Sample O Q3 = 140 LPM
Loss in Permeability, LMBH/H (Comparative Sample- No feed diffusing system = 15.8)	7.24	10.9	4.2
Max Shear Stress, Pa	7.48	2.15	2.26
Min Shear Stress, Pa	0.21	0.05	0.01
Average Shear Stress, Pa	2.21	0.63	0.95
Sum Shear Stress	2282.17	635.442	1238.43
% Area below (0.2)	48.97	42.88	15.16
% Area below (0.4)	76.25	75.03	51.16
% Area below (0.6)	88.81	89.34	80.31
% Area below (0.8)	96.19	96.34	94.91

The reduction in the loss of permeability for Inventive Sample O shows that a technical effect of having a uniform shear stress enables a lower loss of permeability of 4.2 relative to

Inventive Sample M. A lower loss of permeability of 4.2 means that there is less membrane fouling as the solids and/or precipitate are in the feed mixture in the feed tank.

Overall, the above results of the reduced loss of permeability of membranes with inventive feed diffusing systems according to the present invention show that having one or more feed outlets diffusing feed mixture at an average feed outlet velocity v greater than or equal to 1 m/s according to the present invention achieves a technical effect of reducing fouling on a membrane surface of a membrane disposed in a membrane module for treating water. Consequently, by reducing membrane fouling and minimizing risk of membrane damage at the same time, there is reduced energy consumption and membrane life span may be increased thereby reducing operational and maintenance costs of membrane based water treatment systems.

The dimensions and values disclosed herein are not to be understood as being strictly limited to the exact numerical values recited. Instead, unless otherwise specified, each such dimension is intended to mean both the recited value and a functionally equivalent range surrounding that value. For example, a dimension disclosed as “40 mm” is intended to mean “about 40 mm.”

Every document cited herein, including any cross referenced or related patent or application and any patent application or patent to which this application claims priority or benefit thereof, is hereby incorporated herein by reference in its entirety unless expressly excluded or otherwise limited. The citation of any document is not an admission that it is prior art with respect to any invention disclosed or claimed herein or that it alone, or in any combination with any other reference or references, teaches, suggests or discloses any such invention. Further, to the extent that any meaning or definition of a term in this document conflicts with any meaning or definition of the same term in a document incorporated by reference, the meaning or definition assigned to that term in this document shall govern.

While particular embodiments of the present invention have been illustrated and described, it would be obvious to those skilled in the art that various other changes and modifications can be made without departing from the spirit and scope of the invention. It is therefore intended to cover in the appended claims all such changes and modifications that are within the scope of this invention.

CLAIMS

What is claimed is:

- 5 1. A feed diffusing system (10, 20, 30, 40, 50, 70, 80) for reducing membrane fouling in a membrane module (100, 200, 300, 400, 500) disposed in an environment, the system (10, 20, 30, 40, 50, 70, 80) comprising:
 - a feed inlet (11, 22, 32, 72, 82) for receiving a feed mixture;
 - one or more feed outlets (12, 14, 26, 36, 38, 42, 44, 52, 54, 73-76, 83-86) configured to
 - 10 be in fluid communication with the feed inlet (11, 22, 32, 72, 82) and for diffusing the feed mixture to a membrane disposed in an environment;
 - wherein the one or more feed outlets (12, 14, 26, 36, 38, 42, 44, 52, 54, 73-76, 83-86) are arranged adjacent to a membrane in a membrane module for diffusing the feed mixture to the membrane at an average feed outlet velocity, v in the range of 1 m/s to 10 m/s.
- 15 2. The system (10, 20, 30, 40, 50, 70, 80) according to claim 1, wherein each of the one or more feed outlets (12, 14, 26, 36, 38, 42, 44, 52, 54, 73-76, 83-86) is arranged at a tilting angle relative to a longitudinal axis of the membrane, wherein the tilting angle is in a range from 0 to 180 degrees.
- 20 3. The system (10, 20, 30, 40, 50, 70, 80) according to any one of the preceding claims, wherein the feed inlet (11, 22, 32, 72, 82) is characterized by an inlet cross sectional area (A_{in}), and each of the one or more feed outlets (12, 14, 26, 36, 38, 42, 44, 52, 54, 73-76, 83-86) is characterized by an outlet cross sectional area (A_{out}) wherein A_{in} is greater than or equal to A_{out} .
- 25 4. The system (10, 30, 40, 50, 70, 80) according to any one of the preceding claims wherein the system (10, 30, 40, 50, 70, 80) comprises a plurality of feed outlets (12, 14, 36, 38, 42, 44, 52, 54, 73-76, 83-86) arranged in a spaced apart arrangement adjacent to the membrane in the membrane module based on a membrane area.
- 30 5. The system (30, 80) according to claim 4, wherein the plurality of feed outlets (36, 38, 83-86) comprise a first feed outlet (36, 83) proximal to the feed inlet (32, 82) and a second feed outlet (38, 86) distal from the feed inlet (32, 82), wherein the first feed outlet (36, 83) is characterized by a first feed outlet cross sectional area (A_{out1}), wherein the second feed outlet

(38, 86) is characterized by a second feed outlet cross sectional area (A_{out2}), wherein A_{out1} is greater than or equal to A_{out2} .

6. The system (30, 80) according to any one of the preceding claims, wherein the feed mixture is selected from the group consisting of: a solid-liquid phase system, a liquid-gas phase system, a liquid-liquid system.

7. A membrane module (100, 200, 300, 400, 500) for two-phase separation of a feed mixture, wherein the system comprises:

a reservoir;

a header;

a membrane (50) disposed in the reservoir, wherein the membrane is releasably attached to the header at the top of the membrane, and the membrane comprises a bottom;

at least one feed diffusing system according to a feed diffusing system arranged in the reservoir in fluid communication with the membrane,

the feed diffusing system (10, 20, 30, 40, 50, 70, 80) comprising:

a feed inlet (11, 22, 32, 72, 82) for receiving a feed mixture;

one or more feed outlets (12, 14, 26, 36, 38, 42, 44, 52, 54, 73-76, 83-86) configured to be in fluid communication with the feed inlet (11, 22, 32, 72, 82) and for diffusing the feed mixture to the membrane;

wherein the one or more feed outlets (12, 14, 26, 36, 38, 42, 44, 52, 54, 73-76, 83-86) are arranged adjacent to the membrane for diffusing the feed mixture to the membrane at an average feed outlet velocity, v in the range of 1 m/s to 10 m/s,

wherein each of one or more the feed outlets is proximal to at least one membrane surface.

8. The module according to claim 7, further comprising a pump; and a programmable logic controller (PLC) operably connected to the pump; wherein the feed inlet is connected to the pump;

wherein the PLC is configured to provide a pulsed feed mixture flow in the reservoir through the feed inlet to the one or more feed outlets, such that the pulsed feed mixture flow moves past the at least one membrane surface to dislodge fouling materials therefrom.

9. The module according to any one of claims 7 to 8, wherein the at least one feed diffusing system is arranged adjacent to the bottom of the membrane.

10. The module according to any one of claims 8 to 9, wherein the at least one feed diffusing system is mounted at the header adjacent to the top of the membrane.

11. The module according to any one of claims 7 to 10, further comprising an aerator having an aeration outlet, wherein the aerator is located adjacent to the bottom of the membrane; wherein the aeration outlet is spaced apart from and opposite to the one or more feed outlets.

12. The module according to any one of claims 7 to 11, wherein the feed mixture is selected from the group consisting of: a solid-liquid phase system, a liquid-gas phase system, a liquid-liquid system.

13. A water treatment system comprising:
 at least one feed diffusing system for receiving a feed mixture;
 a membrane system in fluid connection with the at least one feed diffusing system for treating the feed mixture,
 the feed diffusing system (10, 20, 30, 40, 50, 70, 80) comprising:
 a feed inlet (11, 22, 32, 72, 82) for receiving a feed mixture;
 one or more feed outlets (12, 14, 26, 36, 38, 42, 44, 52, 54, 73-76, 83-86) configured to be in fluid communication with the feed inlet (11, 22, 32, 72, 82) and for diffusing the feed mixture to a membrane of the membrane system;
 wherein the one or more feed outlets (12, 14, 26, 36, 38, 42, 44, 52, 54, 73-76, 83-86) are arranged adjacent to the membrane for diffusing the feed mixture to the membrane at an average feed outlet velocity, v in the range of 1 m/s to 10 m/s,
 a pump; and
 a programmable logic controller (PLC) operably connected to the pump;
 wherein the feed inlet is connected to the pump;
 wherein the PLC is configured to provide a pulsed feed mixture flow in the reservoir through the feed inlet to the one or more feed outlets, such that the pulsed feed mixture flow moves past at least one membrane surface to dislodge fouling materials therefrom.

14. A method of reducing membrane fouling in a membrane system for phase separation of a feed mixture, the method comprising:

(a) providing a membrane system in an environment, wherein at least one surface of the membrane comprises fouling material disposed thereon;

5 (b) providing a feed mixture into the environment through a feed inlet; and

(c) diffusing the feed mixture through one or more feed outlets to the membrane system for reducing membrane fouling from at least one membrane surface of a membrane in the membrane system, at an average feed outlet velocity, v of 1 m/s to 10 m/s.

10 15. The method according to claim 14, wherein step (b) comprises providing a pulsed feed mixture in the reservoir according to the Pulsed Test Method specified within.