

MEMBRANE DISTILLATION SYSTEM AND WATER TRAP

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of priority to the Singapore application no. 10202260152Y filed November 22, 2022, the contents of which are hereby incorporated by reference in their entirety for all purposes.

TECHNICAL FIELD

[0002] This application relates to membrane distillation apparatus.

BACKGROUND

[0003] The membrane distillation process typically operates over a long duration, for example, 24 to 48 hours of continuous operation. Due to the long operational duration, wetting of the membranes, which is detrimental to the performance of the membrane and the MD process, occurs as a result of changes in the surface chemistry of the membrane material. Due to the accumulation of ions, surfactants, and other moieties, the membranes, which are initially hydrophobic, tend to be prone to the incursion of water. Other factors adversely affecting the MD process include the condensation on the permeate side (which is close to the membrane surface) due to heat loss, and the presence of larger pores that allow the liquid or mist to be transferred to the permeate side.

SUMMARY

[0004] In one aspect, a water trap suitable for use with a membrane distillation (MD) system. The water trap includes a vessel having an upper chamber and a lower chamber. The lower chamber is disposed below the upper chamber. The upper chamber and the lower chamber are in fluid

communication with one another. A feed inlet opening into the lower chamber is configured to bypass the upper chamber to provide a feed path from the MD system to the lower chamber. A vapour outlet leading from the upper chamber is configured to provide a vapour exit path out of the vessel. The vapour outlet is in fluid communication with the upper chamber above the feed inlet opening. A discharge outlet leading from the lower chamber is configured to provide a discharge path out of the vessel. The vessel is operable to output a vapour via the vapour outlet responsive to receiving a fluid mixture from the MD system via the feed inlet.

[0005] In another aspect, a system includes a membrane distillation (MD) module and a water trap. The MD module includes an MD module inlet, a membrane, and a MD module drain outlet. The water trap includes a vessel having an upper chamber and a lower chamber. The water trap includes a feed inlet that opens into the lower chamber, a vapour outlet that leads from the upper chamber, a pressure regulation channel in fluid communication with the vessel solely via the lower chamber, and a discharge outlet leading from the lower chamber. The lower chamber is disposed below the upper chamber. The upper chamber and the lower chamber are in fluid communication with one another. The feed inlet is configured to bypass the upper chamber to provide a feed path from the MD module drain outlet to the lower chamber. The feed path is operable to open/close by a feed inlet valve coupled to the feed inlet. The vapour outlet is configured to provide a vapour exit path out of the vessel. The vapour outlet is in fluid communication with the upper chamber above the feed inlet opening. The vapour exit path is operable to open/close by a vapour outlet valve coupled to the vapour outlet. The pressure regulation channel is operable to open/close by a pressure regulation valve coupled to the pressure regulation channel. The discharge outlet is configured to provide a discharge path out of the vessel. The discharge path is operable to open/close by a discharge valve coupled to the discharge outlet. The vessel is operable to output a

vapour via the vapour outlet responsive to receiving a fluid mixture from the MD module drain outlet via the feed inlet.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] Various embodiments of the present disclosure are described below with reference to the following drawings:

[0007] FIG. 1 is a schematic diagram of a MD system and a water trap according to embodiments of the present disclosure;

[0008] FIG. 2 is another schematic diagram of a MD system and a water trap according to various embodiments;

[0009] FIG. 3 is another schematic diagram of a MD system and a water trap according to an exemplary embodiment;

[0010] FIG. 4 is yet another schematic diagram of a MD system and a water trap according to various embodiments;

[0011] FIGs. 5A and 5B are schematic diagrams of the MD system of FIG. 4 in different process steps;

[0012] FIG. 6 is another schematic diagram of a MD system and a water trap according to another exemplary embodiment;

[0013] FIG. 7 is a schematic diagram illustrating the operation of the water trap according;

[0014] FIG. 8 is a flowchart of a MD method according to various embodiments of the invention;

[0015] FIG. 9 is a schematic diagram of a MD module according to various embodiments;

[0016] FIG. 10 is a schematic diagram of a prototype of the proposed MD system as used in experiments/simulations;

[0017] FIG. 11 is a plot of the respective concentrations of the feed and the permeate over time in the MD system of FIG. 10 without the water trap;

[0018] FIG. 12 is a plot of the respective concentrations of the feed and the permeate over time in the MD system of FIG. 10 with the water trap;

[0019] FIG. 13 is a plot of the permeate flowrate over time of the MD system of FIG. 10;

[0020] FIG. 14 compares the concentration factors of the feed in MD system of FIG. 10 ; and

[0021] FIG. 15 compares the efficiency of the MD system of FIG. 10.

DETAILED DESCRIPTION

[0022] The following detailed description is made with reference to the accompanying drawings, showing details and embodiments of the present disclosure for the purposes of illustration. Features that are described in the context of an embodiment may correspondingly be applicable to the same or similar features in the other embodiments, even if not explicitly described in these other embodiments. Additions and/or combinations and/or alternatives as described for a feature in the context of an embodiment may correspondingly be applicable to the same or similar feature in the other embodiments.

[0023] In the context of various embodiments, the articles “a”, “an” and “the” as used with regard to a feature or element include a reference to one or more of the features or elements.

[0024] In the context of various embodiments, the term “about” or “approximately” as applied to a numeric value encompasses the exact value and a reasonable variance as generally understood in the relevant technical field, e.g., within 10% of the specified value.

[0025] As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

[0026] For the sake of brevity, the term "vessel" is used herein in referring generically to a physical container capable of containing a fluid mixture. In the present disclosure, the terms "vessel", "container", "tank", and "enclosed structure" may be used interchangeably. a container" "a pressure tank", "a sealable container", "a pressure vessel", "an enclosable structure", etc., as will be understood from the context. In some instances, the vessel may be sealed and/or unsealed, or a pressure in the vessel may be varied.

[0027] The term "chamber" as used herein refers generically to a volumetric space, e.g., a contiguous volumetric space. For example, two physical containers may be connected in fluid communication with one another such that they form one contiguous space corresponding to one chamber. In another example, one physical container may be divided internally into multiple chambers.

[0028] As used herein, the terms "fluid mixture" and "mixture of fluid" may be used interchangeably in referring generically to a mixture including at least one of a liquid and a gas. For example, a fluid mixture may include a mixture of a liquid and a gas in substantially equal mass or volume. For example, a fluid mixture may include a mixture of a liquid and a gas with substantially more gas than liquid (in terms of mass or volume. For example, a fluid mixture may include a mixture of a liquid and a gas with substantially more liquid than gas (in terms of mass or volume. For example, a fluid mixture may include one or more materials in a liquid phase and/or one or more materials in a gaseous phase. For example, a fluid mixture may include one or more liquid materials, in which none of the material(s) is in a gaseous phase. For example, a fluid mixture may include one or more gaseous materials, in which none of the material(s) is in a liquid phase. In some instances, one or more materials may be present in a solid phase (e.g., in the form of solid particles) may be present in the fluid mixture without departing from the meaning of the term "fluid mixture" as used herein.

[0029] In a MD module or a MD process, a liquid feed is separated at a membrane into a gaseous permeate (distillate) and a liquid retentate (concentrate). The feed or feed solution may generally be in the form of a liquid solution with various concentrations of salts (e.g., mixed salts or solely one salt) and/or organic mixtures (e.g., some alcohols and/or esters mixtures with water). The solutions may include synthetic solutions, seawater, and/or brine solutions, etc. The permeate of a MD module may be a gaseous mixture including one or more types of vapour molecules. The vapour molecules of the permeate are then condensed to form a condensate. In some examples, the permeate solutions may be 100% or near 100% pure water. The salt concentration in the solutions may be measured or described in terms of process variables such as conductivity or electrical conductivity. The conductivity of feed solutions may be in the range of MilliSiemens per centimetre (mS/cm), and the conductivity of permeate solutions may be in the range of MicroSiemens per centimetre (μ S/cm). The conductivity of condensate formed within the MD module is usually lower than the conductivity of condensate formed outside the MD module.

[0030] The membrane may be a microporous hydrophobic membrane. The hydrophobic membrane acts as a barrier for the liquid or liquid phase, while the pores or holes of the membrane (membrane pores) allow the vapour or the gaseous phase (water vapour, volatile organic compounds (VOCs), etc.) to pass through the membrane. The MD process is driven by a partial vapour pressure difference (also referred to as “vapour pressure difference”). The partial vapour pressure difference is provided by a temperature difference across the membrane (e.g., a temperature gradient from one surface of the membrane to the other surface of the membrane). For example, a temperature difference may be provided by a hotter feed on a feed side of the membrane and a colder permeate on the permeate side of the same membrane. The MD process may be carried out at various temperatures.

[0031] The technical solution proposed herein may be implemented with various types of MD modules. In some implementations, the solutions may be pumped into the feed side (bore side) of hollow fibre membranes of the MD module. In other implementations, the membranes in the MD module may be flat sheets wound in a spiral configuration. The permeate side may be referred to as the shell side. In yet other implementations, the feed side and the permeate side may be on different sides of a plate-and-frame MD module.

[0032] In the normal operations of some MD systems, condensation of the permeate to form the condensate may occur within the MD modules (at the shell side or the vapour permeate side). Even in the normal operations of some MD systems that provide an external condenser, condensation of the permeate vapour may nevertheless occur within the MD module.

[0033] Vacuum membrane distillation (VMD) is one example of a MD system/process with an external condenser. VMD employs a vacuum source/vacuum pump to drive the process in the MD module. For example, a heated feed solution (aqueous solution) is fed into the MD module. A hydrophobic membrane is provided in the MD module. A vacuum is applied at the permeate side of the membrane to draw vapour molecules through the membrane (via the membrane pores). To maintain the drawing force, the applied vacuum pressure is kept lower than the saturation pressure of the various volatile compounds to be separated from the feed solution. Even though the permeated vapour molecules are directed to the condenser external of the MD module (external condenser), there will inevitably be some condensation in the membrane module owing to the lower pressure/vacuum at the permeate side.

[0034] As another example of a MD system/process, the sweep gas membrane distillation (SGMD) uses air or an inert gas to collect vapour from brine fed into the SGMD module(s). In SGMD, cold inert gas is blown to sweep permeated vapour molecules out of the MD module to a condenser external of the MD module (external condenser).

[0035] Similar to the VMD process, in the SGMD process, the conditions that enable efficient operation of the MD process (temperature gradient across the membrane with a hotter feed side and a colder permeate side) inevitably produces some condensation within the MD module. Despite developments in terms of different types of MD processes and different types of membranes, wetting and flooding remain as largely unresolved technical challenges.

[0036] In the present disclosure, the terms “wetting”, “membrane wetting”, “pore wetting, etc., can be used interchangeably. In the MD system, when pore wetting occurs, the wetted pores themselves serve as channels for the liquid feed to permeate through the membrane. Wetting is a concern because the hydrophobic membrane can no longer effectively serve to block the liquid phase from passing through the membrane. Unwanted molecules (contaminants) can thus also be found in the permeated liquid. It can be appreciated that such a phenomenon, also referred to as “flooding”, is undesirable. Unfortunately, wetting is a fairly common occurrence in the conventional MD system. In view of the challenges presented by the wetting of membranes during the MD process, the present disclosure includes various embodiments of a water trap for membrane distillation and a MD system.

[0037] Flooding in MD systems may occur in two separate and/or simultaneous ways: (i) when the MD module is not drained, the liquid/water from wetting accumulates in the permeate side (in some spiral MD modules, “shell side” and “permeate side” are interchangeable terms) until it is inundated and the solution is transported along with the permeate, resulting in a sudden increase in conductivity (or other measurement of concentration, e.g., refraction index, infrared spectra, etc); and (ii) when one or more fibres, or section(s) of the flat sheet, have pinhole(s), or pore sizes at the higher end, allowing the free pass of feed solutions to the permeate side. In this case, the solution is transported along with the permeate, resulting in a sudden increase in conductivity and flow. Therefore, in addition to vapour, an output from the MD module may often include liquid (which

has a higher concentration than the vapour due to presence of salt or other compounds) forming a fluid mixture or a distillation product. The concentration of the condensate due to wetting may be equal or even higher than the feed solutions due to evaporation that occurs in the permeate side (also referred to as the “shell side” in some spiral wound MD modules).

[0038] Various embodiments of the proposed MD system 100 and the proposed water trap 300 are described in the following with reference to the appended figures to aid understanding and not to be limiting. For the sake of brevity, the following will describe various examples in the context of VMD or SGMD, but it will be understood that the MD system 100 and the water trap 300 may be used in various application scenarios pertaining to membrane distillation and is not limited to the specific examples disclosed herein.

[0039] FIG. 1 is a schematic diagram of a part of a MD system 100 in which the proposed water trap 300 is in use with the proposed MD module 500, according to various embodiments of the present disclosure. In an example of a VMD system, the MD process is semi-continuous in the sense that the vacuum (e.g., approximately 0.16 bar) is not applied during the topping up of the feed to the MD module 500. The temperature in the heated part of the MD module 500 is allowed to reach a temperature closer to the setpoint before the vacuum is applied and the MD process continues.

[0040] In operation, the MD module 500 receives a MD module feed solution via a MD module feed path 210. The MD module feed solution enters the MD module 500 through an MD module inlet 213.

[0041] The liquid retentate (concentrate) exits the MD module 500 via the MD module liquid exit path 220 (concentrate exit path). The concentrate exits the MD module 500 through the concentrate outlet 221.

[0042] The vapour permeate from the MD module 500 is directed via a MD module vapour exit path 230 to a condenser 180 (in a VMD system or a SGMD system). The vapour permeate exits the MD module 500 through the MD module vapour outlet 231. The MD module vapour exit path 230 may be open or closed by controlling a valve 232.

[0043] The resulting condensate from the condenser 180 may be collected from the condenser exit path 240.

[0044] Condensation in the MD module 500 will occur as a result of heat loss 150.

[0045] The proposed MD system 100 provides the water trap 300 to receive a fluid mixture (water trap feed) from the MD module 500, concurrently with the operation of the MD module 500. The fluid mixture exits the MD module 500 through a MD module drain outlet 251 and feeds into a water trap 300 via a water trap feed path or feed path 250. The feed path 250 may be open or closed by controlling a feed inlet valve 252. The fluid mixture enters the water trap 300 through a water trap feed inlet or feed inlet opening 253 into the water trap 300.

[0046] Vapour exits the water trap 300 through the water trap vapour outlet or vapour outlet 261. Only vapour is directed from the water trap 300 to the condenser 180 via a water trap vapour exit path or vapour exit path 260. The vapour exit path 260 may be open or closed by controlling a vapour outlet valve 262.

[0047] A pressure regulation channel 270 may open into the water trap 300 through a pressure regulation inlet/outlet 271. The pressure regulation channel 270 may be open or closed by controlling a pressure regulation valve 272.

[0048] Liquid or the fluid mixture (discharge) in the water trap 300 may be discharged out of the water trap 300 via a water trap discharge path or discharge path 280. The discharge may exit the water trap 300 through a discharge outlet 281. The discharge path 280 may be open or closed by controlling a discharge valve 282.

[0049] In one example, the module feed solution in the module feed flow path 210 is brine. The vapour in the MD module vapour exit path 260 and the water trap vapour exit path 260 is water vapour. The resulting condensate from the condensor 180 (in the condensor exit path 240) is water. The fluid mixture discharged by the water trap 300 via the water trap discharge path 280 includes water from condensation and/or wetting.

[0050] The proposed MD module 500 would take significantly longer than a conventional MD module to reach a state in which wetting has caused the active area of the membrane to decrease to the extent that there is significant efficiency loss. In the case of a conventional MD module, the MD system would need to be completely shut down in order to drain out the conventional MD module. The membrane in the proposed MD module 500 will not need to undergo cycles of wetting and draining, and this will help prolong the lifespan of the membrane. For example, the proposed water trap 300 can control the condensation such that the MD module 500 does not need to be regularly shut down for draining. For example, the MD module 500 can be continuously used until it is time to change the whole MD module 500 or when there is a serious leak.

[0051] FIG. 2 shows a partial schematic diagram of a MD system 100 including a MD module 500 and the proposed water trap 300. The MD system 100 may include a retentate tank 190 in fluid communication with the water trap 300. The MD system 100 may include a condensor 180. The water trap 300 includes a vessel 310. The vessel includes an upper chamber 311 and a lower chamber 312. The vessel 310 is installed with the lower chamber 312 disposed below the upper chamber 311. In some embodiments, the upper chamber 311 and the lower chamber 312 are in fluid communication with one another. In some examples, the upper chamber 311 and the lower chamber 312 may form a contiguous volumetric chamber. In other examples, the upper chamber 311 and the lower chamber 312 may be in fluid communication with each other via one or more channels or conduits.

[0052] In some embodiments, the vessel 310 includes a feed inlet 253 opening into the lower chamber 312. The feed inlet 253 may bypass the upper chamber 311 to provide a feed path 250 to the lower chamber 312. In some embodiments, the feed inlet 253 may be an opening of a tube extending through the upper chamber 311, and opening directly or immediately into the lower chamber 312 to provide a fluid mixture 70 into the lower chamber 312. The vessel 310 may further include a vapour outlet 261 leading from the upper chamber 311. The vapour outlet 261 may be in fluid communication with the upper chamber 311 above the feed inlet 253. The vapour outlet 261 may be configured to provide a vapour exit path 260 out of the vessel 310. The vessel 310 may further include a discharge outlet 281 leading from the lower chamber 312. The discharge outlet 281 may provide a discharge path 280 out of the vessel 310. In some embodiments, the discharge valve 282 is provided to controllably control the discharge of the liquid collected in the lower chamber 312 via the discharge path 280 to the retentate tank 190.

[0053] In some embodiments, a vacuum pressure may be provided at least in the upper chamber 311 of the vessel 310, such that the fluid mixture 70 is drawn into the vessel 310.

[0054] In some embodiments, upon receiving the fluid mixture 70 from the MD module 500 via the feed inlet 253, the fluid mixture 70 may separate into a vapour (or a gas) 81 and a liquid 91 by gravity. It may be appreciated that the liquid 91 may be held in the lower chamber 312 as a result of gravity, while the vapour 81 may occupy both the upper chamber 311 and the lower chamber 312.

[0055] In some embodiments, the vapour 81 in at least the upper chamber 311 may be drawn out of or exit the vessel 310 via the vapour outlet 261 and directed along the vapour exit path 260. In some embodiments, the vapour 81 may be drawn through the vapour outlet 261 or exit the vessel 310 as a result of a vacuum or a lower pressure at the condenser 180. In some instances, vapour 81 in both the upper chamber 311 and lower chamber 312 may exit the vessel via the vapour

outlet 322 towards the condenser 180. In some embodiments, the vapour 81 from the fluid mixture 70 may be drawn to the condenser 180 from the water trap 300 solely via the vapour outlet 261.

[0056] When the feed inlet valve 252 closes the feed path 250 and when the vapour outlet valve 262 closes the vapour exit path 260, the discharge valve 282 may be opened to safely discharge any liquid (discharge or discharge fluid mixture) in the lower chamber 312 via the discharge outlet 281. In some embodiments, the discharge outlet 281 may be located at the base (or at a lowest part) of the vessel 310, such that liquid in the vessel 310 may be fully drained via the discharge path 280.

[0057] In some embodiments, a vapour outlet valve 262 may be provided coupled to the vapour outlet 261, to controllably output the vapour via the vapour exit path 260 to the condenser 180. In some embodiments, the vapour received at the condenser 180 may be condensed to form a liquid or a condensate. In some embodiments, the vapour exit path 260 may be in fluid communication with a vacuum pump or vacuum source, such that vapour is pushed out of the vessel 310 via a pressure differential between the upper/lower chambers 311/312 and the vapour exit path 260. Alternatively, the condenser 180 may be in fluid communication with a vacuum pump or vacuum source.

[0058] In some embodiments, discharge fluid mixture may be directed to a storage tank. For example, the discharge fluid mixture may be sent to a tank 190 (e.g. feed tank or retentate tank). The feed tank or the retentate tank 190 may be at atmospheric pressure. In some embodiments, the liquid in the lower chamber 312 may be discharged from the discharge path 280 at least by gravity.

[0059] FIG. 3 is a partial schematic diagram of the MD system 100 and the water trap 300 for membrane distillation according to various embodiments of the present disclosure. In this embodiment, the feed tank 190 may be in fluid communication with the MD feed solution of the MD module 500, to provide a closed feed loop within the MD system 100.

[0060] As illustrated, the feed inlet 253 may open directly within the lower chamber 312, bypassing the upper chamber 311 externally of the vessel 310. For example, the feed inlet 253 may be an opening in a tube extending directly into the lower chamber 312 without passing through the upper chamber 311.

[0061] The vessel 310 includes a perforated member 330 disposed between the upper chamber 311 and the lower chamber 312. In some embodiments, the feed inlet (opening) 253 may open proximal to and/or below the perforated member 330. The perforated member 330 is selected to or configured to act as a filter or a fluid flow restrictor to prevent liquid/mist from escaping or exiting the lower chamber 312 (e.g., liquid is prevented from exiting the vessel 310 via the vapour outlet 261 or via the vapour exit path 260).

[0062] In some embodiments, the perforated member 330 may extend across a cross section of the vessel 310, or in other words, extending across an interface 332 between the upper chamber 311 and lower chamber 312. Further, the perforated member 330 may include a body defining a plurality of perforations. Therefore, the upper chamber 311 and the lower chamber 312 are in fluid communication with one another solely via the plurality of perforations. In some embodiments, the perforated member 330 is sintered.

[0063] Still referring to FIG. 3, in some embodiments, the vessel 310 further includes a pressure regulation channel 270 in fluid communication with a pressure regulation valve 272 and the lower chamber 312. The pressure regulation channel 270 may be at atmospheric pressure or in fluid communication with an environment which is at atmospheric pressure. The pressure regulation channel 270 may be in fluid communication with the vessel 310 solely via the lower chamber 312. The pressure regulation valve 272 may be operable to open the pressure regulation channel 270 and to provide atmospheric pressure in the vessel 310. In some embodiments, the pressure regulation channel 270 provides atmospheric pressure at least to the lower chamber 312.

[0064] In some embodiments, the vessel 310 further includes a liquid level sensor 340 disposed in the lower chamber 312. The liquid level sensor 340 is configured to determine a liquid level in the lower chamber 312.

[0065] The operation of the water trap 300 or a water trapping process may be described in terms of a feed step, a separation step, and a vapour output step. In the feed step, a fluid mixture 70 is fed into the vessel 310, e.g., into the lower chamber 312. Thereafter, upon feeding the fluid mixture 70 into the vessel 310, in the separation step, the fluid mixture 70 is allowed to separate into a vapour and a liquid. In a vapour output step, which occurs concurrently or substantially with the separation step, the vapour is output from the vessel 310. From time to time, a discharging step may be performed in which the liquid in the vessel 310 is discharged out of the vessel 310.

[0066] In various embodiments of the feed step, where the vapour exit path 260 is in fluid communication with a vacuum source (or a sweep gas pressure source, or a low pressure source) and the feed inlet 253 is not pressurized, both the feed inlet valve 252 and the vapour outlet valve 262 are opened while the discharge valve 282 and the pressure regulation valve 272 (if provided) are closed. This allows the fluid mixture 70 to be fed or drawn into the vessel 310 via the pressure differential between the vapour exit path 260, the vessel 310 and the feed inlet 253. Thereafter, the operation proceeds to the separation step, in which the fluid mixture 70 is allowed to separate within the lower chamber 312 into a vapour and a liquid. In some embodiments, the vapour may occupy both the upper chamber 311 and the lower chamber 312, while the liquid settles or collects in the lower chamber 312 due to gravity. The operation further proceeds to the vapour output step where the vacuum pressure (or low pressure) in the vapour exit path 260 draws the vapour out of the vessel 310 via the vapour outlet 261.

[0067] It may be noted that the discharge valve 282 and the pressure regulation valve 272 (if provided) remain closed throughout the feed step, the separation step and the vapour output step.

Therefore, with the opening of both the feed inlet valve 252 and the vapour outlet valve 262 and the closing of the discharge valve 282 and the pressure regulation valve 272 (if provided), the feed step, the separation step and the vapour output step may proceed simultaneously and/or sequentially without requiring further actions. In addition, the feed step, the separation step, and the vapour output step may be performed iteratively or cyclically.

[0068] The water trapping process may further include performing a liquid discharge step. In the liquid discharge step, liquid collected in the lower chamber 312 may be discharged from the vessel 310 via the discharge path 280. In some embodiments, the liquid discharge step is activated responsive to a predetermined criterion of the water trap 300. In some embodiments, the liquid discharge step may be activated responsive to a liquid level in the lower chamber 312 exceeding a predetermined threshold. The predetermined threshold may be a liquid level within the lower chamber 312. As an example, the liquid level may be one selected from a range from a quarter to an eighth of the depth of the lower chamber 312.

[0069] In other embodiments, the liquid discharge step may be activated responsive to the MD system 100 operating beyond a predetermined duration. For example, the predetermined duration may correspond to the water distillation cycle duration, such as 24 hours to 48 hours. It may be noted that during or upon completion of the vapour output step, the vessel 310 may be in a low pressure or near vacuum pressure. Therefore, the vessel 310 may be brought back or returned to atmospheric pressure to discharge the liquid from the vessel 310 via gravity.

[0070] In the liquid discharge step, both the feed inlet valve 252 and the vapour outlet valve 262 are closed while the discharge valve 282 and the pressure regulation valve 272 (if provided) are opened. For embodiments where the discharge path 280 is at atmospheric pressure and the pressure regulation valve 272 is not present (e.g., FIG. 2), the discharge valve 282 may be opened such that at least the pressure in the lower chamber 312 is equalized or is returned to atmospheric

pressure. Sequentially or concurrently, the liquid collected in the lower chamber 312 may discharge from the lower chamber 312 at least via gravity.

[0071] In other embodiments where the discharge path 280 is in fluid communication with a sealed feed tank 190 and the pressure regulation valve 272 is provided, both the feed inlet valve 252 and the vapour outlet valve 262 are closed while both the pressure regulation valve 272 and the discharge valve 282 may be opened. This allows pressure equalization in the vessel 310 (or at least the lower chamber 312) and simultaneously discharging of the liquid collected in the lower chamber 312 via gravity. Alternatively, the pressure regulation valve 272 may first be opened while the discharge valve 282 is kept closed to allow the vessel 310 to return to atmospheric pressure, and thereafter the discharge valve 282 may be opened to discharge the liquid collected in the lower chamber 310 via gravity. Upon completion of the liquid discharge step, the process may return to the iterative process of the feed step, the separation step, and the vapour output step.

[0072] FIG. 4 illustrates various exemplary embodiments of a MD system 100 and a water trap 300. The MD system 100 may include a MD module 500, a chiller/condenser 180, and a feed tank 190 in fluid communication with the water trap 300. The water trap 300 may include a sealed vase/vessel 310 including an upper chamber 311 and a lower chamber 312. The vessel 310 may include two inlets (feed inlet 253 and pressure regulation inlet/outlet 271) and two outlets (vapour outlet 261 and discharge outlet 281). The feed inlet 253 may be an opening in a tube 321 in which the opening is disposed in the lower chamber 312, and a sintered/perforated plate/perforated member 330 attached at the end of the tube 321. The inlets 253/271 and outlets 261/281 may be connected to or in fluid communication with valves such as ball valves, solenoid valves, level valves, float valves, etc. The vessel 310 may include a screw cap for easy opening and cleaning of the vessel 310 when not in operation.

[0073] In some examples, the vessel 310 may be made from materials such as chlorinated polyvinyl chloride (CPVC), reinforced glass, Teflon, etc. which are able to resist temperature, pressure (vacuum and positive), and corrosive environments, such as in contact with acids, alkali, oxidants (depending on the application). In some examples, the tube 321 may have a length between a third to half of the vessel's height. This enables a fluid mixture (vapour-liquid (mist) mixture) to be discharged into the vessel 310 while preventing liquid and/or mist from escaping from the vessel 310 through the vapour outlet 261. The sintered/perforated plate/perforated member 330 at the end of the tube 321 may be an added barrier to prevent the liquid/mist from escaping through the vapour outlet 261. As merely illustrative examples, the tube 321 may be made of polyethylene (PE), polypropylene (PP), Teflon, etc. The sintered/perforated plate/perforated member 330 may be made from Teflon, polyvinylidene fluoride (PVDF), stainless steel, etc.

[0074] In some examples, both the feed inlet valve 252 and the vapour outlet valve 262 may be solenoid valves which aids in the continuous automated operation of the MD system 100. In some examples, the discharge valve 282 may be a check valve or a one-way valve, such that the liquid discharged from the vessel 310 is prevented from re-entering the vessel 310. In some examples, the pressure regulation valve 272 may be a float valve that is responsive to a liquid level in the lower chamber 312. In other words, the float valve opens when the liquid level in the vessel 310 reaches a predetermined level, to discharge the liquid.

[0075] FIG. 5A and FIG. 5B illustrate different states of the water trap 300 according to various embodiments. FIG. 5A illustrates an operational state of the water trap 300, in which the concurrent or sequential processes of the feed step, the separation step and the vapour output step are performed. In the operational state, at programmed times, both the feed inlet valve 252 and the vapour outlet valve 262 are opened while both the discharge valve 282 and the pressure regulation valve 272 are closed. The mixture of vapor and liquid (fluid mixture) flows into the vessel 310

through the feed path 250 due to the vacuum pressure from the chiller/condenser 180 and/or the gas pressure from the MD module 500 to the vessel 310. Further, due to the vacuum pressure, the separated vapour may be drawn towards the condenser (chiller) 180 through the vapour outlet 261. After a certain duration (which may be programmed), both the feed inlet valve 252 and the vapour outlet valve 262 may be closed ending the feed state.

[0076] FIG. 5B illustrates a discharge state following the feed state of the water trap 300. The liquid in the vessel 310 may be at a predetermined liquid level or the MD system 100 has been in the operational state for a programmed time duration. The discharge valve 282 and the pressure regulation valve 272 may be opened, to discharge the liquid from the vessel 310 through the discharge outlet 281 to be returned, e.g., to a feed tank. In some embodiments, responsive to a liquid level in the lower chamber 312 exceeding a predetermined threshold, the feed path 250 and the vapour exit path 260 are closed, and the pressure regulation channel 270 and the discharge outlet 280 are opened. In some embodiments, the pressure regulation valve 272 is configured to open in response to the MD system 100 operating beyond a predetermined duration.

[0077] After the liquid is discharged (for a programmed time duration) from the vessel 310, the discharge valve 282 and the pressure regulation valve 272 may be closed. When both the feed inlet valve 252 and the vapour outlet valve 262 are opened, the discharge valve 282 and the pressure regulation valve 272 are closed, vice versa. This facilitates a change of pressure in the vessel 310, e.g., by application of a vacuum pressure or a sweep gas at atmospheric pressure. In some examples, the volume capacity of the water trap 300 (or the vessel 310) may be approximately 1 litre for a 2-inch MD module (without leaking). This allows for six to eight hours of operation without discharging/draining. The above are mere exemplary embodiments and does not limit the operation of the MD system 100 to these particular parameters.

[0078] FIG. 6 schematically illustrates a MD system 100 and a water trap 300 according to another exemplary embodiment. The MD system 100 includes a MD module 500, a vacuum pressure (P_{vac}) 480, and a feed tank 190 in fluid communication with the water trap 300. The water trap 300 may include a sealed vessel 310 including an upper chamber 311 and a lower chamber 312. The vessel 310 may include two inlets: a feed inlet 253 for the feed path 250 and a pressure regulation inlet/outlet 271 for a pressure regulation channel 270. The vessel 310 may include two outlets: a vapour outlet 261 for the vapour exit path 260 and a discharge outlet 281 for the discharge path 280. The feed path 250 may include a pipe directly opening into the lower chamber 312. The MD system 100 may include a feed inlet valve 252, a vapour outlet valve 272, a discharge valve 282 and a pressure regulation valve 272 may be in fluid communication with the feed path 250, the vapour exit path 260, the discharge path 280, and the pressure regulation channel 270, respectively. In some embodiments, a level sensor 440 may be provided in the vessel 310, disposed in the lower chamber 312, to measure a liquid level in the vessel 310. In some examples, the level sensor 440 is disposed to detect if the level of liquid collected in the lower chamber 312 has exceeded a threshold liquid level.

[0079] In various embodiments, a feed path 250 may provide a feed from the MD module 500 to the lower chamber 312 via the feed inlet 253. Additionally, the pressure regulation channel 270 may also be in fluid communication with the feed path 250. In this example, pressure equalization of or a supply of air at atmospheric pressure to the vessel 310 may be performed via the feed inlet 253. In some embodiments, to discharge the liquid collected from the vessel 310, the pressure regulation valve 272 may be opened and a feed inlet valve 252 may be closed, to return the vessel 310 to atmospheric pressure. In various embodiments, the feed inlet valve 252, the vapour outlet valve 262, the discharge valve 282 and the pressure regulation valve 272 may be solenoid valves. Further, a controller 450 may be provided in signal communication with and to control each of the

valves 252/262/272/282, to enable an automated / semi-automated MD process that will automatically drain the MD system 100 from time to time, or in response to detecting a liquid level in the water trap 300 that exceeds the threshold level.

[0080] In some embodiments, the controller 450 may be configured to determine if the MD module 500 has a leak across the membrane 515, responsive to the flowrate and/or volume of the liquid collected in the vessel 310 and/or the electrical conductivity of the liquid. For example, the controller 450 may be configured to differentiate if the MD module 500 has a leak across the membrane 515 or is experiencing condensation in the shell side. As condensation occurs in the shell side of the MD module 500 and some channels may be in fluid communication, this causes an increase in conductivity in the liquid in the vessel 310. Under normal operating conditions, the increase in the permeate conductivity/condensate conductivity will not be as high as the conductivity of the MD module feed solution. An higher permeate conductivity may be indicative that wetting has occurred or is occurring, e.g., when there is a direct link or fluid communication across the membrane due to a high pore size or a small leak. A sudden spike (sharp and significant increase) in permeate conductivity may be indicative of flooding, e.g., when the leak of liquid is relatively high such that the shell side fills up quickly with liquid.

[0081] The water trap 300 can be operated with a quick response time to dewet the MD module 500 since the dewetting can be performed without shutting down the entire MD system 100. The warning of wetting is also earlier in the present MD system 100 than in a conventional MD system. The present MD system 100 therefore provides a relatively early warning or alert system such that the MD system parameters can be adjusted or such that dewetting can be performed before the condenser condensate becomes contaminated with unwanted substances / impurities from the MD module feed solution.

[0082] The MD system 100 is configured to perform a method of draining the MD module 500 without shutting down the MD module 500. The method of draining may involve steps of (i) collecting, (ii) switching modes, and (iii) discharging, as schematically represented in FIG. 7. Concurrent with the membrane distillation process occurring in the MD module 500, the water trap 300 is configured to collect the liquid part of a fluid mixture drained from the MD module as well as output the vapour part of the fluid mixture out of the water trap 300. For example, when the MD module 500 is in operation, the water trap feed path or feed path 250 (equivalent to the MD module drain path) may be kept open to allow a fluid mixture from the condensate or permeate side of the MD module 500 to enter the water trap 300, and concurrently the vapour exit path 260 may be kept open to allow only vapour to exit the water trap 300.

[0083] The water trap 300 is configured to perform a switching of modes. For example, if the level of accumulated liquid in the water trap 300 reaches a threshold level, the water trap 300 may responsively close off the water trap feed path or feed path 250 (or the MD module drain path) and open the discharge path 280 of the water trap 300. When the water trap feed path or feed path 250 is closed, the vapour exit path 260 is closed.

[0084] The water trap 300 is configured to perform a discharging of the liquid collected in the lower chamber of the water trap 300. To discharge the collected liquid, the water trap discharge path 280 is opened. The pressure regulation channel 270 may be operated to regulate the pressure in the water trap 300 and facilitate the flow of all or substantially all of the liquid out of the water trap 300. The discharging step is performed with the MD module drain (equivalent to the feed path 250) closed so that the pressure conditions within the MD module 500 are not affected by the draining or discharging.

[0085] The draining can be performed with the MD module 500 continuing its membrane distillation processes without an interruption that is made solely to perform draining and avoid wetting.

[0086] To drain the MD system 100, firstly, the MD module 500 can continue to operate, while the feed path 250 is closed and the vapour exit path 260 is closed. Next, the MD module 500 can continue to operate while the discharge path 280 and the pressure regulation channel 270 are opened.

[0087] FIG. 8 illustrates a dewatering method 700 for a MD system 100. The dewatering method 700 includes a step 710 of receiving in a lower chamber of a vessel of the water trap, a fluid mixture from a MD module. The dewatering method 700 includes a step 720 of separating the fluid mixture into a liquid and a vapour. The dewatering method 700 includes a step 730 of drawing the vapour from the vessel via a vapour outlet leading from an upper chamber of the vessel. The dewatering method 700 includes a step 740 of discharging the liquid from the vessel via a discharge outlet leading from the lower chamber of the vessel.

[0088] FIG. 9 schematically illustrates a MD module 500 according to various embodiments of the disclosure. The MD module 500 includes a MD module feed path 210 to receive the MD module feed solution at one end (MD module inlet 213) of the MD module 500. The MD module 500 is configured to output a concentrate to a concentrate exit path 220 via a concentrate outlet 221 disposed at an opposing end of the MD module 500 (feed tangential flow). For the sake of brevity, the plurality of membrane elements (extending between the MD module inlet 213 and the concentrate outlet 221) are referred to as a membrane 515. The membrane 515 may be configured as an in-to-out array of hollow fibre membrane modules or as flat sheet modules.

[0089] The MD module inlet 213 may be coupled to a feed tank to receive a MD module feed solution from a feed source, such as a feed tank 190. The MD module drain outlet 251 is coupled to the feed path 250 of the water trap 300.

[0090] A MD module vapour outlet 230 is be disposed at the permeate side or at the shell 520 of the MD module 500. In some embodiments, the MD module 500 includes more than one MD module vapour outlet 230 for vapour collection. For example, a MD module vapour outlet 532 and a spare MD module vapour outlet 534 may be disposed proximal to the opposing ends of the MD module 500. In operation, one of the MD module vapour outlets may be closed by a valve, and the other one of the MD module vapour outlets may be open. Optionally, the MD module 500 may be symmetrically configured as shown to provide the convenience of allowing the MD module 500 to be installed and operated in any orientation.

[0091] In various embodiments, the MD module 500 includes one or more drainage collector 550 leading to a respective drain 540. The drainage collector 550 may be disposed in the potting section 522 of the MD module 500. The drainage collector 550 may have a conical shape or other shapes, e.g., with a relatively larger mouth to receive condensed liquids and a relatively smaller port to direct the condensed liquids out to the drain 540.

[0092] In some embodiments, one drainage collector 552 is disposed at one end of the MD module 500 and a spare drainage collector 554 is disposed at the other end (opposing end) of the MD module 500. For example, the drainage collector 552 and the spare drainage collector 554 may be symmetrically disposed so that the MD module as a whole may be symmetrically configured for convenient installation.

[0093] The drainage collector 552 that is at the lower end of the installed MD module 500 is connected to the drain 542. When the MD module 500 is in operation, the drain 542 is open and in fluid communication with the water trap 300, while the other drain (spare drain) 544 is closed. This

allows liquid in the shell side of the MD module 500 to be drained completely. This in contrast to conventional modules which have to be entirely shut down in order to remove condensed liquids which have accumulated in the MD module 500.

[0094] In some embodiments, a flowmeter may be coupled to the drain 540 coupling the MD module 500 and the water trap 300. A larger flowrate in the drain 540 (e.g, the lower drain 542 in FIG. 9) may be indicative of an initial wetting of the membrane 515 in the MD module 500. A leaking or wetting of the MD module 500 may be detected prior to the flooding. Concurrent with the MD process, adjustment to the operating parameters of the MD system 100 may be made in response to a larger amount of liquid being detected by the flowmeter in the drain 540.

[0095] In various embodiments, when the water trap is used with the VMD systems/processes, the water trap 300 may separate the vapour from the condensate formed on the shell side. The fluid mixture of the vapour and the condensate may be fed into the water tap 300 using vacuum pressure in the MD system 100 provided from the spare outlet of the MD module 500.

[0096] In various embodiments where the water trap 300 is used with SGMD systems/processes, the water trap 300 may be installed in-line following the wet air/gas outlet or installed using the spare outlet in the MD module 500.

[0097] In various embodiments, the water trap 300 may be installed between the MD module(s) 500 and the condenser 180. The water trap 300 may be connected to one or more MD modules 500. The water trap 300 may be connected to the respective lower outlet(s) of one or more existing MD modules 500, while the respective upper outlet of the MD modules may be used to collect only the vapour continuously. This enables the MD system 100 to operate continuously, preventing shutdowns or down-time for draining the MD modules 500 experiencing wetting or leaking. Further, the water trap 300 may be switched on and off over predetermined periods to extract the condensate from the MD module(s) 500.

[0098] In embodiments where the water trap is coupled to the proposed MD module, the water trap may extract all condensates from the MD modules, thus preventing accumulation of condensates in the shell side of the MD modules. Further, when a respective flowmeter is coupled to each MD module, the water trap may aid in detecting leaking and/or excessive wetting during MD operations. In various embodiments, the water trap and MD module may be suitable for use with current membrane materials, from PVDF or PTFE, to other newly developed membrane materials, without requiring any specific material to operate.

[0099] A comparison between a conventional MD system and one embodiment of the proposed MD system 100 is briefly presented below to highlight various useful and beneficial aspects of the present MD system 100. In these examples, the present MD system 100 includes the proposed water trap and the proposed MD module 500.

[00100] In a first aspect, a dewatering operation is essentially carried out concurrently with the operation of the proposed MD system 100. For example, the proposed MD system 100 simultaneously enables a dewatering of the MD module 500 with the MD operation. The conventional MD system cannot provide a dewatering function that can be implemented when the MD module is in operation. The conventional MD module needs to be periodically and entirely shut down in order for the MD module to be drained of water that may have accumulated inside the MD module or water that has wetted the membrane inside the MD module.

[00101] In a second aspect, the proposed MD system 100 can be continuously operated for a comparatively longer period of time since the proposed MD module 500 is less likely to experience wetting of the membrane, e.g., it would not be required to completely shut down the proposed MD module for the purpose of draining the MD module or for the purpose of replacing the membrane. The conventional MD system typically has to be completely shut down at regular intervals in order to replace the wetted membrane before the efficiency of the MD module is too low.

[00102] In a third aspect, the proposed MD system 100 can be used with any type of membrane. The conventional approach to address membrane wetting is often focused on changing the membrane or changing the material properties of the membrane. The conventional method can be costly to implement if special membranes are required. In contrast, the proposed MD system provides a technical solution that can be applied to any membrane.

[00103] In a fourth aspect, the proposed MD system 100 provides a convenient way to deal with the condensation at the permeate side. For example, in the proposed MD system, condensation at the permeate side can be reduced by the water trap and any condensation can be collected in the proposed MD module. In contrast, in the conventional MD system, condensation at the permeate side is unavoidable and a major cause of membrane wetting.

[00104] In a fifth aspect, in the conventional MD system, condensation at the permeate side is aggravated by condensation of permeate vapours. In contrast, in the proposed MD system 100, there is no condensation of permeate vapours.

[00105] In a sixth aspect, the present MD system 100 is configured to prevent flooding in the MD module. In the present MD module, any accumulation of condensate is minimal. In contrast, in the conventional MD system, the wetting of the membrane may result in flooding and hence cross-contamination in the MD module.

[00106] In a seventh aspect, the quality of the permeate is more consistent in the present MD system 100. For example, in the present MD system 100, the composition of the permeate (or quality of the permeate) may vary minimally in terms of the respective concentrations of various constituting materials. In the conventional MD system, once wetting occurs, the material composition and respective concentrations of the constituents can vary significantly.

[00107] In an eighth aspect, in the conventional MD system, leaks are detectable when the MD module experiences flooding. In contrast, in the proposed MD system 100, the presence of leaks

may be assessed by measuring the flowrate of liquid flowing out of the water trap 300 or by measuring the volume of the liquid collected in the water trap 300. For example, a decreasing flowrate may be indicative of a leak.

[00108] In a ninth aspect, in the conventional MD module, there is no provision to deal with accumulated water inside the conventional MD module. In contrast, the present MD module 500 includes a drain that serves module drainage.

[00109] These and other advantages were experimentally verified based on an MD system 100 incorporating the water trap 300. The MD system 100 used in the experiments is illustrated in FIG. 10, and the data is shown in FIGS. 11 to 15.

[00110] FIG. 11 are plots of the respective concentrations of the MD module feed solution 812 and the MD module permeate 814 over time in a MD system without the water trap 300. FIG. 12 are plots of the respective concentrations of the MD module feed solution 822 and the MD module permeate 824 over time in the MD system 100 of FIG. 10 with the water trap 300. The MD module 500 was operated under similar conditions in which the MD module feed solution is 3.7% sodium chloride heated to at least 70 °C.

[00111] Within 60 hours of runtime, the permeate conductivity 814 in FIG. 11 fluctuated greatly and had increased to be extremely high. The MD module was clearly flooded and inoperable by that time, and the permeate was contaminated. The entire MD system would need to shut down to drain out the MD module. as the feed conductivity (conductivity of the module feed solution).

[00112] In FIG. 12, the MD system 100 with the water trap 300 shows very different plots for the permeate conductivity 824. The permeate conductivity 824 remained close to zero (lower than 4 $\mu\text{S}/\text{cm}$) with no significant fluctuation for each of the three MD processes performed. The MD module feed solution conductivity plots 822 show a cyclical variation as a result of topping up the MD module feed solution from time to time.

[00113] FIG. 13 shows measured permeate flowrates 834 at different time instances. The permeate flowrate (of the permeate of the MD module) can be used as an indicator of the water trap performance. The water trap 300 enables continuous water production of about 3.2 kg/hr with an efficiency higher than 80% (compared against a theoretical permeate flowrate 832 of 4 kh/hr calculated for the MD system used).

[00114] The results suggest that it is possible to obtain good quality permeated water (with very low conductivities) at an efficiency that is promising for scaled up production. The proposed MD system 100 can be used with membranes that are more prone to wetting.

[00115] FIG. 14 compares the concentration factors 842 of the concentrates obtained using the MD system of FIG. 10. The comparisons were made relative to the MD module feed solution of 3.57% sodium chloride solution. The MD system 100 with the proposed water trap 300 shows good results in the experiments with the concentration factors in the range of 3.0 to 3.4.

[00116] FIG. 15 shows experimental results 852 from three MD operations. The results indicate that the MD process has a high efficiency (permeate efficiency) of about 75.8% to 76.7%, despite heat losses.

[00117] In various embodiments, the water trap may be used for dewatering the MD modules in the VMD and SGMD systems. The water trap may simultaneously separate the vapours in the distillation product from the water in the condensation product and/or from the water due to wetting. This approach departs from various conventional processes of condensing the permeate (product) of the membrane distillation.

[00118] In some embodiments, the water trap for membrane distillation relies on gravity to separate a fluid mixture received from a MD module into a liquid and a gas. In some embodiments, upon separation of the fluid mixture, and responsive to a pressure difference or a pressure equalization between an interior and an exterior of the water trap 300, discharging or moving of

the liquid/gas is achieved. In some embodiments, the separation process and movement process may be timed or scheduled according to the MD process. In other embodiments, the separation process and movement process may be limited to predetermined duration threshold(s), to allow optimization/maximization of the MD process duration, while avoiding wetting to the membranes.

[00119] In some examples, the water trap may be installed in any VMD and/or SGMD system from pilot scale to industrial scale, in which the differences mainly being a difference in volume of the devices. With the utilization of the water trap 300, the VMD and SGMD systems may work continuously, increasing the possibilities of implementations in water desalination, concentration of brines, valuable materials recovery, pre-treatment for crystallization of salts, volatile organic compounds recovery, among others. As the operation of the water trap may be automated, this opens up the possibilities of automation for MD processes, as well as wetting detection, thus allowing continuous operation with minimal changes in product qualities.

[00120] It may be noted that the water trap does not replace the cold traps, condensers, chillers, or other devices used to collect the vapour(s) produced by the membrane distillation. The water trap may be an additional device connected to or in fluid communication with the MD module(s). The water trap may control condensation and prevent wetting of the membranes inside the respective housings, which is an issue not addressed with conventional MD systems. The water trap may prevent cross-contamination of the condensed permeate to produce better output qualities. This may be done by controlling and maintaining the conductivity of the permeates during the entire MD operation, even for instances where the MD module is prone to wetting. Conventional MD systems typically are not able to achieve such control due to spikes in conductivity from a wetting/flooding event.

[00121] In one aspect, the present application discloses a water trap suitable for use with a membrane distillation (MD) system. The water trap includes a vessel having an upper chamber and

a lower chamber. The lower chamber is disposed below the upper chamber. The upper chamber and the lower chamber are in fluid communication with one another. A feed inlet opening into the lower chamber is configured to bypass the upper chamber to provide a feed path from the MD system to the lower chamber. A vapour outlet leading from the upper chamber is configured to provide a vapour exit path out of the vessel. The vapour outlet is in fluid communication with the upper chamber above the feed inlet opening. A discharge outlet leading from the lower chamber is configured to provide a discharge path out of the vessel. The vessel is operable to output a vapour via the vapour outlet responsive to receiving a fluid mixture from the MD system via the feed inlet.

[00122] The water trap may further include a pressure regulation channel in fluid communication with the vessel solely via the lower chamber.

[00123] The water trap may include a perforated member disposed between the upper chamber and the lower chamber. The feed inlet opening may be disposed proximally to and below the perforated member.

[00124] The perforated member may include a body defining a plurality of perforations. The upper chamber and the lower chamber may be in fluid communication with one another solely via the plurality of perforations.

[00125] The perforated member may be sintered.

[00126] The discharge outlet is coupled with a controllable discharge valve. The discharge valve may be configured to discharge a liquid collected in the lower chamber.

[00127] The liquid in the lower chamber may be discharged from the vessel at least by gravity.

[00128] Responsive to an opening of the discharge valve, at least the lower chamber is returned to atmospheric pressure.

[00129] The water trap may further include a pressure regulation valve disposed in the pressure regulation channel. The pressure regulation valve may be operable to open the pressure regulation channel and provide an atmospheric pressure in the vessel.

[00130] The pressure regulation valve may be configured to open in response to a liquid level in the lower chamber exceeding a predetermined threshold.

[00131] The water trap may further include a liquid level sensor disposed in the lower chamber. The liquid level sensor may be configured to determine the liquid level in the lower chamber.

[00132] The pressure regulation valve may include a float valve that is responsive to a liquid level in the lower chamber.

[00133] The pressure regulation valve may be configured to open in response to the MD system operating beyond a predetermined duration.

[00134] In another aspect, a system includes: a membrane distillation (MD) module and a water trap. The MD module includes an MD module inlet, a membrane, and a MD module drain outlet. The water trap includes a vessel having an upper chamber and a lower chamber. The water trap includes a feed inlet that opens into the lower chamber, a vapour outlet that leads from the upper chamber, a pressure regulation channel in fluid communication with the vessel solely via the lower chamber, and a discharge outlet leading from the lower chamber. The lower chamber is disposed below the upper chamber. The upper chamber and the lower chamber are in fluid communication with one another. The feed inlet is configured to bypass the upper chamber to provide a feed path from the MD module drain outlet to the lower chamber. The feed path is operable to open/close by a feed inlet valve coupled to the feed inlet. The vapour outlet is configured to provide a vapour exit path out of the vessel. The vapour outlet is in fluid communication with the upper chamber above the feed inlet opening. The vapour exit path is operable to open/close by a vapour outlet valve coupled to the vapour outlet. The pressure regulation channel is operable to open/close by a

pressure regulation valve coupled to the pressure regulation channel. The discharge outlet is configured to provide a discharge path out of the vessel. The discharge path is operable to open/close by a discharge valve coupled to the discharge outlet. The vessel is operable to output a vapour via the vapour outlet responsive to receiving a fluid mixture from the MD module drain outlet via the feed inlet.

[00135] Responsive to the MD module being in operation, the feed path and the vapour exit path may be opened, and the pressure regulation channel and the discharge path may be closed.

[00136] Responsive to a liquid level in the lower chamber exceeding a predetermined threshold, the feed path and the vapour exit path may be closed, and the pressure regulation channel and the discharge path may be opened.

[00137] The pressure regulation valve may be configured to open in response to the MD system operating beyond a predetermined duration.

[00138] The system may further include a condenser coupled to the vapour exit path, in which a vapour from the fluid mixture is drawn to the condenser from the water trap solely via the vapour exit path.

[00139] The water trap may be operable to discharge a fluid mixture from the lower chamber concurrently with the MD module performing a membrane distillation process on a MD module feed solution. The membrane distillation process produces a vapour permeate and a concentrate from the MD module feed solution. The fluid mixture and the concentrate are from different sides of the membrane.

[00140] The MD module may further include a drain disposed at either end of the MD module. The drain may be disposed at a lower end of the MD module and coupled to the feed inlet in fluid communication.

[00141] All examples described herein, whether of apparatus, methods, materials, or products, are presented for the purpose of illustration and to aid understanding, and are not intended to be limiting or exhaustive. Modifications may be made by one of ordinary skill in the art without departing from the scope of the invention as claimed.

CLAIMS

1. A water trap useable with a membrane distillation (MD) system, the water trap comprising:
a vessel, the vessel including:
 an upper chamber; and
 a lower chamber, the lower chamber being disposed below the upper chamber, the upper chamber and the lower chamber being in fluid communication with one another;
a feed inlet opening into the lower chamber, the feed inlet being configured to bypass the upper chamber to provide a feed path from the MD system to the lower chamber;
a vapour outlet leading from the upper chamber, the vapour outlet being configured to provide a vapour exit path out of the vessel, the vapour outlet being in fluid communication with the upper chamber above the feed inlet opening; and
a discharge outlet leading from the lower chamber, the discharge outlet being configured to provide a discharge path out of the vessel, wherein the vessel is operable to output a vapour via the vapour outlet responsive to receiving a fluid mixture from the MD system via the feed inlet.
2. The water trap as recited in claim 1, further comprising: a pressure regulation channel in fluid communication with the vessel solely via the lower chamber.
3. The water trap as recited in any one of claim 1 or claim 2, comprising a perforated member disposed between the upper chamber and the lower chamber, wherein the feed inlet opening is disposed proximal to and below the perforated member.
4. The water trap as recited in claim 3, wherein the perforated member comprises a body defining a plurality of perforations, and wherein the upper chamber and the lower chamber are in fluid communication with one another solely via the plurality of perforations.
5. The water trap as recited in claim 3 or claim 4, wherein the perforated member is sintered.

6. The water trap as recited in any one of claims 1 to 5, wherein the discharge outlet is coupled with a controllable discharge valve, and wherein the discharge valve is configured to discharge a liquid collected in the lower chamber.
7. The water trap as recited in claim 6, wherein the liquid in the lower chamber is discharged from the vessel at least by gravity.
8. The water trap as recited in claim 6 or claim 7, wherein responsive to an opening of the discharge valve, at least the lower chamber is returned to atmospheric pressure.
9. The water trap as recited in claim 2, further comprising a pressure regulation valve disposed in the pressure regulation channel, wherein the pressure regulation valve is operable to open the pressure regulation channel and provide an atmospheric pressure in the vessel.
10. The water trap as recited in claim 9, wherein the pressure regulation valve is configured to open in response to a liquid level in the lower chamber exceeding a predetermined threshold.
11. The water trap as recited in claim 10, further comprising a liquid level sensor disposed in the lower chamber, the liquid level sensor being configured to determine the liquid level in the lower chamber.
12. The water trap as recited in claim 10, wherein the pressure regulation valve comprises a float valve that is responsive to a liquid level in the lower chamber.
13. The water trap as recited in any one of claims 9 to 12, wherein the pressure regulation valve is configured to open in response to the MD system operating beyond a predetermined duration.

14. A system comprising:

a membrane distillation (MD) module, the MD module including:

an MD module inlet;

a membrane; and

an MD module drain outlet; and

a water trap, the water trap including:

a vessel, the vessel including:

an upper chamber; and

a lower chamber, the lower chamber being disposed below the upper chamber, the upper chamber and the lower chamber being in fluid communication with one another;

a feed inlet opening into the lower chamber, the feed inlet being configured to bypass the upper chamber to provide a feed path from the MD module drain outlet to the lower chamber, the feed path being operable to open/close by a feed inlet valve coupled to the feed inlet;

a vapour outlet leading from the upper chamber, the vapour outlet being configured to provide a vapour exit path out of the vessel, the vapour outlet being in fluid communication with the upper chamber above the feed inlet opening, the vapour exit path being operable to open/close by a vapour outlet valve coupled to the vapour outlet;

a pressure regulation channel in fluid communication with the vessel solely via the lower chamber, the pressure regulation channel being operable to open/close by a pressure regulation valve coupled to the pressure regulation channel; and

a discharge outlet leading from the lower chamber, the discharge outlet being configured to provide a discharge path out of the vessel, the discharge path being operable to open/close by a discharge valve coupled to the discharge outlet, wherein the vessel is operable to output a vapour via the vapour outlet responsive to receiving a fluid mixture from the MD module drain outlet via the feed inlet.

15. The system as recited in claim 14, wherein responsive to the MD module being in operation, the feed path and the vapour exit path are opened, and the pressure regulation channel and the discharge path are closed.
16. The system as recited in claim 14, wherein responsive to a liquid level in the lower chamber exceeding a predetermined threshold, the feed path and the vapour exit path are closed, and the pressure regulation channel and the discharge path are opened.
17. The system as recited in claim 14, wherein the pressure regulation valve is configured to open in response to the MD system operating beyond a predetermined duration.
18. The system as recited in claim 14, further comprising a condenser coupled to the vapour exit path, wherein a vapour from the fluid mixture is drawn to the condenser from the water trap solely via the vapour exit path.
19. The system as recited in any one of claims 14 to 18, wherein the water trap is operable to discharge a fluid mixture from the lower chamber concurrently with the MD module performing a membrane distillation process on a MD module feed solution, the membrane distillation process producing a vapour permeate and a concentrate from the MD module feed solution, wherein the fluid mixture and the concentrate are from different sides of the membrane.
20. The system as recited in any one of claims 14 to 19, wherein the MD module further comprises a drain disposed at either end of the MD module, and wherein the drain disposed at a lower end of the MD module is coupled to the feed inlet in fluid communication.