

Selective Membrane System and Method for Desalination and Mineral Recovery**TECHNICAL FIELD**

[0001] The present disclosure is directed to a selective membrane for separating desalinated water and a selected mineral salt from seawater or another high-salinity solution. The present disclosure is further directed to a seawater reverse osmosis system comprising the selective membrane; as well as a system and method for recovering a selected mineral salt from seawater using a seawater desalination plant.

BACKGROUND

[0002] Seawater contains a large number of valuable mineral salts and metals such as sodium chloride, magnesium, calcium, potassium, lithium, rubidium, and salts thereof. Conventional seawater desalination reverse osmosis (SWRO) membranes, as shown in **Figure 1**, are widely used in commercial seawater desalination systems. Such membranes, acting under pressure, only allow water molecules to pass through them and retain mineral salts contained in the seawater as brine. Brine from such SWRO membranes is then conveyed to the brine exit of the membranes by the force of feed pressure and this results in an output with a high concentration of minerals and salts (brine). The mineral salts discharged from SWRO membranes in conventional desalination plants (collectively known as brine or reject) are a mixture of salts (mixed brine). Although SWRO concentrates the mineral salts in the seawater into a brine solution, it is not a selective process for concentrating specific target mineral salts and it is only designed to generate a permeate comprising low salinity water. When found in a mixture (brine), these mineral salts have no commercial value and to become commercially valuable, they must be separated. However, with the currently available industrial technologies, it is very difficult and/or costly to separate and recover the individual mineral salts from the mixed brine. The cost is high because of the amount of energy required to achieve the isolation of the selected mineral salt. Alternatively, lower cost options such as systems for separating monovalent and polyvalent streams are known, but they are complex, costly and energy intensive. Some of these prior art approaches are mentioned below.

[0003] To separate specific mineral salts from water, it is known to use ion exchange methods which extract selected ions by attracting them on a resin carrier and recovering them by chemical regeneration. This process does not involve membranes and is highly capital cost intensive.

[0004] Other known methods of extracting a specific mineral salt, such as lithium salts, from seawater brine have involved evaporating brine, where a mineral salt-rich brine is pumped into large surface ponds for solar evaporation. This method disadvantageously requires extensive land use and significant amounts of water and involves lengthy processing times.

[0005] While the use of a selective membrane, similar to those seen in nature, may provide a potential solution to some of these challenges, efforts to date to replicate highly selective membranes seen in nature have not been very successful. Particular challenges have been identified with producing membranes for the selective transport of potassium ions, and in particular the selective transport of potassium ions over sodium ions.

[0006] The present disclosure seeks to address at least some of these concerns.

SUMMARY OF THE DISCLOSURE

[0007] The present disclosure is directed to a selective membrane for separating desalinated water and a selected mineral salt from seawater or another high-salinity solution. The selective membrane may be a conventional seawater reverse osmosis (SWRO) membrane comprising one or more ionophores. The present disclosure is also directed to a seawater reverse osmosis (SWRO) membrane comprising the selective membrane.

[0008] The present disclosure is further directed to an industrial integrated system that uses a mineral salt-selective membrane separation process to extract a selected mineral salt from seawater. The mineral salt-selective membranes of the disclosure allow selective passage of a cation of the selected mineral salt. The cation may then be combined (e.g. recombined) with an anion of the selected mineral salt at a later stage in the system to form the selected mineral salt. This industrial integrated system also uses one or more valorisation processes, including membrane crystallization and brine concentration, which enable reclaiming of the selected mineral salt from seawater and enable optimum production of selected target mineral salts and desalinated potable water from seawater. Use of these techniques is more cost effective than using alternative techniques such as thermal crystallisation and solar evaporation ponds. Instead of brine from desalination plants, other high-salinity sources may be used as input, such as produced water (i.e. high-salinity waste water) from the oil industry or geothermal industry (in particular from oil wells), brackish water, high-salinity water from lakes and seas, high-salinity groundwater, mineral water from springs and wells, as well as other natural or human-made high-salinity streams with a total dissolved solid (TDS)/salinity concentration of about 1,000 mg/L or more, for example about 2,000 mg/L or more. Typically, suitable high-salinity solutions have a salinity of up to about 300,000 mg/L. Typically, suitable high-salinity solutions have a salinity of from about 1,000 mg/L to about 300,000 mg/L. Naturally, it will be understood that the different sources of high-salinity solutions may have different salinities. For example, typically seawater has a salinity in the range of from about 35,000 mg/L to about 44,000 mg/L. Typically, produced water has a salinity in the range of from about 100,000 mg/L to about 300,000 mg/L. Typically, brackish water has a salinity in the range of from about 1,000 mg/L to about 4,000 mg/L. It should be understood that where seawater is referenced throughout the disclosure, other high-salinity solutions may be used instead of, or as well as, seawater.

[0009] In order to extract selected valuable mineral salts from seawater, the system of the present disclosure comprises the same processes as a conventional seawater reverse osmosis (SWRO) system but incorporates a special chemically modified membrane with an embedded active substance (e.g. an ionophore) for mineral salt-selective separation. The chemically modified selective membranes allow selective passage of a cation of a selected mineral salt through the membrane. The cation may then be combined (e.g. recombined) with a suitable anion to form the selected mineral salt at a later stage of the process. The anion may be an anion present in the input seawater or other high-salinity solution. As such, the mineral salt-selective membranes may be used to extract a specific mineral salt from the seawater or another high-salinity solution. Advantageously, the mineral salt-selective membranes described herein can be readily implemented in existing SWRO systems without an additional cost or complexity and thereby valorise a particular mineral salt contained in seawater, thereby combining fresh water production and selected mineral salt extraction by the same membrane. This approach can be applied for seawater mining of mineral salts such as potassium salts (e.g. potassium chloride), magnesium salts (e.g. magnesium chloride), lithium salts (e.g. lithium chloride) and rubidium salts (e.g. rubidium chloride). The mineral salt-selective membrane allows the cation of the selected mineral salt (e.g. K^+ , Mg^{2+} , Li^+ or Rb^+) to pass through the membrane, the anion may then be recombined with a negative ion (e.g. a chloride ion) at a later stage of the valorisation method, for example via crystallization, to extract the selected mineral salt. Also, the present system can advantageously be retrofitted to existing desalination plants to greatly improve their seawater valorisation. Advantageously, the present system is 2 to 3 times less capital cost intensive than the ion exchange methods mentioned above.

[0010] As mentioned above, an embodiment of the present disclosure uses membranes with an embedded active substance which can actively select a particular cation such as potassium ions (K^+ ions) from seawater or other high-salinity water source (also referred to as other high-salinity solution). Prior to the present disclosure, membranes that can attract the desired cation and carry it through the membrane, while repelling other mineral salts based on their charge and conductivity were not commercially available. The present system then recovers and concentrates this mineral salt in a subsequent brackish reverse osmosis system more cost effectively than any other mineral salt recovery systems mentioned above. While conventional SWRO membranes have a layer designed to only transfer and separate fresh water from seawater, the membrane of the present disclosure is capable of transferring fresh water and a particular selected cation of a selected mineral salt. The capability of the present disclosure is to select two commercially viable products: fresh water and a targeted selected mineral salt. Such selectivity is achieved by embedding a chemical substance that modifies the structure of the membrane, enabling the membrane to select both water and a cation of the targeted mineral salt. The chemical substance is chosen to have the characteristics of attracting the cation of the target selected mineral salt whilst repelling other ions of non-selected mineral salts. The chemical substance is an ionophore. It is understood that there will be numerous ionophores in the membrane to form ionophore channels through the membrane for the transport of cations of the selected mineral salt. As such, where an ionophore is referred to, this is intended to refer to one type of ionophore and not necessarily a singular ionophore in the membrane. Accordingly, where two or

more ionophores are referred to, this is intended to refer to two or more types of ionophore (e.g. two different types of crown ether ionophores). In some embodiments, when the selected mineral salt is a potassium salt, the ionophore may be a crown ether ionophore. Each different target selected mineral salt will require a specific chemical substance with qualities to attract the specific cations of the target mineral salt and repel all other ions. For example, when the selected mineral salt is a potassium salt (e.g. KCl), the ionophore may be selected from 18-Crown 6-Ether (1,4,7,10,13,16-hexaoxacyclooctadecane), 4'-Aminobenzo-18-crown-6 (2,5,8,11,14,17-hexaoxabicyclo[16.4.0]docosa-1(18),19,21-trien-20-amine), 2-Hydroxymethyl-18-crown-6 (1,4,7,10,13,16-hexaoxacyclooctadecane-2-methanol), Potassium Ionophore I (valinomycin, (3S,6S,9R,12R,15S,18S,21R,24R,27S,30S,33R,36R)-6,18,30-trimethyl-3,9,12,15,21,24,27,33,36-nona(propan-2-yl)-1,7,13,19,25,31-hexaoxa-4,10,16,22,28,34-hexazacyclohexatriacontane-2,5,8,11,14,17,20,23,26,29,32,35-dodecone), Potassium Ionophore II (bis(2,5,8,11,14-pentaoxabicyclo[13.4.0]nonadeca-1(15),16,18-trien-17-ylmethyl) heptanedioate) and/or Potassium Ionophore III ([2-methyl-2-[(18-nitro-2,5,8,11,14-pentaoxabicyclo[13.4.0]nonadeca-1(15),16,18-trien-17-yl)carbamoyloxymethyl]tetradecyl] *N*-(18-nitro-2,5,8,11,14-pentaoxabicyclo[13.4.0]nonadeca-1(15),16,18-trien-17-yl)carbamate). In particular embodiments where the selected mineral salt is a potassium salt (e.g. KCl), the ionophore may be selected from 18-Crown-6, 4'-Aminobenzo-18-crown-6 and/or Potassium Ionophore II. In particular embodiments where the selected mineral salt is a potassium salt (e.g. KCl), the ionophore may be Potassium Ionophore II. In other embodiments, when the selected mineral salt is a lithium salt, the ionophore may be selected from $\text{Li}_{0.33}\text{La}_{0.55}\text{TiO}_3$ (LLTO), Lithium Ionophore VI (6,6-Dibenzyl-1,4,8-11-tetraoxacyclotetradecane, 6,6-Dibenzyl-14-crown-4) and/or Lithium Ionophore VIII (N,N,N',N'',N'''-Hexacyclohexyl-4,4',4''-propylidynetris(3-oxabutamide)). In other embodiments, when the selected mineral salt is a magnesium salt, the ionophore may be selected from Magnesium Ionophore I (ETH 1117, Magnesium-ligand, N,N'-Diheptyl-N,N'-dimethyl-1,4-butanediarnide), Magnesium Ionophore III (ETH 4030, N,N'-Octamethylene-bis(N'-heptyl-N'-methylmalonamide)), Magnesium Ionophore IV (ETH 7025, N,N',N''-Tris[3-(heptylmethylamino)-3-oxopropionyl]-8,8'-iminodioctylamine) and/or Magnesium Ionophore VI (1,3,5-Tris[10-(1-adamantyl)-7,9-dioxo-6,10-diazaundecyl]benzene, ETH 5506). In other embodiments, when the selected mineral salt is a rubidium salt, the ionophore may be selected from potassium cobalt hexacyanoferrate (KCoFC) or zeolitic imidazole frameworks (ZIF) grafted with KCoFC (KCoFC@ZIF).

[0011] The chemically modified membranes used in the SWRO system described herein are semipermeable for water molecules and a specific cation of the target mineral salt. Thus, when these membranes are used in a conventional reverse osmosis process, they allow cations of the target mineral salt (selected mineral salt) and desalinated water to pass but filter out all other seawater impurities such as NaCl and other mineral salts. The target mineral salt is then separated from the permeate, which has passed through the SWRO stage, in a subsequent stage of brackish water reverse osmosis (BWRO) using a conventional membrane.

[0012] In the present system, the target mineral salt is separated from the desalinated water permeate by the membrane of the BWRO process, into a further brine which has a high concentration of the selected mineral salt. Then the target mineral salt is valorised from the brine so as to harvest the selected mineral salt as a commercially valuable mineral salt with low production costs and high purity levels. The process of brine valorisation described herein, recovers a specified type of mineral salt, the selected mineral salt, which would otherwise be considered to be waste and as such provides an advantage over conventional SWRO systems that produce brine mixtures of no commercial value, in addition to desalinated water.

[0013] Embodiments of this disclosure are also directed to recovering the selected mineral salt in a solid form such that the recovered mineral salt is commercially useful without the need for further industrial processing. For example, the concentrated brine with the selected material may be subjected to membrane crystallisation to recover the selected mineral salt in solid usable form.

[0014] The design and operating parameters of a mineral salt-selective reverse osmosis process described herein, can be altered to target specific individual ions. This results in a customized production (reclaiming) of mineral salts when further processes, such as brine concentration and membrane crystallization, are included in the system. The system of the present disclosure significantly reduces the energy and capital costs for valorisation of mineral salts contained in seawater.

[0015] The present disclosure provides a selective membrane for separating desalinated water and a selected mineral salt from seawater or another high-salinity solution, wherein the selective membrane comprises a polysulfone layer and a salt separation layer, and wherein the salt separation layer comprises a polyamide layer comprising one or more ionophore.

[0016] The selective membrane may be a seawater reverse osmosis membrane.

[0017] In some embodiments of the selective membrane according to the disclosure, the selected mineral salt is a potassium salt and the ionophore is a crown ether ionophore.

[0018] In some embodiments of the selective membrane according to the disclosure, the selected mineral salt is a potassium salt and the one or more ionophore is selected from 18-Crown-6, 4'-Aminobenzo-18-crown-6 and/or Potassium Ionophore II.

[0019] In some embodiments, the polyamide layer comprises two or more ionophores. In some such embodiments, the two or more ionophores are selected from the group consisting of 18-Crown-6, 4'-Aminobenzo-18-crown-6, and Potassium Ionophore II.

[0020] In some embodiments of the selective membrane according to the disclosure, the selected mineral salt is a lithium salt and the ionophore is selected from $\text{Li}_{0.33}\text{La}_{0.56}\text{TiO}_3$ (LLTO), Lithium Ionophore VI and/or Lithium Ionophore VIII.

[0021] In some embodiments of the selective membrane according to the disclosure, the selected mineral salt is a magnesium salt and the ionophore is selected from Magnesium Ionophore I, Magnesium Ionophore III, Magnesium Ionophore IV and/or Magnesium Ionophore VI.

[0022] In some embodiments of the selective membrane according to the disclosure, the selected mineral salt is a rubidium salt and the ionophore is selected from potassium cobalt hexacyanoferrate (KCoFC) or zeolitic imidazole frameworks (ZIF) grafted with KCoFC (KCoFC@ZIF).

[0023] In some embodiments, the selective membrane comprises the following layers, in order:

- i. a polyester support layer;
- ii. a polysulfone layer; and
- iii. a salt separation layer,

wherein the salt separation layer comprises a polyamide layer comprising one or more ionophore.

[0024] In some embodiments, the polysulfone layer comprises polysorbate 20 (PS20).

[0025] The disclosure also provides a seawater reverse osmosis (SWRO) system comprising a selective membrane according to the disclosure.

[0026] Further provided is a system for recovering a selected mineral salt from seawater or another high-salinity solution, the system comprising:

- a. a seawater reverse osmosis (SWRO) system according to the disclosure for separating the seawater or other high-salinity solution into an SWRO permeate comprising desalinated water and the selected mineral salt, and an SWRO retentate;
- b. a brackish water reverse osmosis (BWRO) system comprising one or more BWRO stage for concentrating the SWRO permeate to produce desalinated water and a BWRO brine comprising the selected mineral salt; and
- c. a selected mineral valorisation system for extracting the selected mineral salt from the BWRO brine.

[0027] In some embodiments, the SWRO permeate substantially consists of desalinated water and the selected mineral salt.

[0028] The SWRO permeate may comprise 90% or greater of the selected mineral salt present in the input seawater or other high-salinity solution.

[0029] The SWRO retentate may comprise less than 10% of the selected mineral salt present in the input seawater or other high-salinity solution.

[0030] In some embodiments, the BWRO system comprises two or more BWRO stages for further increasing the percentage concentration of the selected mineral salt in the BWRO brine.

[0031] In some such embodiments where the BWRO system comprises two or more BWRO stages, the BWRO system comprises:

- a. a first BWRO stage for concentrating the SWRO permeate to produce desalinated water and a BWRO retentate comprising the selected mineral salt; and
- b. a second BWRO stage for concentrating the BWRO retentate to produce desalinated water and a BWRO brine comprising the selected mineral salt.

[0032] In embodiments where the BWRO system comprises two or more BWRO stages, the BWRO brine may comprise 80% or greater of the selected mineral salt present in the SWRO permeate.

[0033] In some embodiments, the selected mineral valorisation system comprises:

- a. a brine concentration system for concentrating the BWRO brine to produce a concentrated BWRO brine; and
- b. a crystallization system for crystallizing the selected mineral salt out of the concentrated BWRO brine.

[0034] The brine concentration system may comprise one or more osmotically assisted reverse osmosis (OARO) membranes or a thermal evaporation unit. The brine concentration system may comprise one or more OARO membranes. The brine concentration system may comprise two or more OARO membranes.

[0035] The crystallization system may comprise a thermal crystallization unit or a membrane crystallization unit. The crystallization system may comprise a membrane crystallization unit.

[0036] The membrane crystallization unit may comprise one or more membrane crystallizers that use magnesium chloride or sodium chloride as a draw solution to crystallize the selected mineral salt out of the concentrated BWRO brine.

[0037] In embodiments where the selected mineral salt is a potassium containing mineral salt, the one or more membrane crystallizers may use a magnesium chloride draw solution.

[0038] The disclosure additionally provides a method for recovering a selected mineral salt from seawater or another high-salinity solution, the method comprising:

- a. processing the seawater or other high-salinity solution in a seawater reverse osmosis (SWRO) system according to the disclosure, to separate the seawater into an SWRO permeate comprising desalinated water and the selected mineral salt, and an SWRO retentate;
- b. concentrating the SWRO permeate in a brackish water reverse osmosis (BWRO) system comprising one or more BWRO stage to produce desalinated water and a BWRO brine comprising the selected mineral salt;

- c. extracting the selected mineral salt from the BWRO brine in a selected mineral valorisation system.

[0039] In some embodiments of the method for recovering a selected mineral salt from seawater or another high-salinity solution, the SWRO permeate substantially consists of desalinated water and the selected mineral salt.

[0040] The SWRO permeate may comprise 90% or greater of the selected mineral salt present in the input seawater or other high-salinity solution.

[0041] The SWRO retentate may comprise less than 10% of the selected mineral salt present in the input seawater or other high-salinity solution.

[0042] The BWRO brine may comprise 80% or greater of the selected mineral salt present in the SWRO permeate.

[0043] In some embodiments of the method, concentrating the SWRO permeate in the BWRO system comprises passing the SWRO permeate through two or more BWRO stages and wherein each consecutive BWRO stage further increases the percentage concentration of the selected mineral salt in the BWRO brine.

[0044] In some such embodiments, concentrating the SWRO permeate in the BWRO system comprises:

- a. concentrating the SWRO permeate in a first BWRO stage to produce desalinated water and a BWRO retentate comprising the selected mineral salt; and
- b. concentrating the BWRO retentate in a second BWRO stage to produce desalinated water and a BWRO brine comprising the selected mineral salt.

[0045] In some such embodiments, the BWRO retentate may comprise 80% or greater of the selected mineral salt present in the SWRO permeate, and the BWRO brine may comprise 85% or greater of the selected mineral salt present in the BWRO retentate.

[0046] In some embodiments of the method, extracting the selected mineral salt from the BWRO brine comprises:

- a. concentrating the BWRO brine in a concentration system to produce a concentrated BWRO brine; and
- b. crystallizing the selected mineral salt out of the concentrated BWRO brine in a crystallization system.

[0047] Concentrating the BWRO brine may comprise passing the BWRO brine through one or more osmotically assisted reverse osmosis (OARO) membranes or a thermal evaporation unit.

Concentrating the BWRO brine may comprise passing the BWRO brine through one or more OARO membranes. Concentrating the BWRO brine may comprise passing the BWRO brine through two or more OARO membranes.

[0048] The concentrated BWRO brine may have a concentration of from about 215 g/L to about 235 g/L.

[0049] The crystallization system may comprise a thermal crystallization unit or a membrane crystallization unit. The crystallization system may comprise a membrane crystallization unit.

[0050] The membrane crystallization unit may comprise one or more membrane crystallizers that use magnesium chloride or sodium chloride as a draw solution to crystallize the selected mineral salt out of the concentrated BWRO brine.

[0051] In embodiments where the selected mineral salt is a potassium containing mineral salt, the one or more membrane crystallizers may use a magnesium chloride draw solution.

[0052] The disclosure further provides a method of manufacturing a selective membrane according to the disclosure, the method comprising the following steps, in order:

- a. Mixing one or more ionophore into an amine solution;
- b. Depositing the amine solution on a polysulfone layer;
- c. Depositing an acid chloride solution on the amine solution to form a polyamide layer.

[0053] The method of manufacturing a selective membrane according to the disclosure may comprise mixing one or more ionophore into an amine solution, as well as the following steps, in order:

- a. Depositing a polysulfone layer on a polyester layer;
- b. Depositing the amine solution on the polysulfone layer;
- c. Depositing an acid chloride solution on the amine solution to form a polyamide layer.

[0054] In some embodiments, the polysulfone layer may comprise polysorbate 20 (PS20).

BRIEF DESCRIPTION OF THE DRAWINGS

[0055] Embodiments of the disclosure will now be described, by way of example, with reference to the accompanying drawings, in which:

[0056] Figure 1 shows a conventional SWRO system;

[0057] Figure 2 shows a system for recovering a selected mineral salt from seawater or another high-salinity solution, according to an embodiment of the present disclosure; and

[0058] Figure 3 shows the system as shown in Figure 2 in greater detail.

DETAILED DESCRIPTION

[0059] Various exemplary embodiments and details are described hereinafter, with reference to the figures when relevant. It should be noted that the figures may or may not be drawn to scale and that elements of similar structures or functions are represented by like reference numerals throughout the figures. It should be noted that the figures are only intended to facilitate the description of the embodiments. They are not intended as an exhaustive description of the disclosure or as a limitation of the scope of the disclosure. In addition, an illustrated embodiment needs not have all the aspects or advantages shown. An aspect or an advantage described in conjunction with a particular embodiment is not necessarily limited to that embodiment and can be practiced in any other embodiments even if not so illustrated, or if not so explicitly described.

[0060] The figures are schematic and simplified for clarity, and they merely show details which aid understanding of the disclosure, while other details have been left out.

[0061] Figure 1 shows a conventional seawater reverse osmosis (SWRO) membrane system, comprising a conventional SWRO membrane, for separating seawater into desalinated water and a brine comprising a high concentration of all mineral salts from the seawater.

[0062] Generally, the present system 10 can be considered schematically as shown in Figure 2. Here seawater is provided to a Selective Membrane System (also referred to as a SWRO system) 100, which is then used to generate a SWRO permeate 103 comprising a brine containing water and the target mineral salt. Typically, the SWRO permeate 103 substantially consists of desalinated water and the selected mineral salt. Typically, the SWRO permeate 103 comprises 80% or greater of the selected mineral salt, for example 90% or greater of the selected mineral salt present in the input seawater or other high salinity solution. For example, the SWRO permeate may comprise from about 360 mg/L to about 400 mg/L potassium chloride (for example about 380 mg/L potassium chloride). The Selective Membrane System 100 comprises seawater reverse osmosis (SWRO) membranes that are chemically modified to be semi-permeable to water (e.g. distilled water) and cations of the selected mineral salt. The SWRO membranes therefore reject the retentate of all other mineral salts as a brine 110 (also referred to herein as SWRO retentate) containing a high concentration of mineral salts but with a very low concentration of the selected mineral salt. It is noted that the high concentration of mineral salts other than the selected mineral salt in the SWRO retentate, will be of a similar concentration to the input seawater or other high-salinity solution (e.g. within 3% of the concentration of each mineral salt other than the selected mineral salt in the input seawater), in the same way as for a conventional SWRO membrane. Typically, the SWRO retentate comprises 20% or

less of the selected mineral salt, for example 10% or less of the selected mineral salt present in the input seawater or other high salinity solution. It is possible for this brine 110 to be subsequently processed by other systems or disposed of in the conventional manner.

[0063] The SWRO permeate 103 output by the Selective Membrane System 100, is passed through a conventional Brackish Water Membrane Reverse Osmosis (BWRO) System 102. This generates desalinated water 105 as the permeate, and the selected mineral salt is retained in the retentate (BWRO brine 104). By processing the SWRO permeate 103 in the BWRO system the selected mineral salt is separated from water by applying pressure against the BWRO membranes. This results in the mineral salt being retained and concentrated in a BWRO brine 104. Typically, over 99% (w/w) of the salts in the BWRO brine 104 are the selected mineral salt. The BWRO permeate 105 contains all the fresh desalinated water. The concentrated BWRO brine 104 is then passed to a selected mineral salt valorisation system 106 to extract the selected mineral salt 108 from the concentrated brine 104 in crystal form.

[0064] As mentioned above, the BWRO selective membrane system 102 also produces desalinated water 105 and can be applied to any existing or new seawater reverse osmosis desalination plant. Therefore, the SWRO Selective Membrane System 100 in combination with the BWRO membrane system 102 and the Selected Mineral Valorisation System 106, can be used to enhance the function of conventional desalination plants to not only produce fresh water but to also recover the valuable mineral salts contained in the seawater, instead of disposing of them in brine mixtures (typically back into the sea) with little to no commercial value. The present embodiment of the disclosure can thus be widely implemented for brine valorisation worldwide.

[0065] Figure 3 shows the present system 10 in greater detail. In particular, Figure 3 shows the components of the BWRO Membrane System 102 and the Selected Mineral Valorisation system 106. The BWRO Membrane System 102 comprises a plurality of membrane processes including in this embodiment two stages of brackish water reverse osmosis (BWRO) 102a, 102b. The second BWRO stage 102b outputs the brine with the selected mineral salt 104 to the Selected Mineral Valorisation System 106. The purpose of having two stages of BWRO Membrane system 102 is to increase the concentration of the mineral salt which is captured by the membranes of this stage. This not only helps to enable the brackish water to become purer desalinated water permeate 105 but also increases the concentration of the brine with the selected mineral salt 104. It will be understood that the rejection rate of the selected mineral salt will vary with a number of factors, including the source and temperature of the input seawater or other high-salinity solution. However, as has been mentioned before, this arrangement typically produces a BWRO brine 104 with a selected mineral salt rejection rate of greater than 80%, typically greater than 85%, for example greater than 90%, or greater than 95% (e.g. in some embodiments the mineral salt rejection rate may be >99%). More specifically, the output of the first stage BWRO system 102a may recover a BWRO retentate 116 comprising 80% or greater of the mineral salt in the SWRO permeate 103, for example 85% or greater of the mineral salt in the SWRO permeate 103 (e.g. 90% or greater). In embodiments where a

potassium salt is the selected salt, the first stage of the BWRO system 102a may recover a BWRO brine 104 comprising 95% or greater (e.g. about 99.0%) of the mineral salt in the SWRO permeate 103. The output of the second stage of the BWRO system 102b may have an increased recovery such that the BWRO brine 104 may comprise 85% or greater of the mineral salt in the BWRO retentate 116, for example 90% or greater of the mineral salt in the BWRO retentate 116 (e.g. 95% or greater). In embodiments where a potassium salt is the selected salt, the second stage of the BWRO system 102b may recover 98% or greater (e.g. over 99.5%) of the mineral salt in the BWRO retentate 116. In contrast, the desalinated water which may typically contain less than 1% of the selected mineral salt in the SWRO permeate 103. Notably, this recovery of almost all of the selected mineral salt in the seawater is achieved with no additional expenditure of energy and capital costs as the BWRO membrane system 102 is already provided in desalination plants to produce potable desalinated water and the SWRO selective membrane system 100 simply requires a standard polysulphone (polysulfone) membrane with an added chemical (see below).

[0066] The selected mineral salt valorisation system 106 comprises two stages. The first is a brine concentration system 112 comprising a plurality of osmotically assisted reverse osmosis (OARO) membranes. The brine concentration system 112 increases the concentration of the brine to approximately 225 g/L (for example from about 215 g/L to about 235 g/L) so as to increase the quantity and purity of mineral salts that are ultimately obtained. Alternatively, the brine concentration system 112 may comprise a thermal evaporation unit. The second stage in the selected mineral valorisation system 106 is a membrane crystallization unit 114 for crystallizing out the selected mineral salt as a selected mineral salt 108. Alternatively, the selected mineral salt can be crystallized using thermal crystallization. However, membrane crystallization is preferred as it is more energy efficient. The membrane crystallization unit 114 includes membrane crystallizers that use magnesium chloride or sodium chloride as a draw solution to crystallize the selected mineral salt on the surface of the membrane. This method of crystallization enables the selected mineral salt to be easily collected from the surface of the membrane and dried to be used for commercial purposes.

[0067] The combination of obtaining a brine stream with a highly concentrated amount of a selected mineral salt and then carrying out a selected mineral salt valorisation on that stream, provides a significantly more cost-effective way of recovering the selected mineral salt whilst at the same time requiring little additional cost of modification of the desalination plant. In particular, the addition of membrane crystallizers to existing desalination plants is relatively inexpensive when compared to other crystallization systems such as thermal crystallizers. Similarly, the concentration of the selected mineral salt can be completed using thermal evaporation. However, using OARO is much more energy efficient and cost-effective.

[0068] In the current embodiment, standard size seawater reverse osmosis (SWRO) membranes are used, which are conventional polysulfone membranes. Conventional SWRO membranes typically comprise in order a base / support layer (e.g. a polyester layer), a polysulfone layer and a salt separation layer. In some embodiments, the polyester layer and the polysulfone layer are separate,

adjacent layers. However, in some embodiments, there may be a single layer comprising polyester and polysulfone (e.g. a layer of polysorbate 20, PS20). Typically, the salt separation layer comprises polyamide (for example the salt separation layer is a polyamide layer). In the present disclosure, the salt separation layer of these conventional SWRO membranes may be altered by embedding an active chemical ingredient (e.g. an ionophore) into the chemical structure of the separation layer which allows only cations of a particular mineral salt to pass through the membranes along with the fresh water contained in the seawater. The altered membranes enable separation of the target mineral salt from the rest of the mineral salts in the source seawater and allow it to be recovered for beneficial commercial uses as has been described above.

[0069] Various different mineral salts can be recovered from seawater using the above selective mineral salt recovery system 10 and recovery methods described herein. Depending on the selected mineral salt, a different active chemical ingredient can be used to achieve the mineral salt selectivity referred to above. As described above, when the selected mineral salt is a potassium salt (e.g. KCl), the ionophore may be selected from 18-Crown 6-Ether, 4'-Aminobenzo-18-crown-6, 2-Hydroxymethyl-18-crown-6, Potassium Ionophore I, Potassium Ionophore II and/or Potassium Ionophore III. In particular embodiments where the selected mineral salt is a potassium salt (e.g. KCl), the ionophore may be selected from 18-Crown-6, 4'-Aminobenzo-18-crown-6 and/or Potassium Ionophore II. In particular embodiments where the selective mineral salt is a potassium salt (e.g. KCl), the ionophore may be Potassium Ionophore II. In other embodiments, when the selected mineral salt is a lithium salt, the ionophore may be selected from $\text{Li}_{0.33}\text{La}_{0.55}\text{TiO}_3$ (LLTO), Lithium Ionophore VI and/or Lithium Ionophore VIII. In other embodiments, when the selected mineral salt is a magnesium salt, the ionophore may be selected from Magnesium Ionophore I, Magnesium Ionophore III, Magnesium Ionophore IV and/or Magnesium Ionophore VI. In other embodiments, when the selected mineral salt is a rubidium salt, the ionophore may be selected from potassium cobalt hexacyanoferrate (KCoFC) or zeolitic imidazole frameworks (ZIF) grafted with KCoFC (KCoFC@ZIF). Accordingly, the ionophore in the membrane can be selected based on the selected mineral salt. For example, if the selected mineral salt is potassium chloride (KCl), then the system and method described above can be used to extract potassium chloride (KCl). In the embodiment where the selected mineral salt is potassium chloride, the special active chemical ingredient (i.e. the one or more ionophores) may be Potassium Ionophore II. Potassium Ionophore II may be added to the base membrane formulation to increase the surface selectivity of the reverse osmosis membranes. By increasing the surface selectivity, the reverse osmosis membranes only allow potassium cations to pass through it along with water, and reject mineral salts containing other monovalent ions, such as sodium.

[0070] The desalinated water containing potassium chloride is subsequently directed to the BWRO membrane system 102, which includes two BWRO stages, as described above. The first stage separates the potassium chloride from the permeate (desalinated water), recovering about 80% or greater (e.g. to >99%) of the potassium chloride as described above. The second stage further increases the concentration of potassium chloride; recovering about 85% or greater (e.g. about 99.5%) of the potassium chloride as previously described.

[0071] The concentrated potassium chloride is then conveyed to the selected mineral valorisation system 106 to recover potassium chloride crystals that can be used for commercial purposes. In the first stage of the selected mineral valorisation system 106, the concentrated potassium chloride is further concentrated using an OARO membrane comprised in the brine concentration system 112. The potassium chloride is subsequently conveyed to the membrane crystallization system 114 comprising a membrane crystallizer to reclaim potassium chloride crystals. The membrane crystallizer uses a magnesium chloride draw solution. Alternatively, or for the recovery of a different selected mineral salt, a sodium chloride draw solution can be used. However, a magnesium chloride draw solution is preferred for the recovery of potassium chloride because the amount of draw solution required is lower.

[0072] In other embodiments, the retentate comprising the selected mineral salt contained in the brine, can be used in liquid form as it is output from the BWRO membrane system 102. In the present embodiment, brine comprising 85% or greater (e.g. about 99%) of the selected mineral salt as described above is further concentrated and crystallized by membrane crystallization (lowest cost), to obtain a high-purity commercial product. In another embodiment which is less preferred, the membrane crystallisation can be replaced by thermal crystallization though it is appreciated that this is less cost effective than a membrane crystallizer due to the increased power consumption and energy use.

[0073] The disclosure further provides a method of manufacturing a selective membrane according to the disclosure, the method comprising the following steps, in order:

- a. Mixing one or more ionophore into an amine solution;
- b. Depositing the amine solution on a polysulfone layer;
- c. Depositing an acid chloride solution on the amine solution to form a polyamide layer.

[0074] As described above, in some embodiments, the polyester layer and the polysulfone layer are separate, adjacent layers. In such embodiments, the method of manufacture may comprise mixing one or more ionophore into an amine solution, as well as the following steps, in order:

- a. Depositing a polysulfone layer on a polyester layer;
- b. Depositing the amine solution on the polysulfone layer;
- c. Depositing an acid chloride solution on the amine solution to form a polyamide layer.

[0075] In other embodiments, the polysulfone layer may comprise a polysulfone and a polyester. For example, there may be a single layer comprising polyester and polysulfone (e.g. a layer of polysorbate 20, PS20). In such embodiments, the polysulfone layer may comprise polysorbate 20 (PS20), for example the polysulfone layer may consist of polysorbate 20 (PS20).

[0076] Variations of the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure and the

appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. The mere fact that certain features are recited in mutually different dependent claims does not indicate that a combination of these claims cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.

EXAMPLES

Example 1 – Manufacture and testing of potassium selective membranes

[0077] Various potassium selective membranes according to embodiments of the present disclosure were manufactured according to the following method. Different potassium selective compounds (different ionophores) were used to manufacture the different membranes. The membranes were subsequently tested to determine their selectivity and suitability for use as a potassium selective SWRO membrane. It should be understood that the potassium ionophores in the method described herein could be replaced with suitable ionophores for lithium ions, magnesium ions or rubidium ions to produce selective membranes for lithium ions, magnesium ions or rubidium ions, respectively.

[0078] A sheet of ultrafiltration (UF) membrane (e.g. a commercially available PS20 UF membrane) was soaked in sodium hydroxide solution at pH 12 for 30 minutes at 50 °C . The solution was changed, and a fresh sodium hydroxide solution was used under the same conditions and for the same length of time. After that, the membrane was soaked in Milli-Q® water (water purified using a Millipore Milli-Q® lab water system) for 30 minutes at 50 °C . After that, the membrane was rinsed with MilliQ® water at room temperature for 30 minutes. The membrane was then dried in an oven at 30°C overnight.

[0079] A matrix of experiments was designed to produce flat sheet membranes with the target water and seawater permeabilities of a seawater reverse osmosis (SWRO) membrane. In each case, 3.4 g of M-phenylenediamine (MPD, 99.5%) was dissolved in 93.45 g 18 MΩ laboratory deionised water (ultrapure water). To enhance uptake by the support membrane, 0.1 wt.% Sodium dodecyl sulfate (SDS) was added to the amine solution in all cases. In addition, 2 g of (+)-Camphor-10-sulfonic acid (CSA, ≥98%) was added into the amine solution, which dropped the pH to about pH 3 to 4. Then, 1 g of Triethylamine (TEA, ≥ 99%) was added into the amine solution to increase the pH to between 8 and 9. In parallel, a specified amount of a potassium selective compound (see Tables 2 and 3 below) was dissolved in DMSO, which was then added into the bulk amine solution. The concentration of DMSO was designed to be 2 wt.%. To make the acid chloride monomer solution, 1,3,5-Benzenetricarbonyl trichloride (TMC, ≥98%) was dissolved in Isopar™ G (e.g. procured from Gallade Chemical Inc., Santa Ana, CA, USA) to make a 0.17 wt.% solution.

[0080] To make the membrane, a 17 cm x 13 cm clean, dry polysulfone ultrafiltration membrane was placed on a clean, dry glass plate and was clamped down under a 15 cm x 10 cm wooden frame. The

amine solution was poured on the surface of the membrane. The amine monomer solution coating time was fixed at 120 seconds. Extra solution was drained off and excess remaining on the surface of the membrane was removed by a squeegee. After making sure no aqueous droplets remained on the membrane surface, the membrane was then dipped into the acid chloride monomer solution for 60 s. The membrane was put in an oven at 60 °C for 10 minutes, and then, 125 °C for 2 minutes to produce a cured seawater reverse osmosis (SWRO) membrane.

[0081] Next, the cured SWRO membrane was subjected to chemical treatment to wash off unreacted monomers. First, the membrane was soaked in a 2 g/L aqueous solution of sodium carbonate at 50 °C for 10 minutes. The residual sodium carbonate was washed off with 18 MW deionised water at 50 °C for 10 minutes. Finally, the membrane was washed with fresh deionised water at room temperature twice, and then stored in fresh deionised water in light-proof containers in a laboratory refrigerator at 5 °C until use.

[0082] Before the selective membrane could be tested, it was necessary to ascertain if the DMSO in the manufacturing process had any effect on the potassium ion (K⁺) selectivity of the membrane. DMSO is known to improve the water flux in a desalination membrane. Therefore, it was necessary to determine whether the presence of DMSO as a solvent would make the membrane be potassium ion (K⁺) selective to any degree. This was done by comparing the performance of two control membranes (i.e. conventional SWRO membranes), one with DMSO and one without DMSO. The results showed that, with or without DMSO, the control membranes had higher sodium ion (Na⁺) passage than potassium ion (K⁺) passage. Therefore, it was determined that DMSO does not enable the membranes to be K⁺ selective.

[0083] The separation performance of the potassium selective SWRO membranes was evaluated in a Sterlitech crossflow membrane filtration system equipped with three membrane cells (2.54 cm by 7.62 cm each) with an active membrane area of 19.35 cm² in each cell. The permeate flow rate (V/Δt) was measured by a digital flow meter (for example an Optiflow 1000 from Agilent Technology). During testing, the feed solution was held at a constant temperature of 23±1 °C using a recirculating heater/chiller with an immersion coil in the feed tank.

[0084] The feed solution was a standard synthetic seawater with a total dissolved salt of 35 g/L. The exact composition of the feed solution is provided in Table 1 below. This feed solution was passed through the membranes to test both the water flux (A) and the salt rejection (Ro) for each of the membranes.

Table 1:

Salt	Seawater concentration, mg/L
NaCl	25047
NaHCO ₃	158

KCl	655
MgSO ₄	3084
MgCl ₂ ·6H ₂ O	4685
CaCl ₂ ·2H ₂ O	1310
NaBO ₂ ·4H ₂ O	45
SrCl ₂ ·6H ₂ O	17

[0085] Bulk salt concentration in the feed and the permeate were measured by a conductivity meter, and electrical conductivity (EC) calibration curves were found to be linear for concentrations between 0 and 2,000 ppm. Therefore, the observed rejection rate (Ro) was calculated directly from the feed and permeate EC values below 2,000 ppm. The feed solution was diluted 100x and permeate samples above 2,000 ppm were diluted 10x to stay within the EC meter calibration range. After the measurements were taken, the resultant values were converted back to the true concentrations by multiplying them by the dilution ratio.

[0086] The selectivity of K⁺ ions and Na⁺ ions was determined by measuring the feed and permeate concentration using Inductively Coupled Plasma (ICP).

[0087] Table 2 below shows the performance of four potassium selective membranes (according to embodiments of the disclosure) as well as the two control membranes (one with DMSO and one without DMSO).

Table 2:

Membrane	Potassium ionophore(s) (defined in Table 3)	A (lmh/bar)	Ro (%)	Na ⁺ pass. (%)	K ⁺ pass. (%)	α_K
Control (w/o DMSO) (3hr ^{**})		1.68	99.18	0.92	0.78	0.84
Control (w/ DMSO) (3hr ^{**})		1.82	98.98	1.40	1.19	0.85
KSM1 (3hr ^{**})	KSC4 (0.1*)	2.72	99.34	0.68	0.90	1.32
KSM2 (1hr ^{**})	KSC4 (0.2*)	2.23	99.19	0.55	0.69	1.25
KSM3 (1hr ^{**})	KSC1 (0.5*)	4.92	97.01	3.12	4.66	1.49
KSM4 (3hr ^{**})	KSC0 (2*) + KSC1(0.5*)	3.80	97.28	3.49	5.60	1.6

*Concentration of potassium ionophore in wt. %.

**Duration of the performance test in hours.

Table 3:

KSC0	18-Crown-6
KSC1	4'-Aminobenzo-18-crown-6
KSC4	Potassium Ionophore II

[0088] All potassium selective membranes (KSMs) demonstrated higher potassium ion (K⁺) passage through the membrane than sodium ion (Na⁺) passage. The opposite was true for the control membranes. This is highlighted by the α_K values (showing potassium selectivity) of greater than 1 for all potassium selective membranes KSM1, KSM2, KSM3 and KSM4. This confirms that the

ionophores are indeed facilitating the transport of potassium ions. Without wishing to be bound by theory, it is understood that this is because the potassium ionophores form an artificial continuous channel of the K^+ ions across the polyamide layer of the membrane.

[0089] The membrane permeability (A) of each potassium selective membrane was also measured. A higher membrane permeability indicates a lower rejection of salts by the membrane. Naturally the rejection of salts will reduce as potassium ion passage through the membrane increases. However, the balance of potassium ion passage and salt rejection is important to ensure the membranes remain effective to extract desalinated water as well as the selected potassium salt. All potassium selective membranes tested had increased membrane permeability (A) compared to the control membranes, however the membrane permeability of the potassium selective membranes remained within an acceptable level. Therefore, it was shown that an acceptable balance between membrane permeability (A) and potassium selectivity (α_K) could be obtained.

[0090] KSM4 comprised a combination of two potassium ionophores (2 wt.% KSC0 and 0.5 wt.% KSC1). The results show that KSM4 has increased K^+ ion selectivity (α_K) without significantly increased membrane permeability (A) compared to the other potassium selective membranes (KSM1, KSM2 and KSM3).

CLAIMS:

1. A selective membrane for separating desalinated water and a selected mineral salt from seawater or another high-salinity solution, wherein the selective membrane comprises a polysulfone layer and a salt separation layer, and wherein the salt separation layer comprises a polyamide layer comprising one or more ionophore.
2. The selective membrane according to claim 1, wherein the selective membrane is a seawater reverse osmosis membrane.
3. The selective membrane according to claim 1 or 2, wherein the selected mineral salt is a potassium salt and the ionophore is a crown ether ionophore.
4. The selective membrane according to any of claims 1 to 3, wherein the selected mineral salt is a potassium salt and the one or more ionophore is selected from 18-Crown-6, 4'-Aminobenzo-18-crown-6 and/or Potassium Ionophore II.
5. The selective membrane according to any of claims 1 to 4, wherein the polyamide layer comprises two or more ionophores.
6. The selective membrane according to claim 5, wherein the two or more ionophores are selected from the group consisting of 18-Crown-6, 4'-Aminobenzo-18-crown-6, and Potassium Ionophore II.
7. The selective membrane according to claim 1 or 2, wherein the selected mineral salt is a lithium salt and the ionophore is selected from $\text{Li}_{0.33}\text{La}_{0.56}\text{TiO}_3$ (LLTO), Lithium Ionophore VI and/or Lithium Ionophore VIII.
8. The selective membrane according to claim 1 or 2, wherein the selected mineral salt is a magnesium salt and the ionophore is selected from Magnesium Ionophore I, Magnesium Ionophore III, Magnesium Ionophore IV and/or Magnesium Ionophore VI.
9. The selective membrane according to claim 1 or 2, wherein the selected mineral salt is a rubidium salt and the ionophore is selected from potassium cobalt hexacyanoferrate (KCoFC) or zeolitic imidazole frameworks (ZIF) grafted with KCoFC (KCoFC@ZIF).
10. The selective membrane according to any of claims 1 to 9, wherein the selective membrane comprises the following layers, in order:
 - i. a polyester support layer;
 - ii. a polysulfone layer; and
 - iii. a salt separation layer,

wherein the salt separation layer comprises a polyamide layer comprising one or more ionophore.

11. The selective membrane according to any of claims 1 to 9, wherein the polysulfone layer comprises polysorbate 20 (PS20).
12. A seawater reverse osmosis (SWRO) system (100) comprising a selective membrane according to any of claims 1 to 11.
13. A system (10) for recovering a selected mineral salt (108) from seawater or another high-salinity solution, the system comprising:
 - i. a seawater reverse osmosis (SWRO) system (100) according to claim 12 for separating the seawater or other high-salinity solution into an SWRO permeate (103) comprising desalinated water and the selected mineral salt, and an SWRO retentate (110);
 - ii. a brackish water reverse osmosis (BWRO) system (102) comprising one or more BWRO stage (102a/b) for concentrating the SWRO permeate (103) to produce desalinated water (105) and a BWRO brine (104) comprising the selected mineral salt; and
 - iii. a selected mineral valorisation system (106) for extracting the selected mineral salt (108) from the BWRO brine (104).
14. The system (10) according to claim 13, wherein the SWRO permeate (103) substantially consists of desalinated water and the selected mineral salt.
15. The system (10) according to claim 13 or 14, wherein the SWRO permeate (103) comprises 90% or greater of the selected mineral salt present in the input seawater or other high-salinity solution.
16. The system (10) according to any of claims 13 to 15, wherein the SWRO retentate (110) comprises less than 10% of the selected mineral salt present in the input seawater or other high-salinity solution.
17. The system (10) according to any of claims 13 to 16, wherein the BWRO system (102) comprises two or more BWRO stages (102a, 102b) for further increasing the percentage concentration of the selected mineral salt in the BWRO brine (104).
18. The system (10) according to claim 17, wherein the BWRO system comprises:

- i. a first BWRO stage (102a) for concentrating the SWRO permeate (103) to produce desalinated water (105) and a BWRO retentate (116) comprising the selected mineral salt; and
 - ii. a second BWRO stage (102b), for concentrating the BWRO retentate (116) to produce desalinated water (105) and a BWRO brine (104) comprising the selected mineral salt.
- 19. The system (10) according to claim 17 or 18, wherein the BWRO brine (104) comprises 80% or greater of the selected mineral salt present in the SWRO permeate (103).
- 20. The system (10) according to any of claims 13 to 19, wherein the selected mineral valorisation system (106) comprises:
 - i. a brine concentration system (112) for concentrating the BWRO brine (104) to produce a concentrated BWRO brine; and
 - ii. a crystallization system for crystallizing the selected mineral salt (108) out of the concentrated BWRO brine.
- 21. The system (10) according to claim 20, wherein the brine concentration system (112) comprises one or more osmotically assisted reverse osmosis (OARO) membranes or a thermal evaporation unit.
- 22. The system (10) according to claim 20 or 21, wherein the brine concentration system (112) comprises one or more OARO membranes.
- 23. The system (10) according to claim 22, wherein the brine concentration system (112) comprises two or more OARO membranes.
- 24. The system (10) according to any of claims 20 to 23, wherein the crystallization system comprises a thermal crystallization unit or a membrane crystallization unit (114).
- 25. The system (10) according to claim 24, wherein the crystallization system comprises a membrane crystallization unit (114).
- 26. The system (10) according to claim 24, wherein the membrane crystallization unit (114) comprises one or more membrane crystallizers that use magnesium chloride or sodium chloride as a draw solution to crystallize the selected mineral salt (108) out of the concentrated BWRO brine.

27. The system according to claim 26, wherein the selected mineral salt is a potassium containing mineral salt and wherein the one or more membrane crystallizers use a magnesium chloride draw solution.
28. A method for recovering a selected mineral salt (108) from seawater or another high-salinity solution, the method comprising:
- i. processing the seawater or other high-salinity solution in a seawater reverse osmosis (SWRO) system (100) according to claim 12, to separate the seawater into an SWRO permeate (103) comprising desalinated water and the selected mineral salt, and an SWRO retentate (110);
 - ii. concentrating the SWRO permeate (103) in a brackish water reverse osmosis (BWRO) system (102) comprising one or more BWRO stage (102a/b) to produce desalinated water (105) and a BWRO brine (104) comprising the selected mineral salt;
 - iii. extracting the selected mineral salt (108) from the BWRO brine (104) in a selected mineral valorisation system (106).
29. The method according to claim 28, wherein the SWRO permeate (103) substantially consists of desalinated water and the selected mineral salt.
30. The method according to claim 28 or 29, wherein the SWRO permeate (103) comprises 90% or greater of the selected mineral salt present in the input seawater or other high-salinity solution.
31. The method according to any of claims 28 to 30, wherein the SWRO retentate (110) comprises less than 10% of the selected mineral salt present in the input seawater or other high-salinity solution.
32. The method according to any of claims 28 to 31, wherein the BWRO brine (104) comprises 80% or greater of the selected mineral salt present in the SWRO permeate (103).
33. The method according to any of claims 28 to 32, wherein concentrating the SWRO permeate (103) in the BWRO system (102) comprises passing the SWRO permeate (103) through two or more BWRO stages (102a, 102b) and wherein each consecutive BWRO stage (102a, 102b) further increases the percentage concentration of the selected mineral salt in the BWRO brine (104).

34. The method according to claim 33, wherein concentrating the SWRO permeate (103) in the BWRO system (102) comprises:
- i. concentrating the SWRO permeate (103) in a first BWRO stage (102a) to produce desalinated water (105) and a BWRO retentate (116) comprising the selected mineral salt; and
 - ii. concentrating the BWRO retentate (116) in a second BWRO stage (102b) to produce desalinated water (105) and a BWRO brine (104) comprising the selected mineral salt.
35. The method according to claim 34, wherein the BWRO retentate (116) comprises 80% or greater of the selected mineral salt present in the SWRO permeate (103), and wherein the BWRO brine (104) comprises 85% or greater of the selected mineral salt present in the BWRO retentate (116).
36. The method according to any of claims 28 to 35, wherein extracting the selected mineral salt (108) from the BWRO brine (104) comprises:
- i. concentrating the BWRO brine (104) in a concentration system (112) to produce a concentrated BWRO brine; and
 - ii. crystallizing the selected mineral salt (108) out of the concentrated BWRO brine in a crystallization system.
37. The method according to claim 36, wherein concentrating the BWRO brine (104) comprises passing the BWRO brine (104) through one or more osmotically assisted reverse osmosis (OARO) membranes or a thermal evaporation unit.
38. The method according to claim 36 or 37, wherein concentrating the BWRO brine (104) comprises passing the BWRO brine (104) through one or more OARO membranes.
39. The method according to claim 38, wherein concentrating the BWRO brine (104) comprises passing the BWRO brine (104) through two or more OARO membranes.
40. The method according to any of claims 36 to 39, wherein the concentrated BWRO brine has a concentration of from about 215 g/L to about 235 g/L.
41. The method according to any of claims 36 to 40, wherein the crystallization system comprises a thermal crystallization unit or a membrane crystallization unit (114).

42. The method according to claim 41, wherein the crystallization system comprises a membrane crystallization unit (114).
43. The method according to claim 41 or 42, wherein the membrane crystallization unit (114) comprises one or more membrane crystallizers that use magnesium chloride or sodium chloride as a draw solution to crystallize the selected mineral salt (108) out of the concentrated BWRO brine.
44. The method according to claim 43, wherein the selected mineral salt is a potassium containing mineral salt and wherein the one or more membrane crystallizers use a magnesium chloride draw solution.
45. A method of manufacturing a selective membrane according to any of claims 1 to 11, the method comprising the following steps, in order:
- i. Mixing one or more ionophore into an amine solution;
 - ii. Depositing the amine solution on a polysulfone layer;
 - iii. Depositing an acid chloride solution on the amine solution to form a polyamide layer.
46. The method of manufacture according to claim 45, the method comprising mixing one or more ionophore into an amine solution, as well as the following steps, in order:
- i. Depositing a polysulfone layer on a polyester layer;
 - ii. Depositing the amine solution on the polysulfone layer;
 - iii. Depositing an acid chloride solution on the amine solution to form a polyamide layer.
47. The method of manufacture according to claim 45 or 46, wherein the polysulfone layer comprises polysorbate 20 (PS20).