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(54) Abstract Title**: Cleaning a membrane of a reverse osmosis desalination plant**

(57) A method of cleaning a membrane of a reverse osmosis desalination plant that is submerged in a body of water wherein the reverse osmosis plant comprises a plurality of on-line reverse osmosis units 14 and at least one off-line reverse osmosis unit 15. The retentate streams 16 from each unit are combined to produce a waste retentate stream which is discharged. The permeate streams 18 from each of the reverse osmosis units are combined to form a low salinity water stream 19. The cleaning method comprises interrupting the normal operation of the plant by dividing the low salinity water stream into a first stream and a second stream, a chemical solution is dosed into the water stream via line 22 generating a cleaning water stream 25. The cleaning water stream is then passed to the first side of the membrane of the off-line reverse osmosis unit for a sufficient period to purge the raw high salinity process water from the unit. The cleaning water is then purged from the reverse osmosis unit. Also claimed is a low maintenance submerged reverse osmosis plant.

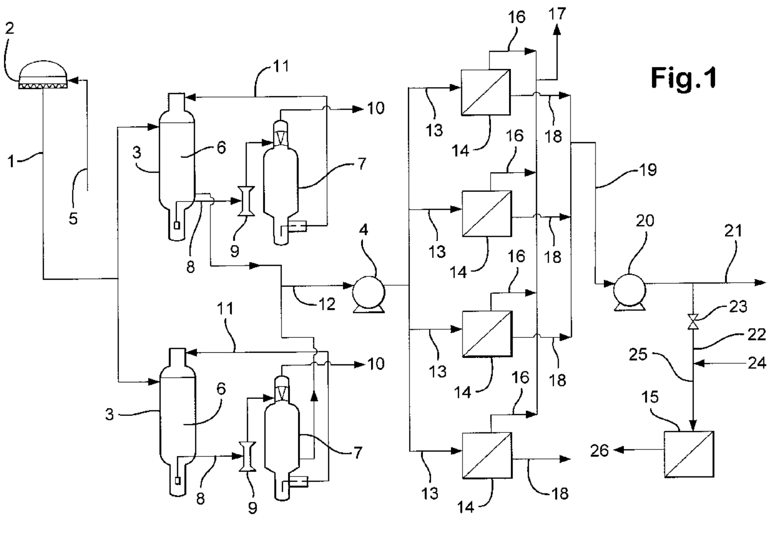

Fig.1

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

Original Printed on Recycled Paper

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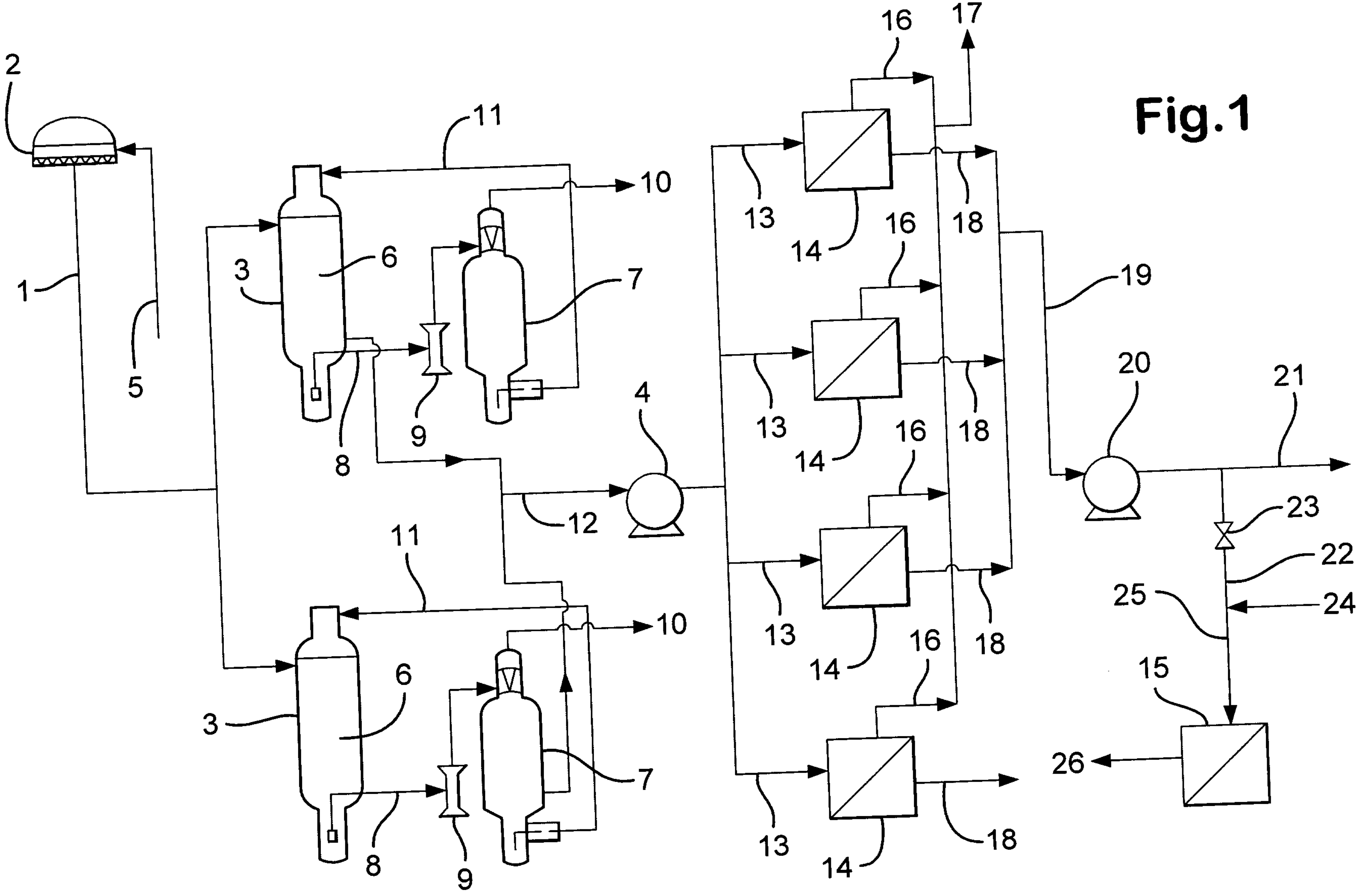
Fig.1



DESALINATION METHOD

The present invention relates to a low maintenance submerged reverse osmosis desalination plant and, in particular, to a membrane cleaning system for the plant. The submerged reverse osmosis desalination plant produces low salinity water for use in the recovery of hydrocarbons from a porous hydrocarbon-bearing subterranean formation.

It has long been known that only a portion of the oil can be recovered from a permeable oil-bearing subterranean formation as a result of the natural pressure of the reservoir. So-called secondary recovery techniques are used to force the oil out of the reservoir. The simplest method of forcing the oil out of the reservoir rock is by direct replacement with another fluid. Water-flooding is one of the most successful and extensively used secondary recovery methods. Water is injected, under pressure, into reservoir rocks via injection wells, driving the oil through the rock toward the production wells.

It has been reported that the salinity of an injection water can have a major impact on the recovery of hydrocarbons during waterfloods, with increased recovery resulting from the use of diluted brines (see, for example, "Labs Spin Out Oilfield Technologies", American Oil & Gas Reporter, Vol 41, No. 7, July 1988, 105-108; "Effect of brine composition on recovery of Moutray crude oil by waterflooding", Journal of Petroleum Science and Engineering 14 (1996), 159-168; and "Prospects of improved oil recovery related to wettability and brine composition", Journal of Petroleum Science and Engineering 20 (1998) 267-276.

It is also known that the injection water used in a waterflood should be compatible with the formation water. Thus, underground formation waters can contain resident ions such as barium (e.g. at a concentration of up to 3000 mg/l, for example 50-500 mg/l) and usually also calcium (e.g. at a concentration of up to 30,000 mg/l, for example 1000-5000 mg/l) both in the form of soluble chlorides, but also in the presence of sulphate ions, so the water is saturated with barium sulphate, and usually also calcium sulphate. This formation water can meet seawater, which can contain precipitate precursor ions such as soluble carbonate (e.g. at 100 - 5000 mg/l) and sulphate (e.g. at 1000 - 3500 mg/l). Mixing the two waters produces an aqueous supersaturated solution of barium sulphate and/or barium carbonate, and/or calcium sulphate and/or calcium carbonate, from which scale comprising these compounds deposits on surfaces. The meeting of the two waters can be in the formation, when seawater containing precipitate precursor ions is injected into the formation through an injection well at a distance from a production well to enhance oil recovery (i.e. a water flood treatment). The scaling may occur in the production well or downstream thereof e.g. in flow lines, or gas/liquid separators (for separating oil/water from gas) or in transportation pipelines leaving the gas/liquid separators. Carbonate scale may particularly form in the gas/liquid separator or downstream thereof, due to reduction in gas pressure causing soluble calcium bicarbonate to form insoluble calcium carbonate.

US 4,723,603 relates to a process for reducing or preventing plugging in fluid passageways of hydrocarbon-bearing formations and in production wells which is caused by the accumulation of insoluble salt precipitates therein. This objective is achieved by removing most or all of the precursor ions of the insoluble salt precipitates from an injection water at the surface before the water is injected into the formation. Thus, insufficient precursor ions are available to react with ions already present in the formation to form significant amounts of the insoluble salt precipitates. The precursor ions of the insoluble salt precipitates are removed by means of a reverse osmosis membrane.

International patent application number PCT/GB05/01939 relates to producing a low salinity water by feeding a high salinity water to a submerged reverse osmosis desalination plant and injecting the treated water into a porous subterranean hydrocarbon-bearing formation for recovering hydrocarbons therefrom, for example, via a subsea injection system. An advantage of employing a submerged reverse osmosis desalination plant and a subsea injection system is that this reduces the costs and risks associated with supporting production equipment on a platform. A further advantage of submerging the reverse osmosis desalination plant in a body of water is that hydrostatic head pressure provides at least a major component of the pressure required to overcome the osmotic pressure across the membrane of the reverse osmosis unit(s) thereby reducing pumping costs. However, problems arise in maintaining a submerged reverse osmosis desalination plant, in particular, with avoiding fouling of the filters that are used for removing particulates from the high salinity feed water and in cleaning the membranes of the reverse osmosis units. Accordingly, the present invention relates to a low maintenance submerged reverse osmosis desalination plant having a filtration system that has a reduced susceptibility to fouling and to an improved system for cleaning the membranes of the reverse osmosis units. The present invention also relates to a method of cleaning the membranes of the reverse osmosis units of a submerged reverse osmosis desalination plant. In addition, the present invention relates to a method of recovering hydrocarbons from a porous subterranean formation wherein during normal operation of the submerged reverse osmosis plant, treated low salinity water from the plant is injected into the formation via a subsea injection system.

Thus, according to the present invention there is provided a method of cleaning a membrane of a reverse osmosis desalination plant that is submerged in a body of water wherein the reverse osmosis plant comprises a plurality of on-line reverse osmosis units and at least one off-line reverse osmosis unit and each reverse osmosis unit comprises a membrane having a first side and a second side wherein, during normal operation of the plant, a high salinity water feed stream is passed to the first side of the membrane of each on-line reverse osmosis unit; a concentrated waste brine retentate stream is withdrawn from the first side of the membrane of each on-line reverse osmosis unit and a low salinity water permeate stream is withdrawn from the second side of the membrane of each on-line reverse osmosis unit, and the permeate streams from each of the on-line reverse osmosis units are combined to produce a low salinity water stream in an amount sufficient to satisfy the injection water requirements of an injection well, wherein the cleaning method comprises:

(i) interrupting the normal operation of the plant by dividing the low salinity water stream into a first stream and a second stream;

(ii) dosing a cleaning chemical into the first stream to form a cleaning water stream and passing the cleaning water stream to the first side of the membrane of the off-line reverse osmosis unit at a pressure less than the osmotic pressure across the membrane for a sufficient period of time to purge the high salinity water from the reverse osmosis unit;

(iii) shutting in the off-line reverse osmosis unit for a period of at least 0.5 hour, preferably, at least 1 hour; and

(iv) purging the cleaning water from the off-line reverse osmosis unit.

Typically, the high salinity water feed stream flows over the first side of the membrane of each of the on-line reverse osmosis units becoming increasingly more saline as water is driven across the membrane. Accordingly, it is preferred to back-flow the cleaning water stream over the first side of the membrane of the off-line reverse osmosis unit as the fresh cleaning water stream will encounter the portion of the membrane which has been exposed to the most concentrated brine.

Thus, according to a preferred embodiment of the present invention there is provided a method of cleaning a membrane of a reverse osmosis desalination plant that is submerged in a body of water wherein the reverse osmosis plant comprises a plurality of on-line reverse osmosis units and at least one off-line reverse osmosis unit and each reverse osmosis unit comprises a membrane having a first side and a second side wherein, during normal operation of the plant, a high salinity water feed stream flows over the first side of the membrane of each on-line reverse osmosis unit and becomes progressively more saline as water is driven across the membrane to the second side of the membrane; a concentrated waste brine retentate stream is withdrawn from the first side of the membrane of each on-line reverse osmosis unit and a low salinity water permeate stream is withdrawn from the second side of the membrane of each on-line reverse osmosis unit, and the permeate streams from each of the on-line reverse osmosis units are combined to produce a low salinity water stream in an amount sufficient to satisfy the injection water requirements of an injection well, wherein the cleaning method comprises:

(i) interrupting the normal operation of the plant by dividing the low salinity water stream into a first stream and a second stream;

(ii) dosing a cleaning chemical into the first stream to form a cleaning water stream and back-flowing the cleaning water stream over the first side of the membrane of the off-line reverse osmosis unit at a pressure less than the osmotic pressure across the membrane for a sufficient period of time to purge the high salinity water from the off-line reverse osmosis unit;

(iii) shutting in the off-line reverse osmosis unit for a period of at least 0.5 hour, preferably, at least 1 hour; and

(iv) purging the cleaning water from the off-line reverse osmosis unit.

An advantage of the cleaning method of the present invention is that there is no requirement for a cleaning water storage tank. In addition, the cleaning method only requires the cleaning water stream to be passed through the off-line reverse osmosis unit for short periods of time.

The membrane of the reverse osmosis unit(s) that is cleaned using the method of the present invention may be any of those known in the art. Reverse osmosis membranes can be divided into two categories (1) asymmetric membranes prepared from a single polymeric material and (2) thin-film composite membranes prepared from a first and a second polymeric material. Asymmetric membranes have a dense polymeric discriminating layer supported on a porous support formed from the same polymeric material. Examples include asymmetric cellulose acetate membranes. Thin-film composite membranes comprise a permselective discriminating layer formed from a first polymeric material anchored onto a porous support material formed from a second polymeric material. Generally the permselective discriminating layer is comprised of a cross-linked polymeric material, for example, a cross-linked aromatic polyamide. Suitably, the porous support material is comprised of a polysulfone. Polyamide thin-film composite membranes are more commonly used in reverse osmosis desalination plants since they typically have higher water fluxes, salt and organic rejections and can withstand higher temperatures and larger pH variations than asymmetric cellulose acetate membranes. The polyamide thin-film composite membranes are also less susceptible to biological attack and compaction. The reverse osmosis membrane should at least be capable of preventing significant amounts of dissolved solids from entering the treated low salinity water product stream while allowing the water solvent to pass across it. Preferably, the membrane of the reverse osmosis unit is in the form of a spiral wound membrane module or a hollow fibre membrane module located within a pressurized housing. Suitable spiral wound or hollow fibre membrane modules are well known to the person skilled in the art.

During operation of the cleaning method, the low salinity water stream is divided into a first stream and a second stream. Preferably, the first stream comprises a major portion of the low salinity water stream. Preferably, the first stream comprises at least 80%, more preferably, at least 90% of the low salinity water stream.

The cleaning chemical that is dosed into the first stream of low salinity water to form the cleaning water stream is preferably an acid or a base. Preferred acids include hydrochloric acid, nitric acid, sulfuric acid, acetic acid, formic acid, citric acid, and phosphoric acid. Preferred bases include ammonium hydroxide, sodium hydroxide and potassium hydroxide, in particular sodium hydroxide. Preferably, a concentrated solution of the cleaning chemical is continuously dosed into the first stream. It is envisaged that mixtures of cleaning chemicals may be dosed into the first stream to form the cleaning water stream.

Optionally, a concentrated aqueous solution of a biocide is continuously dosed into the first stream. Examples of water soluble biocides include tetrakis(hydroxymethyl)phosphonium sulfate, zinc pyrithione, 1,2-benzisothiazolin-3-one, 2-(thiocyanomethylthio)benzothiazole, 2,2-dibromo-3-nitropropionamide, benzalkonium chloride, benzyl C10-16 alkyldimethyl ammonium chloride, didecyl-dimethyl-ammonium chloride, formaldehyde, glutaraldehyde, N-coco alkyl-1,3,-propylenediamine acetate, sodium hypochlorite, sodium bisulfite, 2-methyl-4-isothiazolin-3-one, and 5-chloro-2-methyl-4-isothiazolin-3-one. Preferably, the biocide is sodium bisulfite.

Where sodium hydroxide is dosed into the first stream, the concentration of hydroxide in the resulting cleaning water stream is typically 0.1 to 10 mM. Where sodium bisulfite is dosed into the first stream, the concentration of sulfite in the resulting cleaning water stream is typically 1 % by volume. Suitably, the pH of the cleaning water stream is in the range 10 to 11.75.

A concentrate of the cleaning chemical may be either delivered from the surface via a flow line or the plant may be provided with a concentrate storage tank that may be actuated from the surface to deliver the cleaning chemical into the first stream, for example, via a remotely actuatable valve and pumping means. Similarly, the optional biocide may be delivered from the surface via a flow line or the plant may be provided with a concentrate storage tank for the biocide. It is envisaged that the concentrate storage tank(s) may be removable from the submerged reverse osmosis desalination plant, via a releasable connection means. This releasable connection means is preferably actuated from the surface. A replacement tank may be lowered from the surface and may be connected to the desalination plant via the releasable connection means. Alternatively, the concentrate storage tank(s) may be replaced using a remotely operated vehicle (ROV).

Suitably the flow rate of the cleaning water stream to the off-line reverse osmosis unit is at least 2 times, preferably, at least 3 times the flow rate of the high salinity water feed to each of the on-line reverse osmosis units. Preferably, the flow rate of the cleaning water stream to the off-line reverse osmosis unit is at least 150 m^3/hour, more preferably, at least 200 m^3/hour. Preferably, the cleaning water stream is discharged to the body of water.

The pressure of the cleaning water stream is less than the osmotic pressure across the membrane so as to avoid osmosis occurring during the cleaning operation. Preferably, the pressure of the cleaning water stream is in the range 1 to 6 bar absolute, preferably, 2 to 4 bar absolute.

Preferably, the cleaning water stream is passed to the first side of the membrane of the off-line reverse osmosis unit for 5 to 60 minutes, preferably 15 to 45 minutes, more preferably, 20 to 30 minutes. Thereafter, the off-line reverse osmosis unit(s) is left shut in for at least 0.5 hours, preferably 1 to 24 hours, more preferably, 1 to 10 hours, for example, 1 to 5 hours.

The cleaning water may be purged from the first (retentate) side of the membrane of the off-line reverse osmosis unit by (a) purging the unit with a portion of the low salinity water stream; (b) purging the unit with a portion of the high salinity water feed stream, or (c) purging the unit with a compressed gas, for example, compressed air.

Thus, a portion of the low salinity water stream may be passed to the first side of the membrane of the off-line reverse osmosis unit for a sufficient period of time to purge the cleaning water from the unit. Typically, a side stream is taken from the low salinity water stream and is back-flowed through the reverse osmosis unit at a flow rate of 10 to 50 m^3/hour. Preferably, the pressure of the side stream is 1 to 6 bar absolute, preferably, 2 to 4 bar absolute. Preferably, the purging step is continued for at least 5 minutes, preferably 5 to 10 minutes. The side stream may be passed to the first side of the membrane of the off-line reverse osmosis unit via the cleaning water flow line (with the supply of cleaning chemical and optional biocide closed off). Alternatively, the side stream may be passed to the off-line reverse osmosis unit via a dedicated flow line.

The cleaning water may also be purged from the off-line reverse osmosis unit by feeding a portion of the high salinity water feed stream to the first side of the membrane for a sufficient period of time to purge the cleaning water from the unit. This may be achieved by taking another of the reverse osmosis units off-line and switching the feed from that unit to the unit that is to be purged of cleaning water. Preferably, the high salinity water stream flows over the first side of the membrane in the normal direction of flow. The cleaning water that is purged from the unit may be discharged to the body of water.

Where the cleaning water is purged from the off-line reverse osmosis unit using a compressed gas, the gas may be provided via a line from the surface or the plant may be provided with a pressurized gas tank that is actuated from the surface, for example, via a remotely controlled valve.

After the cleaning operation, the reverse osmosis unit may be placed on-line and another of the reverse osmosis units may be taken off-line for cleaning. However, it is envisaged that following cleaning of the membrane, the reverse osmosis unit will be left off-line for a period of time, for example, several weeks, until it is desired to clean the membrane of an on-line reverse osmosis unit. Thus, the membranes of the reverse osmosis units may be cleaned cyclically, for example, the membrane of each of the reverse osmosis units may be cleaned 1 to 5 times per annum.

Preferably, the second stream of low salinity water is a minor portion of the low salinity water stream. Preferably, the second stream is injected into the injection well during operation of the cleaning method. Typically, the flow rate of the second stream is substantially less than required to meet the injection water requirements of the formation. Thus, the flow rate of the second stream may be in the range 15 to 75 m^3/hour, for example, 20 to 50 m^3/hour. However, the period during which the cleaning water stream is passed to the first side of the membrane of the off-line reverse osmosis unit is sufficiently short that this does not have any significant impact on the oil recovery operation.

After cleaning the membrane of the off-line reverse osmosis unit, the plant is returned to normal operation with the low salinity water stream being used to recover hydrocarbons from a porous hydrocarbon-bearing subterranean formation by:

a) injecting the low salinity water stream into the hydrocarbon-bearing formation from an injection well;
b) displacing the hydrocarbons with the low salinity water toward an associated production well; and
c) recovering hydrocarbons from the formation via the production well.

Thus, during normal operation of the plant, the low salinity water output of the on-line reverse osmosis units of the submerged reverse osmosis plant should satisfy the injection water requirement of the hydrocarbon bearing formation and is generally at least 200 m^3/hour, preferably, in the range 200 to 500 m^3/hour. The low salinity water stream from the submerged reverse osmosis desalination plant may be fed to a subsea injection system via a flow line. Suitable subsea injection systems for injecting water into an injection well are well known to the person skilled in the art. Alternatively, the low salinity water stream may be pumped to the surface, for example, via a riser, and may be subsequently introduced into an injection well via a surface injection system. An advantage of pumping the low salinity water stream to the surface from a submerged desalination plant compared with pumping untreated high salinity water to a surface desalination plant is that for the same output of low salinity water, the size of the pump and hence pumping costs may be markedly reduced. Generally, the pump that is used to raise the low salinity water stream to the surface will be located either on a platform or in the riser rather than being part of the submerged reverse osmosis desalination plant.

Generally, the pressure of the low salinity water stream (combined permeate stream from the on-line reverse osmosis units) is in the range 1 to 5 bar absolute. Where, during normal operation of the plant, the low salinity water stream is fed to a subsea injection system via a flow line, the pressure of the low salinity water stream is raised to above the pressure in the injection well by means of a high pressure booster pump. Preferably, the booster pump raises the pressure of the low salinity water stream to at least 5 bar, more preferably, at least 10 bar higher than the pressure in the injection well. Typically, the pressure in the injection well is at least 300 bar absolute, preferably, in the range 300 to 400 bar absolute, for example, 340 bar absolute. Thus, the pressure of the low salinity water stream downstream of the booster pump is typically at least 305 bar absolute. The pressure downstream of the booster pump may be controlled via a choke on the subsea injection system. Preferably, the booster pump is a centrifugal pump, for example, a FRAMO™ multi-stage centrifugal pump. Suitably, the booster pump is provided with a minimum flow by-pass to the body of water for start-up and shut-down operations. Suitably, the first stream of low salinity water is taken downstream of the booster pump. The pressure of the first stream is then reduced to 1 to 6 bar absolute, preferably 4 to 6 bar absolute by means of a valve so as to avoid osmosis occurring during the cleaning operation. Although, the first stream of low salinity water could, in theory, be taken upstream of the booster pump the flow rate of the remaining low salinity water (second stream) to the high pressure booster pump may be insufficient to operate the high pressure pump.

Where, during normal operation of the plant, the low salinity water stream is passed to a surface injection facility, there is no requirement for the submerged reverse osmosis plant to have a high pressure booster pump. Thus, the low salinity water stream may be raised to the surface through a riser by means of an electric submersible pump (ESP) located in the riser or by means of a surface pump. As discussed above, the low salinity water stream from the on-line reverse osmosis units may be at a pressure in the range 1 to 5 bar absolute. Also, as discussed above, the cleaning water stream is fed to the off-line reverse osmosis unit(s) at a pressure in the range 1 to 6 bar absolute, preferably 2 to 4 bar absolute. Accordingly, it may be possible to pass the cleaning water through the off-line reverse osmosis unit(s) without having to provide a circulation pump. However, if desired, a low pressure circulation pump may be provided to raise the pressure of the cleaning water stream, for example, from 1 to 2 bar absolute to 3 to 4 bar absolute.

A filtration system is provided for the high salinity water feed stream to prevent particulate material from entering the plant thereby protecting the membrane(s) of the reverse osmosis unit(s) from fouling. Preferably, the filtration system comprises at least one coarse filter and at least one fine filter.

It is essential that the coarse filter efficiently separates both mineral particulates such as sand and organic particulates. It is also essential that the coarse filter is capable of being operated for prolonged periods without the need for regular maintenance. The coarse filter is preferably located upstream of a circulation pump. The coarse filter is open to the body of water and is arranged to remove particulates from high salinity water drawn through it by the circulation pump. Preferably, the coarse filter is a clarifier and comprises an inclined tube settler disposed such that particulates separate from high salinity water flowing through it are discharged to the body of water, preferably, at a distance from the intake to the inclined tube settler (hereinafter "settling tube").

The desalination plant may be provided with a single settling tube or, preferably, with a plurality of settling tubes. The flow rate through the settling tube(s) can be sufficiently low to ensure a very high percentage of mineral and denser-than-water organic particulates are discharged from the tube(s) and therefore do not contribute to the load on the fine filter which is primarily provided to remove neutral buoyancy particulates.

Inclined tube settlers are well known and are used in, for example, water treatment plants to separate coagulated/flocculated material from processed water. In such known tube settlers, separated particulates are delivered to a discharge mechanism which is periodically actuated so as to discharge separated particulates from the system but there are concerns over the viability of such discharge mechanisms given that it is expected that large quantities of particulates will be separated from the high salinity water and therefore the ejection system will have to be operated at regular intervals, for example, many times each day. However, provided the tube(s) is appropriately positioned, separated particulates can be allowed to accumulate beneath the tube(s) until turbulent conditions arise which result in the dispersal of those particulates. Thus, the discharge mechanism may be eliminated. Where the reverse osmosis plant is located at or near a seabed, simply by ensuring that the seawater inlet/particulate discharge end of the tube(s) is at a sufficient height above the seabed to prevent the end(s) becoming buried in accumulating sand and debris ensures reliable continuous operation. Preferably, the settler tube(s) is of sufficient length that the inlet to the tube(s) is at a sufficient distance from the outlet that turbulent conditions do not result in the particulates from re-entering the filter. Where the reverse osmosis plant is submerged in a sea, it is preferred that the inlet to the settler tube(s) is at least 20 metres, preferably, at least 25 metres above the seabed, as the particulate loading of the seawater will be lower than at the seabed. Suitably, the inlet to the settler tube(s) is below the photosynthetic layer of the body of water (for example, at a depth of 30 metres below the surface of the body of water) so as to minimize the amount of biomaterial in the high salinity water feed stream to the reverse osmosis unit(s).

Preferably, the coarse filter is a settler tube unit comprising a plurality of settler tubes. Preferably, the tubes of the settler unit have an anti-fouling coating, for example, a copper-laden antifouling coating, for controlling biofouling. The tubes of the settler tube unit may be manufactured in any appropriate manner. However, it is preferred that the tubes of the settler unit are formed from an array of superimposed corrugated sheets with the corrugations of adjacent sheets offset and secured together, for example, by welding, or in the case of composite polymeric materials, by adhesion. The corrugations may be of any suitable geometric shape, for example, corresponding to a sine wave, the objective being to maximize the width of each tube whilst minimizing the height and maximizing the number of tubes packed within a unit volume and yet retaining an acceptable flow cross-section. The use of an array of superimposed corrugated sheets results in a very robust and yet easy to manufacture structure. Tube settler units of this type are described in more detail in US 6,171,483.

The use of longer tubes significantly improves particulate removal efficiency. It is therefore preferred that the tubes of the settler unit have a length of at least 1 metre, preferably, at least 1.5 metres. Suitably, the tubes have lengths of from 1 to 2 metres, preferably, 1.5 to 1.8 metres. Preferably, the tubes of the settler unit are inclined at an angle of from 20 to 50° to the horizontal, preferably, 35 to 50°, for example 40 to 45° to the horizontal.

Where the tubes of the settler units are of circular cross-section, the internal diameter of the tubes is preferably in the range 3 to 10 cm, for example, 4 to 6 cm. However, it is preferred that the tubes are not of a circular cross section. In other words, the cross-sectional shape of the tube should be designed to minimize the settling depth by maximizing the ratio of wetted perimeter to the cross-section and settling area as compared with a circular cross-section. Where the tubes are formed from corrugations, the tubes preferably have a width in the range 5 to 10 cm, preferably, 6 to 8 cm. Suitably, the depth of each tube is less than 40% of the width, for example, less than 30% of the width.

Preferably, the settler tube unit should achieve 99% removal of particles having a size of at least 22 microns and 100% removal of all particles sized over 45 microns.

The number of tubes in the tube settler unit will be dependent upon the length of the tubes, the cross-sectional area of the tubes, the amount of water to be treated per hour and the desired removal efficiency. Generally, the number of tubes will be greater than 500, preferably, greater than 1000, for example, greater than 2000.

The downstream ends of the tubes of the settler tube unit may be in fluid communication with a manifold. Suitably, means are provided to deter marine life from entering the manifold. Marine life may be deterred by chlorinating the water within the manifold, for example, by means of an electrochlorinator that converts sodium chloride in the untreated high salinity water feed stream into sodium hypochlorite. Thus, a side stream may be taken from the high salinity water in the manifold and is passed through the electrochlorinator before being returned to the manifold. However, it will be necessary to inject sodium bisulfite downstream of the electrochlorinator in order to protect the membrane of the reverse osmosis units. It is also envisaged that a water-soluble biocide may be dosed into the water within the manifold. Examples of typical water soluble biocides are given above. Where a biocide or sodium bisulfite is dosed into the high salinity water feed stream it is envisaged that a concentrate of the biocide or sodium bisulfite may be either delivered from the surface via a flow line or the plant may be provided with a concentrate storage tank, as described above. Alternatively, marine life may be deterred from entering the manifold by providing an acoustic system or a strobe light system. Suitable acoustic or strobe light systems are available from Fish Guidance Systems Limited.

The slow current flow through each tube of the settler unit avoids the irreversible ingestion of marine animals capable of swimming against that current and out of the facility through the seawater inlet/particulate discharge end of the tubes. A simple device such as a net or a coarse metal grill may be disposed across the upstream end of the tubes to prevent the entry of all but small marine animals or fish. In addition, or as an alternative, the tubes may be vibrated, for example, by coupling the tubes to a vibrating component such as the pump. Such vibration may assist in the self-cleaning of particulates from the tubes.

A fine filter is provided downstream, of the coarse filter and upstream of the circulation pump to remove neutral buoyancy particulates that are not removed by the coarse filter. The fine filter is provided with a means for periodically or continuously discharging accumulations of neutral buoyancy particulates to the surrounding body of water. Typically, the feed to the fine filter has a solids content of 0.1 mg/l. Preferably, the fine filter removes 99% of particulates having a diameter of 5 microns or larger.

Suitably, the fine filter comprises a vessel containing a treatment bed of a particulate treatment medium, and having an inlet for the water to be treated and an outlet for the treated water. Thus, the neutral buoyancy particles are removed from the water flowing through the bed by the particulate treatment medium. It is envisaged that the particulate treatment medium may be periodically rejuvenated which may be achieved by taking the filter off-line while it is backwashed in situ with clean (filtered) water, leaving the fine filter out of action for considerable period. Thus, in this arrangement, it will be necessary to provide at least one redundant (or stand-by) fine filter for use during the rejuvenation process. However, it is preferred that the fine filter is a media filter which cleans and recycles media on-line, thereby eliminating the need for backwashing and for standby units to be used during the wash cycle. In particular, the media filter may be a radial media filter supplied under the trade name FILTORE® by Merpro Tortek Limited.

Thus, the media filter preferably comprises:

(a) a vessel containing a treatment bed of a particulate treatment medium, the treatment bed having a top and a bottom, and the vessel having an inlet for the high salinity water to be filtered and a filtered high salinity water outlet;

(b) a fluidizing unit positioned in the vessel for removing the treatment medium particles from at or near the bottom of the treatment bed; and

(c) a means for supplying regenerated treatment medium particles to at or near the top of the treatment bed to replace the treatment medium removed from the treatment bed by the fluidizing unit.

Suitably, the vessel of the media filter has a diameter of 2 to 4 metres, for example, 3 metres and a height of 5 to 7 metres, for example, 6 metres. Suitably, the treatment bed has a depth of at least 1 metre. Preferably, the bed is composed of a medium having a mean particle diameter of 500 microns (particle diameters in the range 100 to 1000 microns). Suitable filtration media include ceramic beads composed of bauxite. The pressure drop over a clean bed is generally less than about 3 bar, for example 1.8 to 2.6 bar. Preferably, the pressure drop over a contaminated bed is less than 5 bar as high differential pressures may result in the filtrate that is absorbed onto the contaminated bed being forced through the bed thereby decreasing filtration performance. Preferably, at least 2 media filtration units are employed in parallel so as not to exceed the allowable pressure drop. Preferably, the treatment bed is periodically agitated to prevent compaction of the bed. Preferably, the flow rate of high salinity water through the treatment bed is in the range 100 to 600 m^3/hour, preferably, 200 to 500 m^3/hour, for example 440 m^3/hour.

It is preferable that the inlet for high salinity water is provided at the outer periphery of the bed so that the water percolates inwardly through the treatment medium to an outlet which is embedded within the bed, as described in US 5,637,278.

The fluidizing unit ensures that the treatment medium particles can be removed efficiently from the bed without contacting a pump impeller. The treatment medium removed by the fluidizing unit is replaced by particles from above which fall under gravity or pressure into the space created by the removal of the treatment medium. In this way the treatment medium will tend to progress downwardly through the treatment bed, ensuring that all of the bed can be cleaned cyclically. Fluidizing units of a type suitable for use in the present invention are disclosed in US 4,978,251, US 4,952,099, US 4,992,006 and US 5,637,278.

The treatment medium which has been removed from the bed is passed to a rejuvenating means, wherein it is cleaned and is recycled to the top of the treatment bed, via a return duct. It is therefore possible to gradually remove the particulate treatment medium from the treatment bed for rejuvenation while the treatment devise is still on-line. Suitably, the rejuvenating means is a separator for separating contaminants from the treatment medium. The separator for separating contaminants from the treatment medium is preferably a hydrocyclone. It is desirable that this generates sufficient pressure at the outlet, through which the particulate filtration medium leaves, to carry the cleaned particulate filtration medium back to the filtration bed. If necessary, the filtration medium entering the hydrocyclone can be boosted by an additional supply of water to the inlet of the hydrocyclone. Depending upon the relative particle sizes or density of the filter medium and contaminants, the cleaned treatment medium outlet may be either the underflow outlet or the overflow outlet of the hydrocyclone.

A pump, preferably, a jet pump may be provided between the vessel containing the particulate treatment medium and the hydrocyclone thereby ensuring that the pressure in the hydrocyclone is greater than the pressure in the vessel. The motive power for the jet pump may be provided by a choke taken upstream of the low pressure circulation pump. Typically, the pressure in the hydrocyclone is at least 2 bar higher than the pressure in the vessel. Preferably, the flow rate through the hydrocyclones is in the range 5 to 50 m^3/hour, preferably 15 to 30 m^3/hour. Suitably, the residence time of the treatment bed in the vessel is 1 to 12 weeks.

It is envisaged that the coarse filter may be eliminated in which case the high salinity water feed to the media filter will generally have a solids concentration of about 1 mg/l. However, the increase in the solids concentration of the feed would require the bed to regenerated more often. The cleaning of the filtration medium may be operated on a semi-continuous basis or may be initiated by high differential pressure across the treatment bed. Suitably, the wash detritus is discharged to the body of water.

Preferably, a scale inhibitor is dosed into the filtered high salinity water feed stream upstream of the circulation pump, to protect the desalination plant, in particular, the reverse osmosis membranes from fouling by deposits of inorganic salt precipitates. Examples of suitable scale inhibitors include water-soluble organic molecules having at least 2 carboxylic and/or phosphonic acid and/or sulphonic acid groups e.g. 2-30 such groups. Preferred scale inhibitors are oligomers or polymers, or may be monomers with at least one hydroxyl group and/or amino nitrogen atom, especially in hydroxycarboxylic acids or hydroxy or aminophosphonic, or, sulphonic acids. A concentrate of the scale inhibitor may be delivered from the surface via a flow line or the plant may be provided with a concentrate storage tank, as described above for delivering a biocide.

Suitably, the circulation pump that is arranged downstream of the fine filter and upstream of the reverse osmosis unit draws the high salinity water through the coarse and fine filters and circulates the high salinity water through the reverse osmosis unit(s).

As discussed above, an advantage of submerging the reverse osmosis desalination plant in a body of water, for example, in a sea or an estuary, is that the high salinity water feed stream to the on-line reverse osmosis unit(s) will be at a higher pressure (owing to the hydrostatic head of the column of high salinity water) than a high salinity water feed stream to a surface located reverse osmosis desalination plant, for example, a plant located on a platform. The hydrostatic head pressure exerted by the high salinity water feed stream on the feed side of the membranes of the on-line reverse osmosis units should provide at least a major component of the pressure required to overcome the osmotic pressure (often referred to as "trans-membrane pressure"), for the feed conditions and the membrane type employed in the on-line reverse osmosis units, to bring about reverse osmosis. Accordingly, the hydrostatic head pressure may be used to offset pumping energy requirements. Suitably, the hydrostatic head pressure exerted by the high salinity water feed stream on the feed side of the membrane of the on-line reverse osmosis units provides at least 50%, preferably at least 75%, more preferably at least 90%, preferably substantially all of the pressure required to overcome the osmotic pressure. Generally, the process of the present invention is operated using a high salinity water feed stream having a hydrostatic head pressure in the range of 25 to 80 bar absolute corresponding to a submerged depth of 250 to 800 metres. Where the hydrostatic head pressure of the high salinity water feed stream is sufficient to drive a portion of the high salinity water feed across the membranes of the on-line reverse osmosis units, the circulation pump may be a low pressure pump. Where it is necessary to boost the hydrostatic head pressure of the high salinity water feed stream in order to drive a portion of the water across the membranes of the on-line reverse osmosis units, it may become necessary to employ a high pressure pump. However, where the hydrostatic head pressure is marginally below the osmotic pressure for the feed conditions and membrane type, a low pressure pump may be adequate.

An advantage of positioning the circulation pump downstream of the coarse and fine filters (as opposed to upstream of the filters), is that this avoids the circulation pump becoming clogged by debris. A further advantage of positioning the circulation pump downstream of the coarse and fine filters is that the filtered high salinity water feed from the circulation pump may have a vacuum break valve set to a pressure above the collapse pressure of the membranes of the on-line reverse osmosis units, for example, set to a pressure 1 to 2 bar absolute. This has an advantage that when the pressure in the injection well falls to below 1 bar absolute (i.e. a partial vacuum is established in the injection well), the vacuum break valve will operate to shut the reverse osmosis units in thereby preventing the membranes from collapsing under the partial vacuum.

Preferably, the circulation pump has an upper design pressure of 100 bar absolute. The output pressure of the circulation pump and hence the filtered high salinity water flow rate is controlled by means of a choke. Suitably, the circulation pump is a centrifugal pump, for example, a FRAMO™ multistage centrifugal pump. The circulation pump is preferably provided with a minimum flow by-pass that is employed during start-up and shut-down operations to discharge filtered water to the body of water.

Preferably, the flow rate of the filtered water downstream of the circulation pump is at least 400 m^3/hour, for example 400 to 800 m^3/hour (a flow rate of 440 m^3/hour corresponds to a 100 barrel/day plant). Preferably, the filtered high salinity water feed stream is divided substantially equally between the plurality of on-line reverse osmosis units.

Preferably, the submerged reverse osmosis plant has 3 to 10, preferably 4 to 8, for example, 5 or 6 on-line reverse osmosis plants arranged in parallel with 1 off-line reverse osmosis unit. Preferably, the flow rate of filtered high salinity water to each on-line reverse osmosis unit is in the range 30 to 100 bar absolute, preferably 50 to 90 bar absolute. Alternatively, the submerged desalination plant may have at least one train of on-line reverse osmosis units and at least one train of off-line reverse osmosis units wherein each train comprises a plurality of reverse osmosis units arranged in series with the low salinity injection water comprising the combined permeate streams from the reverse osmosis units of the on-line train(s). Preferably, each train of reverse osmosis units comprises 2 or 3 reverse osmosis units arranged in series. Preferably, there is a single off-line train to reduce the number of off-line reverse osmosis. Preferably, there are 1 to 3 on-line trains. A disadvantage of this arrangement is that at least 2 units are off-line during operation of the plant. A further disadvantage is that the cleaning water must be passed through all of the reverse osmosis units of the off-line train. For example, the cleaning water is passed to the first (retentate) side of the membrane of the last unit of the series and is removed from the first (retentate) side of the membrane of the first unit in the series.

The permeate streams from each of the on-line reverse osmosis units are combined to form the low salinity water stream. Preferably, a flow control monitor is provided for monitoring the dissolved solids content and the pressure and temperature of the low salinity water stream. For example, the conductivity of the low salinity water stream may be measured using a conductivity meter, for example, a conductivity meter supplied by Sea Bird Electronics, thereby allowing the total dissolved solids content of the low salinity water stream to be determined. Optionally, the concentration of dissolved solids in the low salinity water stream may be adjusted by blending in high salinity water via a blending line and choke.

Preferably, the plant is operated such that the low salinity water recovery (low salinity water stream) is at least 35%, preferably, at least 40%, more preferably, at least 45%, most preferably, at least 50% of the high salinity water feed to the reverse osmosis units.

The high salinity water feed stream should be fed to the on-line reverse osmosis units at a pressure below the upper design pressure of the units so as to avoid rupture of the membranes. Typically, each reverse osmosis unit has an upper design pressure of 100 bar absolute. Preferably, the high salinity water feed stream is fed to the reverse osmosis unit(s) at a pressure in the range 60 to 90 bar absolute, preferably, 65 to 80 bar absolute, for example, 70 to 75 bar absolute, with the proviso that the pressure differential across the membrane is greater than the osmotic pressure (often referred to as the "trans-membrane pressure").

Preferably, the desalination plant is arranged at least 20 metres, preferably at least 30 metres above the seafloor, for example, either floating in the body of water or supported on a subsea structure. As discussed above, the desalination plant is preferably submerged at a depth of 250 to 800 metres thereby taking advantage of the hydrostatic head pressure to provide at least a major component of the pressure required to overcome the osmotic pressure. Advantageously, the high salinity water feed stream to the desalination plant is taken at a depth where the hydrostatic head pressure corresponds to the operational pressure of the reverse osmosis membrane of the reverse osmosis unit(s), for example, at a depth of 600 to 800 metres. Typically, the high salinity water feed is taken at a location at or immediately above the reverse osmosis unit(s) of the desalination plant.

A further advantage associated with taking the high salinity water feed stream at a submerged depth of 250 to 800 metres, preferably, 600 to 800 metres, is that the water has a significantly lower oxygen content than water taken from at or near the surface thereby reducing or even eliminating the need for deaerating the low salinity water product stream.

Preferably, the submerged reverse osmosis desalination plant is provided with ballast thereby allowing the depth at which the plant is submerged to be adjusted. The submerged reverse osmosis desalination plant may also be provided with a gas supply, preferably an air supply, for purging water from the plant thereby allowing the plant to be recovered to the surface for servicing and/or repair. For example, the plant may be provided with a gas supply line that runs from the surface and/or the plant may further comprise a pressurized gas tank that may be actuated from the surface to purge water from the plant. This gas supply may also be used to purge the cleaning water from the off-line reverse osmosis unit.

The components of the reverse osmosis desalination plant may be located within a housing capable of withstanding either the external hydrostatic pressure at the submerged depth or the operational pressure of the on-line reverse osmosis units, whichever is the greater. Alternatively, each of the components of the plant may be provided with dedicated pressure housings. Thus, the filtration vessel and the reverse osmosis units are preferably provided in pressurized housings, for example, stainless steel or other corrosion resistant housings having a thickness of 4 to 6 inches.

During normal operation, the reverse osmosis desalination plant is preferably operated in a continuous manner by continuously feeding the high salinity water feed stream to the on-line reverse osmosis unit(s) thereby continuously producing a low salinity water stream (combined permeate) for injection into the injection well and continuously discharging a waste brine stream (combined retentate) to the body of water.

As discussed above, the low salinity water stream is typically at a pressure of about 1 to 5 bar absolute. Thus, there is a pressure differential across the membranes of the on-line reverse osmosis units. Typically, the waste brine stream (combined retentate streams) is at a pressure, $P_3 = P_1-P_2$, (wherein P_1 is the pressure of the high salinity water feed stream to membrane of the reverse osmosis unit(s) and P_2 is the pressure of the low salinity water product stream). It is preferred that the energy associated with the pressurized waste brine stream may be recovered, for example, using a device such as a Pelton Wheel, a Dual work energy exchanger, or a pressure exchanger that is coupled to the rotor of the low pressure circulation pump of the desalination plant.

The waste brine stream outlet of the submerged reverse osmosis desalination plant is preferably located at a distance from the high salinity water feed stream inlet thereby mitigating the risk of waste brine being recycled to the submerged desalination plant. Preferably, the waste brine stream outlet is at a lower depth than the high salinity water inlet to the plant. Preferably, the waste brine stream outlet is at distance of at least 30 metres, preferably, at least 50 metres from the high salinity water feed stream inlet.

Typically the waste brine stream that is discharged to sea has a flow rate of at least 200 m^3/hour. The waste brine stream generally has a total dissolved solids content of at least of 60,000, for example, 65,000 to 90,000 mg/l.

Generally, the desalination plant is operated at the ambient temperature of the high salinity water feed stream. The ambient temperature of the high salinity water feed stream is typically in the range 3 to 15°C, preferably 4 to 10°C.

Suitably, the submerged reverse osmosis desalination plant is provided with a submarine electric cable, preferably, an armored submarine electric cable for transmitting electricity to power the plant. Suitably, the plant is also provided with fibre optic cables and/or electrical cables for data and video transmission. These cables may be combined into a single umbilical. Preferably, the plant is also provided with flow lines (umbilicals) for delivering chemicals (for example, cleaning chemical, biocide, scale inhibitor) to the plant from the surface. Preferably, the plant is also provided with a flow line for delivery of hydraulic fluid for actuating any remotely controlled hydraulic valves.

All of the components of the reverse osmosis desalination plant are designed for retrieval and replacement from the surface or for retrieval and replacement using a remotely operated vehicle (ROV). In addition, inspection, maintenance and repair activities are incorporated into the design.

The submerged reverse osmosis desalination plant may be tethered to the seabed via a submarine cable or may be tethered or otherwise secured to a floating structure such as a tension leg platform, a floating production storage off-loading unit (FPSO) or a riser. It is also envisaged that the submerged reverse osmosis desalination plant may be arranged on an artificial buoyant seabed. Where the submerged reverse osmosis desalination plant is tethered or otherwise secured to a riser, and the low salinity water stream is injected into the injection well via a surface injection facility, the low salinity water stream may be conveyed to the surface through the interior of the riser.

Preferably, the high salinity water feed stream to the plant has a total dissolved solids content of at least 20,000 mg/l, more preferably, at least 30,000 mg/l, most preferably, at least 35,000 mg/l. Preferably, the high salinity water feed stream is seawater or estuarine water. A typical seawater composition is given below:

Component	Concentration (mg/l)
Chloride	18,980
Bromide	65
Sulfate	2,649
Bicarbonate	140
Fluoride	1
Boric acid	26
Magnesium	1,272
Calcium	400
Strontium	13
Potassium	380
Sodium	10,556
Total	34,482

Preferably, the low salinity water stream has a total dissolved solids content of less than 5,000 mg/l, more preferably, less than 4,000 mg/l, for example, less than 3,000 mg/l. In particular, it is preferred that the low salinity water product stream has a total dissolved solids content in the range 250 to 5,000 mg/l, for example 500 to 3,000 mg/l as injection water having this composition has been found to result in increased oil production (for example, of at least 5%, for example in the range 5 to 20%) when compared with using either the untreated high salinity water or a water having a total dissolved solids content of less than 250 mg/l, for example 200 mg/l. Preferred compositions of the low salinity water stream are given below:

Component	Concentration (mg/l)
Chloride	192.6 -1733
Bromide	<0.1
Sulfate	5.7 – 40
Bicarbonate	2.1 – 19
Fluoride	<0.1
Boric acid	<0.1
Magnesium	3 – 27
Calcium	0.9 – 8
Strontium	< 0.1
Potassium	5.4 – 49
Sodium	118.5 – 1066
Total	less than 3,000

The injection water may have a different ionic make-up to the formation water of the porous hydrocarbon formation such that, in the absence of any treatment of the high salinity water, precipitate precursor ions will form insoluble mineral salts with resident ions that are present in the formation water. These insoluble mineral salts may precipitate in the formation and/or in the production well and/or downstream thereof. Precipitate precursor ions are defined herein as ions which form insoluble mineral salt precipitates at the conditions of the formation or in the production well when they contact resident ions. Resident ions are defined herein as naturally or artificially occurring ions already present in the formation. The precipitate precursor ions must be a different ionic species and oppositely charged to the resident ionic species it contacts in the formation.

Specific ions which can be precursor ions of insoluble mineral salt precipitates include SO_4^{2-}, CO_3^{2-}, HCO_3^-, HS^- and mixtures thereof.

Resident ions already present in the formation which have been observed to form insoluble salt precipitates upon contact with the precursor ions include Ba^{2+}, Sr^{2+}, Mg^{2+}, Ca^{2+}, Fe^{2+}, Fe^{3+}, Al^{3+}, Pb^{2+}, Zn^{2+} and mixtures thereof.

The actual precursor ion concentration at which precipitation occurs for a given case is a function of many variables including the concentration of other ions in solution and the in situ conditions of, for example, temperature, pressure and pH.

Where the high salinity water contains precipitate precursor ions, it is preferred that the membrane of the reverse osmosis unit is one which selectively prevents the precipitate precursor ions from crossing the membrane thereby producing a treated low salinity water product stream having a precursor ion concentration insufficient to form insoluble mineral salt precipitates in an amount to substantially plug the pores of the porous formation when the treated injection water product stream contacts resident ions in a formation. Preferably, the reverse osmosis membrane allows harmless ions to pass across it so that the low salinity water stream has a total dissolved solids content in the range 250 to 5000 mg/l, preferably, 500 to 3000 mg/l.

The selectivity of a membrane is a function of the particular properties of the membrane, including the pore size of the membrane or the electrical charge of the membrane. The reverse osmosis unit(s) is advantageously operated such that the percentage ion selectivity of the low salinity water product stream for precursor ions is less than about 10% and preferably less than about 3%. Percentage ion selectivity to the product is defined as the ion concentration in the product divided by the ion concentration in the feed expressed as a percentage.

For example, a polyamide membrane is particularly effective for selectively preventing the precursor ion SO_4^{2-} from passing across it. Suitable ion selective membranes for removing SO_4^{2-} from an injection water include polyamide membranes obtainable from Osmonics Inc., Hydronautics, Dow and Torai. Preferably, the polyamide membrane has a selectivity such that when the high salinity water is seawater, the concentration of sulfate ions in the treated low salinity water is less than 40 mg/l.

According to a further aspect of the present invention there is provided a low maintenance submerged reverse osmosis plant comprising:

(a) a filtration system comprising at least one coarse filter and at least one fine filter wherein the filtration system has an inlet for a high salinity water feed stream and an outlet for a filtered high salinity water feed stream;

(b) a flow line for the filtered high salinity water feed stream that leads from the outlet of the filtration system to an inlet of a high salinity water feed manifold, the flow line having a circulation pump arranged therein;

(c) a plurality of on-line reverse osmosis units arranged in parallel and at least one off-line reverse osmosis unit wherein each on-line reverse osmosis unit has: (i) a dedicated flow line leading from the high salinity water feed manifold to a first side of the membrane of the on-line reverse osmosis unit; (ii) a dedicated flow line leading from the first side of the membrane of the on-line reverse osmosis unit to a waste brine manifold; and (iii) a dedicated flow line leading from the second side of the membrane of the on-line reverse osmosis unit to a low salinity water manifold;

(d) a waste brine flow line leading from the waste brine manifold to a waste brine outlet of the desalination plant;

(e) a low salinity water flow line leading from the low salinity water manifold to a low salinity water outlet of the reverse osmosis plant, the flow line having a high pressure pump arranged therein and having a branch point downstream of the high pressure pump;

(f) a cleaning water flow line leading from the branch point to the first side of the membrane of the off-line reverse osmosis unit, the flow line having a valve therein that is normally closed and is opened when it is desired to pass cleaning water to the off-line reverse osmosis unit;

(g) a cleaning chemical injection line leading to the cleaning water flow line for injecting a cleaning chemical into the cleaning water stream flowing through the flow line when the valve in the cleaning water line is opened; and

(h) a waste cleaning water flow line leading from the first side of the membrane of the off-line unit to a waste water outlet of the plant.

There is a pressure drop across the valve in the cleaning water flow line such that the cleaning water has a pressure below the osmotic pressure, preferably a pressure of 1 to 6 bar absolute, preferably, 2 to 4 bar absolute. Preferably, when the valve in the cleaning water flow line is opened, the majority of the low salinity water flows into the cleaning water flow line, for example, at least 80%, preferably, at least 90% of the flow of low salinity water stream upstream of the branch point.

Preferred coarse and fine filters, for use, in the submerged reverse osmosis plant are described above. Preferred arrangements of the reverse osmosis units are described above. Preferred circulation pumps and high pressure pumps are also described above.

The process of the present invention will now be described with reference to Figure

1 and the Example.

In the flow diagram of Figure 1, a high salinity water feed stream 1 is drawn through a coarse filter 2 and then through two filtration vessels 3 that are arranged in parallel via a low pressure circulation pump 4. A biocide concentrate stream 5, is continuously dosed into the high salinity water feed stream. Each media filtration vessel 3 contains a particulate bed 6. A portion of the particulate bed 6 is continuously removed from the bottom of the filtration vessel 3 and is passed to a hydrocyclone cleaning vessel 7 via a line 8 and jet booster pump 9. Thus, the pressure in the hydrocyclone cleaning vessel 8 is generally at least 2 bar higher than the pressure in the vessel 3. The detritus from the hydrocyclone cleaning vessel 7 is discharged to the body of water via line 10. Clean particulate filtration medium is recycled via line 11 to the top of the particulate bed 6. The filtered high salinity water from the filtration vessels 3 is combined to form a filtered high salinity water feed stream 12 and after being drawn through the low pressure pump 4 is divided to produce dedicated filtered high salinity water feed streams 13 for a plurality of on-line reverse osmosis units 14 that are arranged in parallel. A reverse osmosis unit 15 is off-line. The retentate streams 16 from each of the on-line reverse osmosis units are combined to form a waste brine stream which is discharged to the body of water via line 17. The permeate streams 18 from each of the on-line reverse osmosis units are combined to form a low salinity water stream 19 and the pressure of this low salinity water stream is raised by means of high pressure booster pump 20 to above the pressure in a water injection well (not shown) prior to transporting the low salinity water stream via a flow line 21 to a subsea injection system (not shown). During the cleaning operation, a side stream comprising at least 80 % of the low salinity water stream is taken downstream of the high pressure booster pump via line 22 and the pressure of the side stream is reduced to, for example, 4 to 6 bar absolute via valve 23. A cleaning chemical is continuously dosed into this side stream via line 24 thereby generating a cleaning water stream 25 which is back-flowed through the retentate side of the reverse osmosis unit by feeding the cleaning water into the unit through the "retentate outlet" of the off-line reverse osmosis unit and removing the cleaning water from the "high salinity water feed inlet" of the reverse osmosis unit for discharge to the body of water via line 26. Suitably, the cleaning water is back-flowed through the retentate side of the unit, for example, for 15 minutes. The pressure of the cleaning water stream through the reverse osmosis unit is less than the osmotic pressure across the membrane thereby preventing water from the cleaning water stream passing by osmosis across the membrane and concentrating up the chemical(s) in the cleaning water stream. Thereafter, the off-line reverse osmosis unit 16 is left shut-in for at least 0.5 hour, preferably, at least 1 hour, before taking one of the other reverse osmosis units off-line and feeding a portion of the filtered high salinity water to the inlet of unit 16 for a sufficient time to flush the cleaning water from the unit. The reverse osmosis unit 15 may then be left off-line until it is desired to clean the membrane of one of the other reverse osmosis. At this point, the reverse osmosis unit 15 is put on-line.

Example

A reverse osmosis plant having 6 reverse osmosis units (5 on-line units arranged in parallel and 1 off-line unit) is submerged in a body of water. Filtered high salinity water is passed to the on-line reverse osmosis units at a flow rate of 440 m^3/hour (88 m^3/hour to each on-line reverse osmosis unit). The on-line reverse osmosis units are operated at 50% recovery such that the low salinity water stream (combined permeate) has a flow rate of 220 m^3/hour. The pressure of the low salinity water stream is raised to 345 bar absolute by means of a high pressure booster pump prior to injecting the low salinity water stream into an injection well for recovery of hydrocarbons from a porous hydrocarbon bearing formation. When it is desired to clean the membrane of the off-line reverse osmosis unit, a side stream is taken from the low salinity water stream downstream of the booster pump. The flow rate of the side stream is 200 m^3/hour with the remaining 20 m^3/hour of low salinity water stream being injected into the injection well. The pressure of the side stream is reduced to 4 to 6 bar absolute and sodium hydroxide is continuously dosed into the side stream thereby generating a cleaning water stream having a pH of 10 to 11.75. The cleaning water stream is back-flowed over the first (retentate) side of the off-line reverse osmosis unit for 15 minutes. The off-line reverse osmosis unit is then shut-in for 1 hour during which time the low salinity water stream is injected into the injection well at a flow rate of 220 m^3/hour. After, the reverse osmosis unit has been shut-in, another of the reverse osmosis units is taken off-line and filtered high salinity water is passed to the first (retentate) side of the membrane of the unit that has been cleaned at a flow rate of 88 m^3/hour to displace the cleaning water from the reverse osmosis unit. The cleaned reverse osmosis unit may then remain on-line or may be taken off-line until it is desired to clean one of the other reverse osmosis units.

Claims

1. A method of cleaning a membrane of a reverse osmosis desalination plant that is submerged in a body of water wherein the reverse osmosis plant comprises a plurality of on-line reverse osmosis units and at least one off-line reverse osmosis unit and each reverse osmosis unit comprises a membrane having a first side and a second side wherein, during normal operation of the plant, a high salinity water feed stream is passed to the first side of the membrane of each on-line reverse osmosis unit; a concentrated waste brine retentate stream is withdrawn from the first side of the membrane of each on-line reverse osmosis unit and a low salinity water permeate stream is withdrawn from the second side of the membrane of each on-line reverse osmosis unit, and the permeate streams from each of the on-line reverse osmosis units are combined to produce a low salinity water stream in an amount sufficient to satisfy the injection water requirements of an injection well, wherein the cleaning method comprises:

(i) interrupting the normal operation of the plant by dividing the low salinity water stream into a first stream and a second stream;

(ii) dosing a cleaning chemical into the first stream to form a cleaning water stream and passing the cleaning water stream to the first side of the membrane of the off-line reverse osmosis unit at a pressure less than the osmotic pressure across the membrane for a sufficient period of time to purge the high salinity water from the reverse osmosis unit;

(iii) shutting in the off-line reverse osmosis unit for a period of at least 0.5 hour, preferably, at least 1 hour; and

(iv) purging the cleaning water from the off-line reverse osmosis unit.

2. A method as claimed in Claim 1 wherein the first stream of low salinity water comprises at least 90%, of the low salinity water stream.

3. A method as claimed in Claims 1 or 2 wherein the cleaning chemical that is dosed into the first stream of low salinity water to form the cleaning water stream is selected from the group consisting of hydrochloric acid, nitric acid, sulfuric acid, acetic acid, formic acid, citric acid, phosphoric acid, ammonium hydroxide, sodium hydroxide and potassium hydroxide.

4. A process as claimed in any one of the preceding claims wherein a concentrated solution of the cleaning chemical is continuously dosed into the first stream of low salinity water.

5. A process as claimed in any one of the preceding claims wherein a concentrated aqueous solution of a biocide is continuously dosed into the first stream of low salinity water.

6. A process as claimed in Claim 5 wherein the biocide is selected from the group consisting of tetrakis(hydroxymethyl)phosphonium sulfate, zinc pyrithione, 1,2-benzisothiazolin-3-one, 2-(thiocyanomethylthio)benzothiazole, 2,2-dibromo-3-nitropropionamide, benzalkonium chloride, benzyl C10-16 alkyldimethyl ammonium chloride, didecyl-dimethyl-ammonium chloride, formaldehyde, glutaraldehyde, N-coco alkyl-1,3,-propylenediamine acetate, sodium hypochlorite, sodium bisulfite, 2-methyl-4-isothiazolin-3-one, and 5-chloro-2-methyl-4-isothiazolin-3-one.

7. A process as claimed in any one of the preceding claims wherein a concentrate of the cleaning chemical is either delivered from the surface via a flow line or the plant is provided with a concentrate storage tank for the cleaning chemical that may be actuated from the surface to deliver the cleaning chemical into the first stream of low salinity water.

8. A process as claimed in any one of Claims 5 to 7 wherein a concentrate of the biocide is either delivered from the surface via a flow line or the plant is provided with a concentrate storage tank for the biocide that may be actuated from the surface to deliver the biocide into the first stream of low salinity water.

9. A process as claimed in any one of the preceding claims wherein the flow rate of the cleaning water stream to the off-line reverse osmosis unit is at least 200 m^3/hour.

10. A process as claimed in any one of the preceding claims wherein the cleaning water stream is discharged to the body of water.

11. A process as claimed in any one of the preceding claims wherein the pressure of the cleaning water stream is in the range 1 to 6 bar absolute.

12. A process as claimed in any one of the preceding claims wherein the cleaning water stream is passed to the first side of the membrane of the off-line reverse osmosis unit for 5 to 60 minutes and the off-line reverse osmosis unit(s) is then left shut in for a period of 1 to 24 hours.

13. A process as claimed in any one of the preceding claims wherein the cleaning fluid is purged from the first side of the membrane of the offline reverse osmosis unit by taking a side stream from the low salinity water stream and back-flowing the side stream through the reverse osmosis unit for at least 10 minutes wherein the side stream has a flow rate in

the range 10 to 50 m^3/hour and a pressure in the range 1 to 6 bar absolute.

14. A process as claimed in any one of Claims 1 to 12 wherein the cleaning water is purged from the first side of the membrane of the off-line reverse osmosis unit by taking another of the reverse osmosis units off-line and switching the high salinity water feed from that unit to the unit that is to be purged of cleaning water thereby bringing the unit back on-line.

15. A process as claimed in any one of claims 1 to 14 wherein the flow rate of the second stream of low salinity water is in the range 15 to 75 m^3/hour.

16. A process as claimed in any one of the preceding claims wherein the high salinity water feed stream is filtered upstream of the reverse osmosis units by passing the feed stream through at least one coarse filter and then through at least one fine filter.

17. A process as claimed in any one of the preceding claims wherein the high salinity water feed stream has a hydrostatic head pressure in the range of 25 to 80 bar absolute.

18. A low maintenance submerged reverse osmosis plant comprising:

(a) a filtration system comprising at least one coarse filter and at least one fine filter wherein the filtration system has an inlet for a high salinity water feed stream and an outlet for a filtered high salinity water feed stream;

(b) a flow line for the filtered high salinity water feed stream that leads from the outlet of the filtration system to an inlet of a high salinity water feed manifold, the flow line having a circulation pump arranged therein;

(c) a plurality of on-line reverse osmosis units arranged in parallel and at least one off-line reverse osmosis unit wherein each on-line reverse osmosis unit has: (i) a dedicated flow line leading from the high salinity water feed manifold to a first side of the membrane of the on-line reverse osmosis unit; (ii) a dedicated flow line leading from the first side of the membrane of the on-line reverse osmosis unit to a waste brine manifold; and (iii) a dedicated flow line leading from the second side of the membrane of the on-line reverse osmosis unit to a low salinity water manifold;

(d) a waste brine flow line leading from the waste brine manifold to a waste brine outlet of the desalination plant;

(e) a low salinity water flow line leading from the low salinity water manifold to a low salinity water outlet of the reverse osmosis plant, the flow line having a high pressure pump arranged therein and having a branch point downstream of the high pressure pump;

(f) a cleaning water flow line leading from the branch point to the first side of the membrane of the off-line reverse osmosis unit, the flow line having a valve therein that is normally closed and is opened when it is desired to pass cleaning water to the off-line reverse osmosis unit;

(g) a cleaning chemical injection line leading to the cleaning water flow line for injecting a cleaning chemical into the cleaning water stream flowing through the flow line when the valve in the cleaning water line is opened; and

(h) a waste cleaning water flow line leading from the first side of the membrane of the off-line unit to a waste water outlet of the plant.

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Application No:	GB0519770.2	**Examiner:**	Mr Chris Archer
Claims searched:	1-18	**Date of search:**	12 January 2007

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1 at least	JP 2001187323 A (NITTO DENKO) see English language abstracts attached.
A	-	DE 4205826 A (ZEHETNER) see English language abstracts attached.
A	-	JP 62254804 A (KYOCERA) see English language abstracts attached.
A	-	DD 254188 A (WASSERAUFBEREITUNGSANLAGEN) see English language abstracts attached.
A	-	US 2004/0134521 A (LIBERMAN) see paragraphs [0072] to [0085].

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
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Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC[X] :

B1X; C1C

Worldwide search of patent documents classified in the following areas of the IPC

B01D; C02F

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC