

METHOD OF PRODUCING PURIFIED WATER AND APPARATUS THEREFOR

Cross-Reference to Related Application

[0001] This application claims the benefit of priority of United States Provisional Application No. 61/326,909, filed 22 April 2010, the contents of which being hereby incorporated by reference in its entirety for all purposes.

Technical Field

[0002] The invention relates to a method of producing purified water from a water source which is suspected to contain impurities, and in particular, to a method of producing purified water via a forward osmosis process. An apparatus for carrying out the purification method is also provided.

Background

[0003] Water scarcity has now become one of the most pressing challenges to human civilization in the earth. Growing population and industrial activities, increasing living standard and changing climate are placing extreme pressure on the already-scarce drinking water and energy resources. Wastewater reuse and seawater desalination are few options to increase drinking water availability. However, current technologies for producing purified drinking water from such resources require substantial energy input, which at some extent worsen the vicious cycle of greenhouse gas emissions and climate change. In order to address these problems, tremendous effort has been taken to identify new technologies for producing purified drinking water at lower energy input capacity in an environmentally sustainable manner.

[0004] In the field of drinking water production, reverse osmosis (RO) membrane process has been widely used globally. The process employs high hydraulic pressure and internal flow circulation to force water through a semipermeable membrane from a high concentration solution to a low concentration solution. This is the 'reverse' of the water's natural osmosis tendency. Heavy consumption of electrical energy for creating high hydraulic pressure, coupled with severe membrane fouling problem, has led to the investigation and development of alternative approaches to the RO process.

[0005] In contrast to the RO process, forward osmosis (FO) process makes use of the natural osmosis phenomenon for the transport of water from a feed solution with a low solute concentration to a draw solution with high solute concentration across a semipermeable membrane, with the osmotic pressure difference between the feed and the draw solutions as the driving force. After water naturally permeates into the draw solution, the diluted draw solution can then be recycled for reuse while high quality product water can be produced. Driven by an osmotic pressure gradient, the FO process does not require significant energy input, only stirring or pumping of the feed and draw solutions are involved. Meanwhile, the FO process offers the advantages of less membrane fouling tendency and high rejection of solutes. Recently, the FO process has attracted great attention in seawater desalination, wastewater reclamation, food and pharmaceutical processing, and power generation. However, the major obstacle of adopting the FO process industrially and globally in the application for producing purified drinking water is a lack of low energy methods to separate draw solutes and the purified water from the diluted draw solutions.

Summary

[0006] Various embodiments provide for a method to separate draw solutes and purified water from a draw solution without a need for considerable amount of energy such as heat and pressure. The method employs a forward osmosis process thereby using much less energy than a reverse osmosis process.

[0007] Various embodiments provide for a method of producing purified water from a water source which is suspected to contain impurities. The method may include:

- (a) contacting the water source with a draw solution, wherein the water source and the draw solution are separated by a semipermeable membrane that is permeable for water but essentially impermeable for solutes contained in the water and wherein the draw solution contains a chemically precipitable water-soluble salt in a concentration that allows the draw solution to draw water from the water source by osmosis;
- (b) allowing water from the water source to flow through the semipermeable membrane to the draw solution, thereby diluting the draw solution and concentrating the water source;
- (c) producing purified water from the diluted draw solution by:
 - (i) adding a precipitant to the diluted draw solution to precipitate the salt, wherein the precipitated salt comprises a plurality of gel particles dispersed in water;
 - (ii) adding a coagulant to the plurality of gel particles to coagulate the plurality of gel particles; and
 - (iii) separating the coagulated gel from the water.

[0008] Various embodiments provide for an apparatus for producing purified water from a water source which is suspected to contain impurities. The apparatus may include:

- (a) a first container configured to receive a semipermeable membrane placed therein thereby forming a first portion for containing the water source and a second portion for containing a draw solution, wherein the semipermeable membrane is permeable for water but essentially impermeable for solutes contained in the water and wherein the draw solution contains a chemically precipitable water-soluble salt in a concentration that allows the draw solution to draw water from the water source by osmosis to thereby form a diluted draw solution; and
- (b) a second container for containing the diluted draw solution, wherein the second container is fluidly connected to the second portion of the first container, wherein the second container is configured to:
 - (i) receive a precipitant feed wherein a precipitant is added to the diluted draw solution to precipitate the salt, wherein the precipitated salt thus formed comprises a plurality of gel particles dispersed in water;
 - (ii) receive a coagulant feed wherein a coagulant is added to the plurality of gel particles to coagulate the plurality of gel particles; and
 - (iii) separate the coagulated gel from the water.

Brief Description of the Drawings

[0009] In the drawings, like reference characters generally refer to the same parts throughout the different views. The drawings are not necessarily drawn to scale, emphasis instead generally being placed upon illustrating the principles of various

embodiments. In the following description, various embodiments of the invention are described with reference to the following drawing.

[0010] **Fig. 1** shows a schematic diagram of the method of producing purified water via a forward osmosis process.

Description

[0011] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the invention may be practised. These embodiments are described in sufficient detail to enable those skilled in the art to practise the invention. Other embodiments may be utilized and structural, logical, and electrical changes may be made without departing from the scope of the invention. The various embodiments are not necessarily mutually exclusive, as some embodiments can be combined with one or more other embodiments to form new embodiments.

[0012] Osmosis is defined as the net movement of water across a selectively permeable membrane driven by a difference in osmotic pressure across the membrane. A selectively permeable membrane (or semipermeable membrane) allows passage of water molecules, but rejects solute molecules or ions. The semipermeable membrane filters the impurities from a water source (feed solution) which is suspected to contain impurities, leaving purified water on the other side (permeate side) of the membrane called permeate water. The impurities left on the membrane may be washed away by a portion of the feed solution that does not pass through the membrane. The feed solution carrying the impurities washed away from the membrane is also called "reject" or "brine".

[0013] Various embodiments of the invention make use of a forward osmosis (FO) process developed as an alternative membrane technology for wastewater treatment due to the low energy requirement as a result of low or no hydraulic pressure applied, high rejection of a wide range of contaminants, and low membrane fouling propensity compared to pressure-driven membrane processes, such as reverse osmosis (RO). FO process uses the osmotic pressure differential across the membrane, rather than hydraulic pressure differential (as in RO processes) as the driving force for transport of water through the membrane. The FO process results in concentration of the feed solution and dilution of a highly concentrated stream (referred to as the draw solution). In other words, the FO process utilizes the natural osmosis phenomenon, which makes use of concentration differences between the two solutions across a semipermeable membrane. The semipermeable membrane acts as a selective barrier between the two solutions, and dominates the efficiency of freshwater transportation in the FO process. A concentrated draw solution on the permeate side of the membrane is the source of the driving force in the FO process. Different terms are used in the literature to name this solution including draw solution, osmotic agent, or osmotic media to name only a few. In a FO process the draw solution has a higher osmotic pressure than the feed solution (or reject or brine).

[0014] The semipermeable membranes used may be polymer-based. Further, the membranes may have a dense selective layer embedded onto a support layer for providing rejection of dissolved compounds and providing mechanical strength respectively.

[0015] Various embodiments provide for a method of producing purified water from a water source which is suspected to contain impurities, and an apparatus therefor. **Fig.**

1 illustrates a schematic flow diagram in one embodiment. The water source shown in this illustration is wastewater.

[0016] The apparatus may include a first container 10 configured to receive a semipermeable membrane 12 placed therein thereby forming a first portion 10a for containing the wastewater and a second portion 10b for containing a draw solution. Wastewater may be fed to the first portion 10a by any suitable means, such as a pipe. The draw solution may be fed to the second portion 10b by any suitable means, such as a pipe. Sufficient time is given to allow water from the water source to flow through the semipermeable membrane to the draw solution, thereby diluting the draw solution and concentrating the water source.

[0017] The semipermeable membrane 12 is permeable for water but essentially impermeable for solutes contained in the water of the draw solution. The semipermeable membrane 12 may be of any suitable type conventionally used in forward osmosis or reverse osmosis process. The membrane materials for such semipermeable membranes can be cellulose, polysulfone, polyethersulfone, and polyamide.

[0018] The draw solution contains a chemically precipitable water-soluble salt in a concentration that allows the draw solution to draw water from the wastewater by osmosis to thereby form a diluted draw solution. The diluted draw solution may be withdrawn from the second portion 10b by any suitable means, such as a pipe. The wastewater may be withdrawn from the first portion 10a by any suitable means, such as a pipe, and is now concentrated with impurities that cannot pass through the semipermeable membrane 12.

[0019] The salt is soluble in the water of the draw solution and can be precipitated upon addition of a precipitant.

[0020] In various embodiments, the chemically precipitable water-soluble salt may be selected from the group consisting of aluminium sulfate, magnesium sulfate, manganese sulfate, iron chloride, iron sulphate, and aluminium chloride.

[0021] In the embodiment shown in **Fig. 1**, the draw solution contains $\text{Al}_2(\text{SO}_4)_3$ as the chemically precipitable water-soluble salt, which is commercially available.

[0022] The apparatus may also include a second container (or separator) **14** for containing the diluted draw solution. The second container **14** may be fluidly connected via a pipe to the second portion **10b** of the first container **10** so that the diluted $\text{Al}_2(\text{SO}_4)_3$ draw solution (or $\text{Al}_2(\text{SO}_4)_3$ recycle) withdrawn from the second portion **10b** is fed to the second container **14** for separation. The second container **14** may be configured to receive a precipitant feed whereby a precipitant is added to the diluted draw solution to precipitate the salt, and whereby the precipitated salt thus formed may include a plurality of gel particles dispersed in water. The precipitant may be added to the second container **14** via a separate pipe, for example. Alternatively, the precipitant may be added to the $\text{Al}_2(\text{SO}_4)_3$ recycle stream before entering the second container **14**.

[0023] In various embodiments, the precipitant may be selected from the group consisting of calcium oxide, calcium hydroxide, sodium hydroxide, potassium hydroxide, barium oxide, and barium silicate.

[0024] In the embodiment shown in **Fig. 1**, the precipitant is calcium oxide (CaO), which is commercially available.

[0025] The second container **14** may be further configured to receive a coagulant feed wherein a coagulant is added to the plurality of gel particles to coagulate the plurality of gel particles. The coagulant may be fed to the second container **14** by any suitable means, such as a pipe. The second container **14** may also be configured separate

the coagulated gel from the water, thereby producing purified water separated from the diluted draw solution.

[0026] In various embodiments, the coagulant may be negatively charged.

[0027] In various embodiments, the coagulant may be in the form of a particulate. The size of the particulate coagulate may be from about 1 nm to about 100 μm .

[0028] In various embodiments, the coagulant may be selected from the group consisting of activated silica, anionic polyelectrolyte, iron (III) oxide, zeolite and silicate.

[0029] In one embodiment, the coagulant may be sodium silicate.

[0030] In another embodiment, the coagulant may be anionic polyacrylamide.

[0031] In further embodiments, the coagulant may also be magnetic. The coagulant may consist of a core/shell nanoparticle. In one such embodiment, the coagulant may consist of an iron (III) oxide core and an activated silica shell.

[0032] In various embodiments where the chemically precipitable soluble salt is aluminium sulfate and the precipitant is calcium oxide, each gel particle is a mixture of aluminium hydroxide and calcium sulfate. When aluminium hydroxide is precipitated in water as the solvent, the hydrated aluminium hydroxide forms gels which are positively charged. Due to such electrical charges, each gel particle repels one another and is dispersed in water as a plurality of gel particles. A negatively charged sodium silicate (Na_2SiO_3) is added as a coagulant to coagulate the gel particles of aluminium hydroxide and calcium sulfate. The coagulated gel mixture of aluminium hydroxide, calcium sulfate, and sodium silicate clump together and form a floc. The floc may be deposited to the bottom of the diluted draw solution and is withdrawn while the top liquid is removed as purified water from the second container 14.

[0033] The second container **14** may be further configured (not shown) to receive an acid feed, wherein the acid is added to the coagulated gel to recover the chemically precipitable water-soluble salt.

[0034] In various embodiments, the acid may be selected from the group consisting of sulfuric acid, chloric acid, and nitric acid.

[0035] In one embodiment where the chemically precipitable water-soluble salt is aluminium sulfate, the acid is sulfuric acid.

[0036] The recovered chemically precipitable water-soluble salt aluminium sulfate may then be reused in the draw solution again.

[0037] Calcium sulfate present in the floc may be subsequently precipitated as a useful by-product. Calcium sulfate has wide applications in construction, fertilizer and biomedicine.

[0038] The coagulant may also be subsequently recovered from the floc and reused in the purification process again.

[0039] The concentrated wastewater withdrawn from the first portion **10a** may be rich in organic matters and may be fed to an anaerobic reactor **16** to generate a biogas (methane) as a useful fuel.

[0040] In order that the invention may be readily understood and put into practical effect, particular embodiments will now be described by way of the following non-limiting examples.

Examples

[0041] The following illustrates examples of various negatively charged coagulants used to coagulate positively charged gel particles dispersed in water. The draw solution consists of aluminium sulfate as the chemically precipitable soluble salt and the

precipitant is calcium oxide. The resultant gel particles are mixtures of aluminium hydroxide and calcium sulfate, and are positively charged.

Example 1: $\text{Fe}_3\text{O}_4@\text{SiO}_2$ as Coagulant

[0042] $\text{Fe}_3\text{O}_4@\text{SiO}_2$ core/shell nanoparticles that are negatively charged and magnetic are added to the diluted draw solution to coagulate the gel particles. The floc is formed by ionic binding between the positively charged gel particles and the negatively charged $\text{Fe}_3\text{O}_4@\text{SiO}_2$ coagulant. The floc is then easily and fully removed under application of an external magnetic field. When placed near a permanent magnet, the draw solution becomes clear within minutes and the floc is deposited near the magnetic field due to the magnetic coagulant particles. The clear top liquid is then taken out as the final water product. The roles of the negatively charged and magnetic $\text{Fe}_3\text{O}_4@\text{SiO}_2$ core/shell nanoparticles are to both coagulate the gel particles and to increase the rate of separation via a magnetic field.

Example 2: Anionic Polyacrylamide (PAM) as Coagulant

[0043] Anionic polyacrylamide (PAM) is added to the diluted draw solution to coagulate the gel particles. The floc is formed by ionic binding between the positively charged gel particles and the negatively charged PAM coagulant. The floc is then precipitated to the bottom of the draw solution. The clear top liquid is then taken out as the final water product.

Example 3: Sodium Silicate (Na_2SiO_3) as Coagulant

[0044] Sodium silicate (Na_2SiO_3) is added to the diluted draw solution to coagulate the gel particles. The floc is formed by ionic binding between the positively charged gel particles and the negatively charged Na_2SiO_3 coagulant. The floc is then precipitated to the bottom of the draw solution. The clear top liquid is then taken out as the final water product.

[0045] While the invention has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the appended claims. The scope of the invention is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

Claims

1. A method of producing purified water from a water source which is suspected to contain impurities, comprising:
 - (a) contacting the water source with a draw solution, wherein the water source and the draw solution are separated by a semipermeable membrane that is permeable for water but essentially impermeable for solutes contained in the water and wherein the draw solution contains a chemically precipitable water-soluble salt in a concentration that allows the draw solution to draw water from the water source by osmosis;
 - (b) allowing water from the water source to flow through the semipermeable membrane to the draw solution, thereby diluting the draw solution and concentrating the water source;
 - (c) producing purified water from the diluted draw solution by:
 - (i) adding a precipitant to the diluted draw solution to precipitate the salt, wherein the precipitated salt thus formed comprises a plurality of gel particles dispersed in water;
 - (ii) adding a coagulant to the plurality of gel particles to coagulate the plurality of gel particles; and
 - (iii) separating the coagulated gel from the water.
2. The method of claim 1, further comprising:
 - (d) recovering the chemically precipitable water-soluble salt by adding an acid to the coagulated gel.
3. The method of claim 1 or 2,

- wherein the chemically precipitable water-soluble salt is selected from the group consisting of aluminium sulfate, magnesium sulfate, manganese sulfate, iron chloride, iron sulphate, and aluminium chloride.
4. The method of claim 3,
wherein the chemically precipitable soluble salt is aluminium sulfate.
 5. The method of any one of claims 1 to 4,
wherein the precipitant is selected from the group consisting of calcium oxide, calcium hydroxide, sodium hydroxide, potassium hydroxide, barium oxide, and barium silicate.
 6. The method of claim 5,
wherein the precipitant is calcium oxide.
 7. The method of claim 6,
wherein the chemically precipitable soluble salt is aluminium sulfate, wherein the precipitant is calcium oxide, and wherein each gel particle is a mixture of aluminium hydroxide and calcium sulfate.
 8. The method of any one of claims 1 to 7,
wherein each gel particle is electrically charged.
 9. The method of any one of claims 1 to 8,
wherein the coagulant negatively charged.

10. The method of any one of claims 1 to 9,
wherein the coagulant is selected from the group consisting of activated silica,
anionic polyelectrolyte, iron (III) oxide, zeolite and silicate.
11. The method of claim 10,
wherein the coagulant is sodium silicate.
12. The method of claim 10,
wherein the coagulant is anionic polyacrylamide.
13. The method of any one of claims 1 to 12,
wherein the coagulant is negatively charged and magnetic.
14. The method of claim 13,
wherein the coagulant comprises a core/shell nanoparticle.
15. The method of claim 14,
wherein the coagulant comprises an iron (III) oxide core and an activated silica
shell.
16. The method of any one of claim 1 to 13,
wherein the coagulant comprises a particulate.
17. The method of claim 16,

wherein the size of the particulate is from about 1 nm to about 100 μm .

18. The method of any one of claims 2 to 17,
wherein the acid is selected from the group consisting of sulfuric acid, chloric acid, and nitric acid.
19. The method of claim 18,
wherein the acid is sulfuric acid.
20. An apparatus for producing purified water from a water source which is suspected to contain impurities, comprising:
 - (a) a first container configured to receive a semipermeable membrane placed therein thereby forming a first portion for containing the water source and a second portion for containing a draw solution, wherein the semipermeable membrane is permeable for water but essentially impermeable for solutes contained in the water and wherein the draw solution contains a chemically precipitable water-soluble salt in a concentration that allows the draw solution to draw water from the water source by osmosis to thereby form a diluted draw solution; and
 - (b) a second container for containing the diluted draw solution, wherein the second container is fluidly connected to the second portion of the first container, wherein the second container is configured to:
 - (i) receive a precipitant feed wherein a precipitant is added to the diluted draw solution to precipitate the salt, wherein the precipitated salt thus formed comprises a plurality of gel particles dispersed in water;

- (ii) receive a coagulant feed wherein a coagulant is added to the plurality of gel particles to coagulate the plurality of gel particles; and
- (iii) separate the coagulated gel from the water.

21. The apparatus of claim 20,
wherein the second container is further configured to receive an acid feed,
wherein the acid is added to the coagulated gel to recover the chemically precipitable water-soluble salt.
22. The apparatus of claim 20 or 21,
wherein the chemically precipitable water-soluble salt is selected from the group consisting of aluminium sulfate, magnesium sulfate, manganese sulfate, iron chloride, iron sulphate, and aluminium chloride.
23. The apparatus of claim 22,
wherein the chemically precipitable soluble salt is aluminium sulfate.
24. The apparatus of any one of claims 20 to 23,
wherein the precipitant is selected from the group consisting of calcium oxide, calcium hydroxide, sodium hydroxide, potassium hydroxide, barium oxide, and barium silicate.
25. The apparatus of claim 24,
wherein the precipitant is calcium oxide.

26. The apparatus of claim 25,
wherein the chemically precipitable soluble salt is aluminium sulfate, wherein the precipitant is calcium oxide, and wherein each gel particle is a mixture of aluminium hydroxide and calcium sulfate.
27. The apparatus of any one of claims 20 to 26,
wherein each gel particle is electrically charged.
28. The apparatus of any one of claims 20 to 27,
wherein the coagulant negatively charged.
29. The apparatus of any one of claims 20 to 28,
wherein the coagulant is selected from the group consisting of activated silica, anionic polyelectrolyte, iron (III) oxide, zeolite and silicate.
30. The apparatus of claim 29,
wherein the coagulant is sodium silicate.
31. The apparatus of claim 29,
wherein the coagulant is anionic polyacrylamide.
32. The apparatus of any one of claims 20 to 31,
wherein the coagulant is negatively charged and magnetic.
33. The apparatus of claim 32,

wherein the coagulant comprises a core/shell nanoparticle.

34. The apparatus of claim 33,
wherein the coagulant comprises an iron (III) oxide core and an activated silica shell.
35. The apparatus of any one of claim 20 to 32,
wherein the coagulant comprises a particulate.
36. The apparatus of claim 35,
wherein the size of the particulate is from about 1 nm to about 100 μm .
37. The apparatus of any one of claims 21 to 36,
wherein the acid is selected from the group consisting of sulfuric acid, chloric acid, and nitric acid.
38. The apparatus of claim 37,
wherein the acid is sulfuric acid.