soluble salt from a first volume of contaminated water, said first volume of contaminated water including said water soluble salt in solution therein, by introducing a water-miscible solvent to said first volume of contaminated water, thereby resulting in a mixture of precipitated salt, dissolved salt, and water-miscible solvent in water; transporting said mixture directly from said apparatus to at least one membrane and removing said water-miscible solvent from said mixture of precipitated salt, dissolved salt, and water-miscible solvent in water by bringing said mixture into contact with at least one membrane, thereby providing recovered water-miscible solvent; and using said recovered water-miscible solvent to precipitate a water soluble salt from a second volume of contaminated water, said second volume of contaminated water including said water soluble salt in solution therein, by introducing the recovered water-miscible solvent to said second volume of contaminated water. In another aspect, there is provided a method of separating a salt or salts from a solution containing dissolved salts and a solvent, comprising: ~~passing~~ introducing a first solution including a liquid, dissolved salts, and a solvent through a membrane having a first side and a second side, wherein said membrane includes a structure or configuration that does not allow the solvent to pass through the membrane from the first side to the second side, wherein the introduction of the first solution to the membrane occurs directly following introduction of the solvent to a volume of water, the introduction of solvent resulting in the first solution; and recovering the solvent that does not pass through the membrane for use in precipitating a salt from a second solution by introduction of the recovered solvent to the second solution to cause precipitation of said salt. In yet another aspect, there is provided a method of treating water having contaminants therein, the contaminants including at least a water soluble salt, the method comprising a plurality of active treatment steps, the plurality of active treatment steps comprising in sequence: a first active treatment step of precipitating a water

soluble salt from a first volume of contaminated water, said first volume of contaminated water including said water soluble salt in solution therein, by introducing a water-miscible solvent to said first volume of contaminated water, thereby resulting in a mixture of precipitated salt, dissolved salt, and water-miscible solvent in water; and a second active treatment step of introducing the mixture of precipitated salt, dissolved salt, and water-miscible solvent in water to a membrane having a first side and a second side, wherein said membrane includes a structure or configuration that does not allow the water-miscible solvent to pass through the first side of the membrane to the second side of the membrane. Other embodiments of the present disclosure may include further processing to (1) remove the precipitated salt from the water and (2) remove the solvent from the water. Another embodiment of the present disclosure is that the method and apparatus accomplish this in an efficient, low-energy, and low-cost manner.

We claim:

1. A method of treating water having contaminants therein, the contaminants including at least a water soluble salt, the method comprising:

precipitating a water soluble salt from a first volume of contaminated water in an apparatus, said first volume of contaminated water including said water soluble salt in solution therein, by introducing a water-miscible solvent to said first volume of contaminated water, thereby resulting in a mixture of precipitated salt, dissolved salt, and water-miscible solvent in water;

transporting said mixture directly from said apparatus to at least one membrane and removing said water-miscible solvent from said mixture of precipitated salt, dissolved salt, and water-miscible solvent in water by bringing said mixture into contact with at least one membrane, thereby providing recovered water-miscible solvent; and

using said recovered water-miscible solvent to precipitate a water soluble salt from a second volume of contaminated water, said second volume of contaminated water including said water soluble salt in solution therein, by introducing the recovered water-miscible solvent to said second volume of contaminated water.

2. The method of claim 1, wherein the mass ratio of the water-miscible solvent to the total mass of aqueous mixture is about 0.05 to 0.3.

3. The method of claim 1, wherein removing said water-miscible solvent from said mixture of precipitated salt, dissolved salt, and water-miscible solvent in water is accomplished via said at least one membrane, wherein said membrane has a first side and a second side, and wherein the membrane includes a structure or configuration that does not allow the water-miscible solvent to pass through the membrane from the first side to the second side.

4. The method of claim 3, wherein water-miscible solvent that does not pass through the membrane is used as the source of recovered water-miscible solvent for said step of using said recovered water-miscible solvent to precipitate a water soluble salt from said second volume of contaminated water, said second volume of contaminated water including said water soluble salt in solution therein, by introducing the recovered water-miscible solvent to said second volume of contaminated water.

5. The method of claim 1, wherein said use of at least one membrane includes the use of a plurality of membranes arranged in series, and further comprises bringing said mixture of precipitated salt, dissolved salt, and water-miscible solvent in water sequentially into contact with said plurality of membranes arranged in series, each membrane of said plurality of membranes having a first side and a second side, wherein at least one membrane of said plurality of membranes includes a structure or configuration that does not allow the water-miscible solvent to pass through the membrane from the first side to the second side.

6. The method of claim 5, wherein said plurality of membranes includes at least a first membrane, a second membrane, and a third membrane.

7. The method of claim 6, wherein said first membrane is an ultrafiltration membrane, said second membrane is a nanofiltration membrane, and said third membrane is a reverse osmosis membrane.

8. The method of claim 7, wherein any water-miscible solvent that does not pass through any membrane of the plurality of membranes is used as the source of recovered water-miscible solvent for said step of using said recovered water-miscible solvent to precipitate a water soluble salt from said second volume of contaminated water, said second volume of contaminated water including said water soluble salt in solution therein, by introducing the recovered water-miscible solvent to said second volume of contaminated water.

9. The method of claim 1, further including the use of a hydrocyclone to separate said mixture into an underflow fraction and an overflow fraction, wherein said overflow fraction includes water-miscible solvent and dissolved salt in water but is substantially free of precipitated salt.

10. The method of claim 9, wherein said overflow fraction is used as a second source of recovered water-miscible solvent for said step of using said recovered water-miscible solvent to precipitate a water soluble salt from said second volume of contaminated water, said second volume of contaminated water including said water soluble salt in solution therein, by introducing the recovered water-miscible solvent to said second volume of contaminated water.

11. The method of claim 1, wherein the contaminated water has been pretreated to remove one or more materials comprising oily residues, gel particles, suspended solids, strontium, calcium, or a mixture of two or more thereof.

12. The method of claim 1, wherein the water-miscible solvent is an organic solvent or inorganic solvent.

13. The method of claim 1, wherein the water-miscible solvent is a mixture of two or more solvents.

14. The method of claim 1, wherein the water-miscible solvent is chosen from methylamine, dimethylamine, trimethylamine, ethylamine, acetaldehyde, methylformate, isopropylamine, propylene oxide, dimethoxymethane, t-butylamine, propionaldehyde, N-propylamine, allylamine, diethylamine, acetone, s-butylamine, or a mixture of two or more thereof.

15. The method of claim 1, wherein said first volume of contaminated water and said second volume of contaminated water are from the same source of contaminated water.

16. The method of claim 1, wherein the steps of:

(1) precipitating a water soluble salt from a first volume of contaminated water; (2) removing said water-miscible solvent from said mixture of precipitated salt, dissolved salt, and water-miscible solvent in water; and (3) using said recovered water-miscible solvent to precipitate a water soluble salt from a second volume of contaminated water,

can be repeated in a continuous loop.

17. A method of separating a salt or salts from a solution containing dissolved salts and a solvent, comprising:

introducing a first solution including a liquid, dissolved salts, and a solvent to a membrane having a first side and a second side, wherein said membrane includes a structure or configuration that does not allow the solvent to pass through the membrane from the first side to the second side, wherein the introduction of the first solution to the membrane occurs directly following introduction of the solvent to a volume of water, the introduction of solvent resulting in the first solution; and

recovering the solvent that does not pass through the membrane for use in precipitating a salt from a second solution by introduction of the recovered solvent to the second solution to cause precipitation of said salt.

18. The method of claim 17, wherein the membrane is chosen from an ultrafiltration membrane, a nanofiltration membrane, and a reverse osmosis membrane.

19. The method of claim 17, wherein solvent concentration increases exterior to the membrane on the first side of the membrane, and such increased solvent concentration precipitates salt out of the first solution.

20. The method of claim 1, wherein the apparatus is chosen from a mixing tank, a settler tank, and a hydrocyclone.

21. A method of treating water having contaminants therein, the contaminants including at least a water soluble salt, the method comprising a plurality of active treatment steps, the plurality of active treatment steps comprising in sequence:

a first active treatment step of precipitating a water soluble salt from a first volume of contaminated water, said first volume of contaminated water including said water soluble salt in solution therein, by introducing a water-miscible solvent to said first volume of contaminated

water, thereby resulting in a mixture of precipitated salt, dissolved salt, and water-miscible solvent in water; and

a second active treatment step of introducing the mixture of precipitated salt, dissolved salt, and water-miscible solvent in water to a membrane having a first side and a second side, wherein said membrane includes a structure or configuration that does not allow the water-miscible solvent to pass through the first side of the membrane to the second side of the membrane.

We claim:

1. A method of treating water having contaminants therein, the contaminants including at least a water soluble salt, the method comprising:

precipitating a water soluble salt from a first volume of contaminated water, said first volume of contaminated water including said water soluble salt in solution therein, by introducing a water-miscible solvent to said first volume of contaminated water, thereby resulting in a mixture of precipitated salt, dissolved salt, and water-miscible solvent in water;

removing said water-miscible solvent from said mixture of precipitated salt, dissolved salt, and water-miscible solvent in water, thereby providing recovered water-miscible solvent; and

using said recovered water-miscible solvent to precipitate a water soluble salt from a second volume of contaminated water, said second volume of contaminated water including said water soluble salt in solution therein, by introducing the recovered water-miscible solvent to said second volume of contaminated water.

2. The method of claim 1, wherein the water-miscible solvent is characterized by:

a. infinite solubility in water at 25°C;

b. a boiling point of greater than 25°C at 0.101 MPa;

c. a heat of vaporization of about 0.5 cal/g or less; and

d. no tendency to azeotrope with water.

3. The method of claim 2, wherein the mass ratio of the water-miscible solvent to the total volume of aqueous mixture is about 0.05 to 0.3.

4. The method of claim 1, wherein removing said water-miscible solvent from said mixture of precipitated salt, dissolved salt, and water-miscible solvent in water is accomplished via a physical separation.

5. The method of claim 4, wherein said physical separation includes the use of at least one membrane, and further comprises passing said mixture of precipitated salt, dissolved salt, and water-miscible solvent in water through a membrane having a first side and a second side, wherein said membrane includes a structure or configuration that does not allow the water-miscible solvent to pass through the membrane from the first side to the second side.

6. The method of claim 5, wherein water-miscible solvent that does not pass through the membrane is used as the source of recovered water-miscible solvent for said step of using said recovered water-miscible solvent to precipitate a water soluble salt from said second volume of contaminated water, said second volume of contaminated water including said water soluble salt in solution therein, by introducing the recovered water-miscible solvent to said second volume of contaminated water.

7. The method of claim 5, wherein said membrane is chosen from an ultrafiltration membrane, a nanofiltration membrane, and a reverse osmosis membrane.

8. The method of claim 4, wherein said physical separation includes the use of a plurality of membranes arranged in series, and further comprises passing said mixture of precipitated salt, dissolved salt, and water-miscible solvent in water sequentially through said plurality of membranes arranged in series, each membrane of said plurality of membranes having a first side and a second side, wherein at least one membrane of said plurality of membranes includes a structure or configuration that does not allow the water-miscible solvent to pass through the membrane from the first side to the second side.

9. The method of claim 8, wherein said plurality of membranes includes at least a first membrane, a second membrane, and a third membrane.

10. The method of claim 9, wherein said first membrane is an ultrafiltration membrane, said second membrane is a nanofiltration membrane, and said third membrane is a reverse osmosis membrane.

11. The method of claim 10, wherein any water-miscible solvent that does not pass through any membrane of the plurality of membranes is used as the source of recovered water-miscible solvent for said step of using said recovered water-miscible solvent to precipitate a water soluble salt from said second volume of contaminated water, said second volume of contaminated water including said water soluble salt in solution therein, by introducing the recovered water-miscible solvent to said second volume of contaminated water.

12. The method of claim 4, wherein said physical separation includes the use of a hydrocyclone to separate said mixture into an underflow fraction and an overflow fraction, wherein said overflow fraction includes water-miscible solvent and dissolved salt in water but is substantially free of precipitated salt.

13. The method of claim 12, wherein said overflow fraction is used as the source of recovered water-miscible solvent for said step of using said recovered water-miscible solvent to precipitate a water soluble salt from said second volume of contaminated water, said second volume of contaminated water including said water soluble salt in solution therein, by introducing the recovered water-miscible solvent to said second volume of contaminated water.

14. The method of claim 1, wherein removing said water-miscible solvent from said mixture of precipitated salt, dissolved salt, and water-miscible solvent in water is accomplished via evaporation.

15. The method of claim 14, wherein said evaporation includes the use of an evaporator apparatus including at least one hollow cylindrical housing having a top opening, a bottom opening, an inner wall, and an outer wall, and comprising a helical threaded feature disposed on at least a portion of the inner wall.

16. The method of claim 15, further comprising flowing said mixture of precipitated salt, dissolved salt, and water-miscible solvent in water through said housing, resulting in a

substantial portion of said water-miscible solvent evaporating from said mixture during flow of said mixture through said housing.

17. The method of claim 16, further comprising a condenser apparatus attached to the evaporator apparatus and situated to condense the evaporated water-miscible solvent exiting the top opening of the cylindrical housing of the evaporator apparatus.

18. The method of claim 17, wherein the condensed water-miscible solvent is used as the source of recovered water-miscible solvent for said step of using said water-miscible solvent to precipitate a water soluble salt from said second volume of contaminated water, said second volume of contaminated water including said water soluble salt in solution therein, by introducing the recovered water-miscible solvent to said second volume of contaminated water.

19. The method of claim 1, wherein the contaminated water has been pretreated to remove one or more materials comprising oily residues, gel particles, suspended solids, strontium, calcium, or a mixture of two or more thereof.

20. The method of claim 1, wherein the water-miscible solvent is an organic solvent or inorganic solvent.

21. The method of claim 1, wherein the water-miscible solvent is a mixture of two or more solvents.

22. The method of claim 1, wherein the water-miscible solvent is chosen from methylamine, dimethylamine, trimethylamine, ethylamine, acetaldehyde, methylformate, isopropylamine, propylene oxide, dimethoxymethane, t-butylamine, propionaldehyde, N-propylamine, allylamine, diethylamine, acetone, s-butylamine, or a mixture of two or more thereof.

23. The method of claim 1, wherein said first volume of contaminated water and said second volume of contaminated water are from the same source of contaminated water.

24. The method of claim 1, wherein the steps of:

(1) precipitating a water soluble salt from a first volume of contaminated water; (2) removing said water-miscible solvent from said mixture of precipitated salt, dissolved salt, and water-miscible solvent in water; and (3) using said recovered water-miscible solvent to precipitate a water soluble salt from a second volume of contaminated water, can be repeated in a continuous loop.

25. A method of separating a salt or salts from a solution containing dissolved salts and a solvent, comprising:

passing a first solution including a liquid, dissolved salts, and a solvent through a membrane having a first side and a second side, wherein said membrane includes a structure or configuration that does not allow the solvent to pass through the membrane from the first side to the second side; and

recovering the solvent that does not pass through the membrane for use in precipitating a salt from a second solution by introduction of the recovered solvent to the second solution to cause precipitation of said salt.

26. The method of claim 25, wherein the membrane is chosen from an ultrafiltration membrane, a nanofiltration membrane, and a reverse osmosis membrane.

27. The method of claim 25, wherein solvent concentration increases exterior to the membrane on the first side of the membrane, and such increased solvent concentration precipitates salt out of the solution.