CLAIMS

What is claimed:

1. A process for purifying water, comprising:

   contacting an aqueous mixture with a flotation medium, wherein the flotation medium has a density greater than or equal to the density of ice or hydrate and less than the density of the aqueous mixture or concentrated brine at its freezing point;

   reducing the temperature of the aqueous mixture to a temperature equal to or below the freezing point of the aqueous mixture to form ice or hydrate and a concentrate;

   phase separating the concentrate and the flotation medium;

   recovering the concentrate; and

   recovering the ice or hydrate and flotation medium as a slurry.

2. The process of claim 1, wherein the flotation medium has a density in the range from about 0.8 to about 1.0 g/cc.
3. The process of claim 1 or claim 2, further comprising melting the ice in the slurry of ice in flotation medium to form an aqueous fraction comprising water.
4. The process of any one of claims 1-3, further comprising separating the aqueous fraction from the flotation medium.
5. The process of any one of claims 1-4, further comprising washing the slurry with a wash liquid comprising at least one of fresh water, the aqueous fraction, and flotation medium, which may be the same or different than the flotation medium used in the contacting step.
6. The process of claim 5, further comprising adding to the wash liquid one or more additives improving the displacement of concentrate adhering to the ice surfaces.
7. The process of any one of claims 5-6 in which the temperature of the wash liquid is varied to enhance the displacement of concentrate adhering to the ice.
8. The process of any one of claims 1-7, wherein the temperature of the aqueous mixture is reduced by direct heat exchange, indirect heat exchange, or a mixture thereof, or by vacuum evaporation of some water contained in the mixture.
9. The process of any one of claims 1-8, wherein the temperature of the aqueous mixture is reduced by direct heat exchange, indirect heat exchange, or a mixture thereof, with

at least one of liquid natural gas (LNG), expanded LNG, ethane, propane, ethylene, propylene, and other cryogenic liquids.

10. The process of any one of claims 1-9, wherein the contacting and temperature reducing steps are performed at the same time.
11. The process of any one of claims 1-9, wherein the contacting step is performed prior to the temperature reducing step.
12. The process of any one of claims 1-11, wherein the aqueous mixture comprises at least one of seawater, brackish water, brine, saline water, produced water, salts of any kind, alcoholic beverages, coffee, tea, orange juice, and urine.
13. The process of any one of claims 1-12, wherein the flotation medium comprises at least one of an organic oil, a saturated or unsaturated paraffinic, cycloparaffinic, and aromatic hydrocarbon, a synthetic oil or lubricant, and a low temperature synthetic base fluids.
14. The process of any one of claims 1-13, further comprising:

    contacting the flotation medium-ice slurry with a fluid having a higher density than the flotation medium;

    displacing adhering or occluded concentrate into the concentrate; and

    phase separating the flotation medium/ice, the fluid, and the concentrate.
15. The process of any one of claims 1-14, further comprising:

    contacting the recovered concentrate with a second flotation medium, which may be the flotation medium, wherein the second flotation medium has a density greater than or equal to 0.8 and less than the density of the concentrate at its freezing point;

    reducing the temperature of the concentrate to a temperature equal to or below the freezing point of the concentrate to form ice or hydrate and a second concentrate;

    phase separating the second concentrate and the second flotation medium;

    recovering the second concentrate; and

    recovering the ice or hydrate and second flotation medium as a slurry.
16. The process of claim 15, further comprising

    forming a precipitate while removing heat from the aqueous mixture.
17. The process of claim 16, further comprising:

    forming a second precipitate during further heat removal from the concentrate.

18. The process of claim 17, wherein the precipitate comprises a different salt or a different metal or mixtures of salt and/or metals than the second precipitate.
19. The process of any one of claims 1-18, wherein purified water recovered is greater than 85% of the water contained in the original aqueous mixture.
20. The process of any one of claims 1-19, further comprising one or more of:
    i. determining a ratio of brine adherence to ice for a given aqueous mixture as a function of one or more of aqueous mixture composition, freezing rates, flotation medium feed rate, flotation medium feed temperature, flotation medium, aqueous mixture feed temperature, aqueous medium feed rate, water wash temperature, and water wash rate;
    ii. calculating the number of theoretical transfer units to result in a desired water purity or water recovery percentage for the aqueous mixture;
    iii. determining a height of a theoretical transfer unit for the aqueous mixture;
    iv. determining a feed location for the aqueous mixture and/or the flotation medium, based on one or more of the determined height, the determined brine adherence ratio, the calculated number of theoretical transfer units, desired concentrate slurry concentration, desired water purity, desired water recovery percentage, freezing temperature, minimum flotation medium temperature, and mixture eutectic temperature;
    v. adjusting a temperature of the flotation medium and/or the water wash based on the determined ratio of brine adherence; and
    vi. adjusting a flow rate of the water wash, the flotation medium, and the brine based on the determined ratio of brine adherence.
21. A method of designing a water purification system, comprising:
    i. determining a ratio of brine adherence to ice for a given aqueous mixture, as a function of one or more of aqueous mixture composition, freezing rates, flotation medium feed rate, flotation medium feed temperature, flotation medium, aqueous mixture feed temperature, aqueous medium feed rate, water wash temperature, and water wash rate;
    ii. calculating a number of theoretical transfer units to result in a desired water purity for the aqueous mixture;

iii. determining a height of a theoretical transfer unit for the aqueous mixture;

iv. designing or constructing a water purification process using one or more countercurrent flow columns having a height or combined height equivalent to or within 20% of the determined height multiplied by the number of theoretical transfer units.

22. An apparatus for purifying water, comprising:

a flow conduit or column for contacting an aqueous mixture with a flotation medium, wherein the flotation medium has a density greater than or equal to 0.8 and less than the density of the aqueous mixture or concentrated brine at its freezing point;

a direct or indirect heat exchange system for reducing the temperature of the aqueous mixture to a temperature equal to or below the freezing point of the aqueous mixture to form ice or hydrate and a concentrate;

at least one phase separator for phase separating the concentrate and the flotation medium;

a flow conduit for recovering the concentrate; and

a flow conduit for recovering the ice or hydrate and flotation medium as a slurry.

23. The apparatus of claim 20, further comprising a direct or indirect heat exchange system for melting the ice to form an aqueous fraction comprising water.

24. The apparatus of claim 20 or claim 21, further comprising a separator for separating the aqueous fraction from the flotation medium.

25. The apparatus of any one of claims 20-22, further comprising a flow conduit for introducing a wash fluid for washing the slurry with at least one of fresh water, the aqueous fraction, and flotation medium, which may be the same or different than the flotation medium used in the contacting step.

26. The apparatus of any one of claims 20-23, further comprising:

a flow conduit or column for contacting the concentrate with a second flotation medium, wherein the second flotation medium has a density greater than or equal to 0.8 and less than the density of the concentrate at its freezing point;

a direct or indirect heat exchange system for reducing the temperature of the concentrate to a temperature equal to or below the freezing point of the concentrate to form ice or hydrate and a second concentrate;

at least one phase separator for phase separating the second concentrate and the second flotation medium;

a flow conduit for recovering the second concentrate; and

a flow conduit for recovering the ice or hydrate and second flotation medium as a slurry.

CLAIMS

What is claimed:

1. A process for purifying water, comprising:

   contacting an aqueous mixture with a flotation medium, wherein the flotation medium has a density greater than or equal to the density of ice or hydrate and less than the density of the aqueous mixture or concentrated brine thereof at its freezing point;

   reducing the temperature of the aqueous mixture to a temperature below the freezing point of the aqueous mixture to form ice or hydrate and a concentrate comprising brine and precipitated solids; and

   phase separating the concentrate and the flotation medium;

   recovering the concentrate; and

   recovering the ice or hydrate and flotation medium as a slurry.

2. The process of claim 1, wherein the flotation medium has a density in the range from about 0.8 to about 1.0 g/cc.
3. The process of claim 1, further comprising melting the ice in the recovered slurry of ice or hydrate and flotation medium to form an aqueous fraction comprising water.
4. The process of claim 3, further comprising separating the aqueous fraction from the flotation medium.
5. The process of claim 1, further comprising washing the slurry with a wash liquid comprising at least one of fresh water, the aqueous fraction, and flotation medium, which may be the same or different than the flotation medium used in the contacting step.
6. The process of claim 5, further comprising adding to the wash liquid one or more additives improving the displacement of concentrate adhering to the ice surfaces.
7. The process of claim 5 in which the temperature of the wash liquid is varied to enhance the displacement of concentrate adhering to the ice.
8. The process of claim 1, wherein the temperature of the aqueous mixture is reduced by direct heat exchange, indirect heat exchange, or a mixture thereof, or by vacuum evaporation of some water contained in the mixture.
9. The process of claim 1, wherein the temperature of the aqueous mixture is reduced by direct heat exchange, indirect heat exchange, or a mixture thereof, with

at least one of liquid natural gas (LNG), expanded LNG, ethane, propane, ethylene, propylene, and other cryogenic liquids.

10. The process of claim 1, wherein the contacting and temperature reducing steps are performed at the same time.

11. The process of claim 1, wherein the contacting step is performed prior to the temperature reducing step.

12. The process of claim 1, wherein the aqueous mixture comprises at least one of seawater, brackish water, brine, saline water, produced water, salts of any kind, alcoholic beverages, coffee, tea, orange juice, and urine.

13. The process of claim 1, wherein the flotation medium comprises at least one of an organic oil, a saturated or unsaturated paraffinic, cycloparaffinic, and aromatic hydrocarbon, a synthetic oil or lubricant, and a low temperature synthetic base fluids.

14. The process of claim 1, further comprising:

contacting the flotation medium-ice slurry with a fluid having a higher density than the flotation medium;

displacing adhering or occluded concentrate into the concentrate; and

phase separating the flotation medium/ice, the fluid, and the concentrate.

15. The process of claim 1, further comprising:

contacting the recovered concentrate with a second flotation medium, which may be the flotation medium, wherein the second flotation medium has a density greater than or equal to 0.8 and less than the density of the concentrate at its freezing point;

reducing the temperature of the concentrate to a temperature equal to or below the freezing point of the concentrate to form ice or hydrate and a second concentrate;

phase separating the second concentrate and the second flotation medium;

recovering the second concentrate; and

recovering the ice or hydrate and second flotation medium as a slurry.

16. The process of claim 15, further comprising

forming a precipitate while removing heat from the aqueous mixture.

17. The process of claim 16, further comprising:

forming a second precipitate during further heat removal from the concentrate.

18. The process of claim 17, wherein the precipitate comprises a different salt or a different metal or mixtures of salt and/or metals than the second precipitate.

19. The process of claim 1, wherein purified water recovered is greater than 85% of the water contained in the original aqueous mixture.

20. The process of claim 1, further comprising one or more of:

    i. determining a ratio of brine adherence to ice for a given aqueous mixture as a function of one or more of aqueous mixture composition, freezing rates, flotation medium feed rate, flotation medium feed temperature, flotation medium, aqueous mixture feed temperature, aqueous medium feed rate, water wash temperature, and water wash rate;

    ii. calculating the number of theoretical transfer units to result in a desired water purity or water recovery percentage for the aqueous mixture;

    iii. determining a height of a theoretical transfer unit for the aqueous mixture;

    iv. determining a feed location for the aqueous mixture and/or the flotation medium, based on one or more of the determined height, the determined brine adherence ratio, the calculated number of theoretical transfer units, desired concentrate slurry concentration, desired water purity, desired water recovery percentage, freezing temperature, minimum flotation medium temperature, and mixture eutectic temperature;

    v. adjusting a temperature of the flotation medium and/or the water wash based on the determined ratio of brine adherence; and

    vi. adjusting a flow rate of the water wash, the flotation medium, and the brine based on the determined ratio of brine adherence.

21. The process of claim 1, wherein the temperature of the temperature of the aqueous mixture is reduced to a temperature in the range from about −10° C. to about −65° C.

22. The process of claim 1, wherein the flotation medium comprises corn oil.

23. A process for purifying water, comprising:

contacting an aqueous mixture with a flotation medium, wherein the flotation medium has a density greater than or equal to the density of ice or hydrate and less than the density of the aqueous mixture or a concentrated brine thereof at its freezing point;

reducing the temperature of the aqueous mixture to a temperature in the range from about −15° C. to about −65° C. to form ice or hydrate and a concentrate;

phase separating the concentrate and the flotation medium;

recovering the concentrate; and

recovering the ice or hydrate and flotation medium as a slurry.

24. The process of claim 23, wherein the temperature of the aqueous mixture is reduced by direct heat exchange, indirect heat exchange, or a mixture thereof, with at least one of liquid natural gas (LNG), expanded LNG, ethane, propane, ethylene, propylene, and other cryogenic liquids.