enabling separation of the ice from the brine, transport of the ice slurry, and recovery of the purified water.

[0015] E~~In one aspect,~~ embodiments disclosed herein relate to a process for purifying water. The process may include: 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. In some embodiments, the flotation medium may have a density in the range from about 0.8 to about 1.0 g/cc.

[0015a] In one aspect, there is provided 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.

[0016] The process may further include one or more of the following steps: melting the ice in the slurry of ice in flotation medium to form an aqueous fraction comprising water; separating the aqueous fraction from the flotation medium; 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; adding to the wash liquid one or more additives improving the displacement of concentrate adhering to the ice surfaces.

[0017] In one or more embodiments, the temperature of the wash liquid is varied to enhance the displacement of concentrate adhering to the ice. In one or more embodiments, 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. For example, in some embodiments, 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, and propylene.

[0018] In some embodiments, the contacting and temperature reducing steps are performed at the same time. In other embodiments, the contacting step is performed prior to the temperature reducing step.

percentage, freezing temperature, minimum flotation medium temperature, and mixture eutectic temperature; (f) adjusting a temperature of the flotation medium and/or the water wash based on the determined ratio of brine adherence; and (g) adjusting a flow rate of the water wash, the flotation medium, and the brine based on the determined ratio of brine adherence.

[0023] Other~~In another aspect,~~ embodiments disclosed herein relate to a method of designing a water purification system. The method may include: (a) 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; (b) calculating a number of theoretical transfer units to result in a desired water purity for the aqueous mixture; (c) determining a height of a theoretical transfer unit for the aqueous mixture; and (d) 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.

[0024] Other~~In another aspect,~~ embodiments disclosed herein relate to an apparatus for purifying water. The apparatus may include: 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.

[0025] The apparatus may also include one or more of the following: a direct or indirect heat exchange system for melting the ice to form an aqueous fraction comprising water; a separator for separating the aqueous fraction from the flotation medium; 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; 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.

[0025a] In another aspect, there is provided 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.

[0026] Other aspects and advantages will be apparent from the following description and the appended claims.

BRIEF DESCRIPTION OF DRAWINGS

[0027] Figures 1A-1F are simplified process flow diagrams of processes for purifying water according to embodiments disclosed herein.

[0028] Figures 2-8 are simplified process flow diagrams of processes for purifying water according to embodiments disclosed herein.

[0029] Figure 9 is a graphical comparison of energy consumption as a function of freezing temperature for processes according to embodiments disclosed herein.

[0030] Figure 10 is a table presenting eutectic temperatures and compositions for various water-salt binary systems.

[0031] Figure 11 is a binary phase diagram of a sodium chloride-water system annotated to illustrate operation of processes for the purification of water according to embodiments disclosed herein.

[0032] Figures 12-15 are charts illustrating the interrelationship of energy consumption, residual brine composition, pure water recovery, freezing temperature and typical recovered water costs for processes according to embodiments disclosed herein.

[0033] Figure 16 is a graph illustrating savings in trucking costs that may be realized by producing purified water and reducing the total wastewater resulting from a produced water stream.