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(54) Title: BUILDING MATERIALS FROM AN AQUEOUS SOLUTION

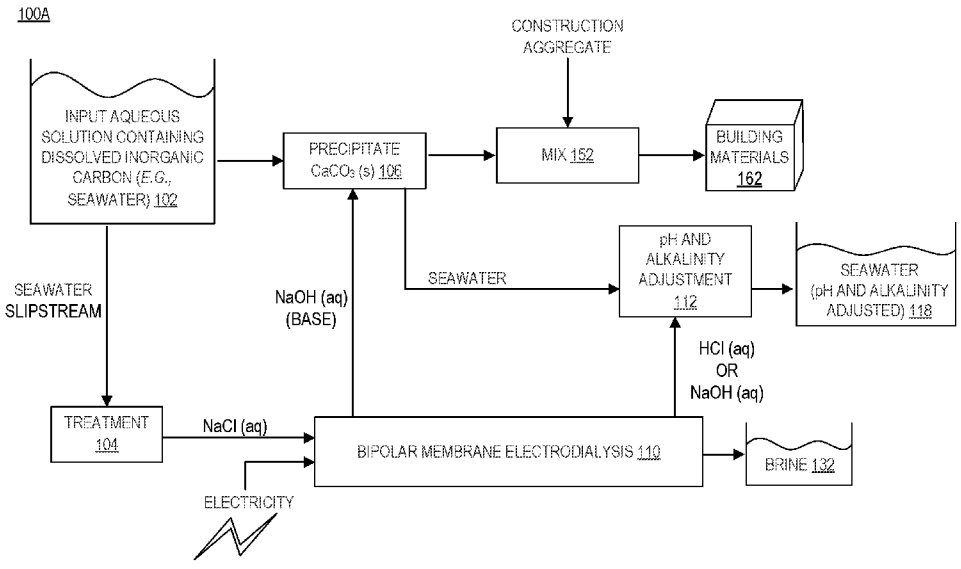


FIG. 1A

(57) Abstract: A method of making building materials from an aqueous solution includes receiving the aqueous solution with dissolved ions and increasing a pH of the aqueous solution so the dissolved ions precipitate from the aqueous solution as salt. The method also includes collecting the salt precipitated from the aqueous solution and forming the building materials from the salt.

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BUILDING MATERIALS FROM AN AQUEOUS SOLUTION

TECHNICAL FIELD

[0001] This disclosure relates generally to fabrication of building materials.

BACKGROUND INFORMATION

[0002] Carbon dioxide (CO_2) may be harmful to the earth's atmosphere in large quantities. The separation of CO_2 from a mixed-gas source (such as the atmosphere) may be accomplished by a capture and regeneration process. The process generally includes a selective capture of CO_2, accomplished by, for example, contacting a mixed-gas source with a solid or liquid adsorber/absorber followed by a generation or desorption of CO_2 from the adsorber/absorber. One technique describes the use of bipolar membrane electrodialysis for CO_2 extraction/removal from potassium carbonate and bicarbonate solutions.

[0003] For capture/regeneration systems, a total volume of mixed-gas source that must be processed is generally inversely related to a concentration of CO_2 in the mixed-gas source, adding significant challenges to the separation of CO_2 from dilute sources such as the atmosphere. CO_2 in the atmosphere, however, establishes equilibrium with the total dissolved inorganic carbon in the oceans, which is largely in the form of bicarbonate ions (HCO_3-) at an ocean pH of 8.1-8.3. Therefore, a method for extracting CO_2 from the dissolved inorganic carbon of the oceans would effectively enable the separation of CO_2 from atmosphere without the need to process large volumes of air.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Non-limiting and non-exhaustive embodiments of the invention are described with reference to the following figures, wherein like reference numerals refer to like parts throughout the various views unless otherwise specified. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles being described.

[0005] FIG. 1A is an illustration of a system for making building materials from an aqueous solution, in accordance with an embodiment of the disclosure.

[0006] FIG. 1B is an illustration of a system for making building materials from an aqueous solution, in accordance with an embodiment of the disclosure.

[0007] FIG. 2 is an example electrodialysis unit, in accordance with an embodiment of the disclosure.

[0008] FIG. 3 is an illustration of a method for making building materials from an aqueous solution, in accordance with an embodiment of the disclosure.

[0009] FIG. 4 is an illustration of a method for making building materials from an aqueous solution, in accordance with an embodiment of the disclosure.

DETAILED DESCRIPTION

[0010] Embodiments of an apparatus and method for making building materials from an aqueous solution are described herein. In the following description numerous specific details are set forth to provide a thorough understanding of the embodiments. One skilled in the relevant art will recognize, however, that the techniques described herein can be practiced without one or more of the specific details, or with other methods, components, materials, etc. In other instances, well-known structures, materials, or operations are not shown or described in detail to avoid obscuring certain aspects.

[0011] Reference throughout this specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, the appearances of the phrases "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more embodiments.

[0012] Throughout the specification and claims, compounds/elements are referred to both by their chemical name (*e.g.,* carbon dioxide) and chemical symbol (*e.g.,* CO_2). It is appreciated that both chemical names and symbols may be used interchangeably and have the same meaning.

[0013] This disclosure provides for the removal of carbon from water sources containing dissolved inorganic carbon (*e.g.,* bicarbonate ions HCO_3^-), and forming building materials from the dissolved ions. The world's oceans act as carbon sinks absorbing large quantities of atmospheric carbon. As will be shown, systems and methods in accordance with the teachings of the present disclosure may be used to remove bicarbonate and carbonate ($CO_3^{(2-)}$)ions from the water and convert the ions into building materials (including limestone-bricks and cement). Removing excess carbon from the oceans may be both lucrative and environmentally restorative.

[0014] FIG. 1A is an illustration of system 100A for making building materials from an aqueous solution, in accordance with an embodiment of the disclosure. System 100A includes: input 102 (to input an aqueous solution containing dissolved inorganic carbon), treatment unit 104, first precipitation unit 106, electrodialysis unit 110, pH and alkalinity

adjustment unit 112, water output 118, brine output 132, mixing unit 152, and building material output 162.

[0015] As shown, input 102 is coupled to a water reservoir containing dissolved inorganic carbon (*e.g.,* bicarbonate ions). The water reservoir may be an ocean, lake, river, manmade reservoir, or brine outflow from a reverse osmosis ("RO") process. Input 102 may receive the water through a system of channels, pipes, and/or pumps depending on the specific design of the facility. As shown, water received through input 102 is diverted into two separate sections of system 100A. A first (smaller) portion of the water is diverted to treatment unit 104, while a second (larger) portion of the water is diverted to first precipitation unit 106. One skilled in the art will appreciate that large aggregate may be removed from the water at any time during the intake process.

[0016] In the illustrated embodiment, the first portion of water is diverted into treatment unit 104. Treatment unit 104 outputs a relatively pure stream of aqueous NaCl. In other words, an aqueous solution (possibly including seawater) is input to treatment unit 104, and aqueous NaCl is output from treatment unit 104. Treatment unit 104 may be used to remove organic compounds and other minerals (other than NaCl) not needed in, or harmful to, subsequent processing steps. For example, removal of chemicals in the water may mitigate scale buildup in electrodialysis unit 110. Treatment unit 104 may include filtering systems such as: nanofilters, RO units, ion exchange resins, precipitation units, microfilters, screen filters, disk filters, media filters, sand filters, cloth filters, and biological filters (such as algae scrubbers), or the like. Additionally, treatment unit 104 may include chemical filters to removed dissolved minerals/ions. One skilled in the art will appreciate that any number of screening and/or filtering methods may be used by treatment unit 104 to remove materials, chemicals, aggregate, biologicals, or the like.

[0017] Electrodialysis unit 110 is coupled to receive aqueous NaCl and electricity, and output aqueous HCl, aqueous NaOH, and brine (to brine output 132). Aqueous HCl and aqueous NaOH output from electrodialysis unit 110 may be used to drive chemical reactions in system 100A. The specific design and internal geometry of electrodialysis unit 110 is discussed in greater detail in connection with FIG. 2 (*see infra* FIG. 2). Brine output from electrodialysis unit 110 may be used in any applicable portion of system 100A. For example, brine may be cycled back into electrodialysis unit 110 as a source of aqueous NaCl, or may be simply expelled from system 100A as wastewater.

[0018] In the illustrated embodiment, first precipitation unit 106 has a first input coupled to receive an aqueous solution including dissolved inorganic carbon (*e.g.,* seawater) from input 102. First precipitation unit 106 also has a second input coupled to electrodialysis

unit 110 to receive aqueous NaOH. In response to receiving the aqueous solution and the aqueous NaOH, first precipitation unit 106 precipitates calcium salts (for example, but not limited to, $CaCO_3$) and outputs the aqueous solution. However, in other embodiments, other chemical processes may be used to basify the aqueous solution in first precipitation unit 106. For example, other bases (not derived from the input aqueous solution) may be added to the aqueous solution to precipitate calcium salts.

[0019] In one embodiment, NaOH is added to incoming seawater until the pH is sufficiently high to allow precipitation of calcium salts without significant precipitation of $Mg(OH)_2$. The exact pH when precipitation of $CaCO_3$ occurs (without significant precipitation of $Mg(OH)_2$) will depend on the properties of the incoming seawater (alkalinity, temperature, composition, etc.); however, a pH of 9.3 is typical of seawater at a temperature of 25 °C. In a different embodiment, the quantity of NaOH added is sufficient to precipitate $CaCO_3$ and $Mg(OH)_2$, which can be used together to form building materials.

[0020] In one embodiment, first precipitation unit 106 may be a large vat or tank. In other embodiments first precipitation unit 106 may include a series of ponds/pools. In this embodiment, precipitation of calcium salts may occur via evaporation driven concentration (for example using solar ponds) rather than, or in combination with, adding basic substances. First precipitation unit 106 may contain internal structures with a high surface area to promote nucleation of $CaCO_3$; these high surface area structures may be removed from the first precipitation unit 106 to collect nucleated $CaCO_3$. First precipitation unit 106 may include an interior with $CaCO_3$ to increase nucleation kinetics by supplying seed crystals. The bottom of first precipitation unit 106 may be designed to continually collect and extract precipitate to prevent large quantities of scale buildup.

[0021] In another or the same embodiment, heat may be used to aid precipitation. For example solar ponds may be used to heat basified water. In continuously flowing systems, low temperature waste heat solution may be flowed through heat exchange tubes with basified seawater on the outside of the tubes. Alternatively, heating the bottom of first precipitation unit 106 may be used to speed up precipitation.

[0022] After $CaCO_3$ is precipitated from the water, $CaCO_3$ is transferred to mixing unit 152. Mixing unit 152 may combine the precipitated $CaCO_3$ with construction aggregate such as sand, gravel, rocks, pebbles, or the like. Mixing unit 152 may also include processing or compression equipment to form bricks or other large structures from the $CaCO_3$. Bricks of limestone ($CaCO_3$) may be cubic or may take any other useful shape. Building materials output from mixing unit 152 may be used to form breakwaters, harbors, buildings, or the like. System 100A may be especially useful in places with limited

terrestrial resource, such as low-lying islands. However, in other embodiments, the $CaCO_3$ may be used directly after removal from first precipitation unit 106 (without being formed into larger structures). For example, $CaCO_3$ removed from first precipitation unit 106 may be used for road bases. Additionally, as will be discussed in greater detail in connection with FIG. 1B, $CaCO_3$ may be heated with other materials to form cement or mortar.

[0023] In the depicted embodiment, the second portion of seawater (that was used as a carbon source in first precipitation unit 106) is flowed to a pH and alkalinity adjustment unit 112. The pH and alkalinity adjustment unit 112 is coupled to electrodialysis unit 110 to receive HCl and NaOH, and adjust a pH and alkalinity of the combined second portion of the aqueous solution and basic solution to a pH of seawater (or other environmentally safe pH value). In one embodiment, the pH and alkalinity of wastewater flowed into pH and alkalinity adjustment unit 112 is monitored in real time, and HCl or NaOH is flowed into pH and alkalinity adjustment unit 112 in response to the real time measurements. Adjusting the pH of wastewater flowing from system 100A ensures minimal environmental impact of running system 100A, while adjusting the alkalinity ensures sufficient reabsorption of atmospheric CO_2 once the water is returned to the ocean. Further, system 100A removes carbon from the oceans, improving ocean heath while producing economically viable building materials.

[0024] FIG. 1B is an illustration of system 100B for making building materials from an aqueous solution, in accordance with an embodiment of the disclosure. System 100B is similar in many respects to system 100A of FIG. 1A. However, system 100B includes: second precipitation unit 122, desalination unit 182, second pH and alkalinity adjustment unit 184, heating unit 170, mixing unit 152, and cement output 164. However, one of ordinary skill in the art will appreciate that any portion of system 100A may be combined with system 100B or vice-versa.

[0025] As shown, calcium salts are precipitated in first precipitation unit 106 by increasing the pH of the aqueous solution with NaOH from electrodialysis unit 110. All or some of these calcium salts may be used to form limestone-based building materials. However, in the depicted embodiment, some of the calcium salts are transferred to a first salt processing unit (*e.g.,* heating unit 107 and grinding unit 152) to receive the calcium salts and convert the calcium salts into other building materials—more specifically cement. In heating unit 170 the calcium salts are mixed with a first material (*e.g.,* clay or shale) including silicon to form a mixture. The mixture is then heated to produce cement clinker.

[0026] In one embodiment, cement clinker is formed by pulverizing the mixture of limestone ($CaCO_3$) and clay—a silicon containing material—to make a "rawmix". The

rawmix is then heated to a sintering temperature (*e.g.,* 1450 °C). During heating of the rawmix, the following chemical process may occur: at 70-110 °C water is evaporated from the mixture, at 400-600 °C clay materials are decomposed into oxides such as SiO_2 and Al_2O_3, at 650-900 °C SiO_2 reacts with the $CaCO_3$ to form Ca_2SiO_4 (belite), at 900-1050 °C residual $CaCO_3$ decomposes to form carbon dioxide, which may be captured and sequestered if desired, and calcium oxide, and at 1300–1450 °C partial melting (and sintering) of the mixture takes place and the belite reacts with calcium oxide to form Ca3O·SiO4. Tricalcium silicate—also known as alite—is a major constituent of Portland cement. The partial melting or sintering process that occurs at roughly 1450 °C is needed to complete the reaction, and the mixture forms lumpy aggregate known as cement clinker. The hot clinker may be cooled and stored. Clinker in its raw form may be sold since clinker may last longer than finely crushed cement powder.

[0027] One skilled in the art will appreciate that other materials may be included in the mixture to make the cement clinker, for instance one of a second material including aluminum or a third material including iron may be added, depending on the desired properties of the cement. In some embodiments, gypsum may be added as well. Furthermore, the cement may fall within the composition guidelines for Portland cement: at least two-thirds by mass calcium silicates with the remainder including aluminum and iron-containing clinker phases along with other compounds.

[0028] A portion of system 100B is also designed to extract magnesium salts to create building materials. In the depicted embodiment, system 100B includes second precipitation unit 122 with a first input coupled to receive the aqueous solution (*e.g.,* seawater) from first precipitation unit 106, and a second input coupled to electrodialysis unit 110 to receive aqueous NaOH. In response to receiving the aqueous solution and the aqueous NaOH, second precipitation unit 122 precipitates magnesium salts (for example, but not limited to, $Mg(OH)_2$) and outputs the aqueous solution. In other words, after precipitating the $CaCO_3$, the pH of the second portion of the aqueous solution is adjusted to a second pH threshold where $Mg(OH)_2$ precipitates (*e.g.,* a pH of 10.4). Like first precipitation unit 106, second precipitation unit 122 can use any number of structures/techniques to speed up nucleation kinetics of $Mg(OH)_2$. For example, second precipitation unit 122 may include high surface area inserts, $Mg(OH)_2$ seed crystals, or may be heated/cooled to promote nucleation of $Mg(OH)_2$.

[0029] As depicted, second precipitation unit 122 is coupled to output the spent aqueous solution to pH and alkalinity adjustment unit 112. As stated above in connection with discussion of FIG. 1A, pH and alkalinity adjustment unit 112 may be coupled to

electrodialysis unit 110 to receive NaOH or HCl. As shown the pH and alkalinity of wastewater may be adjusted to a safe pH for drinking or agricultural uses, or for curing cement. Accordingly, the depicted embodiment shows desalination unit 182 coupled to receive the pH adjusted wastewater. As its name implies, desalination unit 108 may remove NaCl from the wastewater to produce freshwater for any of the uses above or other uses not discussed.

[0030] In order to truly remove carbon from the oceans, second pH and alkalinity adjustment unit 184 may be coupled to desalination unit 182 to increase the pH and alkalinity of the wastewater output from desalination unit 182. Accordingly, the alkalinity of the water is changed to a value that enables sufficient reabsorption of atmospheric CO_2 once the water is returned to the ocean.

[0031] Extracted calcium and magnesium salts may be formed into blocks that can be placed in the ocean to form artificial reefs and breakwaters. In some low-lying islands, blocks of extracted Mg/Ca salts may be used to create land to combat rising sea levels. Ca/Mg salt blocks derived from seawater may be useful on coral-atolls where earth for landfill is already extremely scarce. These Mg/Ca salt blocks may be used in conjunction with concrete. For example concrete made from the processes described here may be used as mortar to hold together bricks of Mg/Ca salt. Similarly, concrete may be used to encase bricks of $CaCO_3$ so the bricks are not damaged by acid rain. System 100B may produce $CaCO_3$, $Mg(OH)_2$, and cement in any ratio to build useful structures.

[0032] Although not depicted in FIGs. 1A-1B, in other embodiments, heavy metals may be extracted from the aqueous solution along with $CaCO_3$ and $Mg(OH)_2$. Extraction of heavy metals may help remove harmful contaminants from the world's oceans.

[0033] Systems 100A-100B may be coupled to, and run by, electronic control systems. Regulation and monitoring may be accomplished by a number of sensors throughout the system that either send signals to a controller or are queried by controller. For example, with reference to electrodialysis unit 110, monitors may include one or more pH gauges to monitor a pH within the units as well as pressure sensors to monitor a pressure among the compartments in electrodialysis unit 110 (to avoid inadvertent mechanical damage to electrodialysis unit 110). Another monitor may be a pH gauge placed within first precipitation unit 106 to monitor a pH within the tank. The signals from such pH monitor or monitors allows a controller to control a flow of seawater (from input 102) and a basified solution (from electrodialysis unit 110) to maintain a pH value of a combined solution that will result in a precipitation of $CaCO_3$.

[0034] Alternatively, systems 100A-100B may be controlled manually. For example, a worker may open and close valves to control the various water, acid, and base flows in systems 100A-100B. Additionally, a worker may remove precipitated calcium salts from first precipitation unit 106. However, one skilled in the relevant art will appreciate that systems 100A-100B may be controlled by a combination of manual labor and mechanical automation, in accordance with the teachings of the present disclosure.

[0035] FIG. 2 is an example electrodialysis unit 110 (*e.g.,* electrodialysis unit 110 of FIG. 1), in accordance with an embodiment of the disclosure. Electrodialysis unit 110 may be used to convert seawater (or other NaCl-containing aqueous solutions) into NaOH and HCL. As shown, in FIGs. 1A-1B, NaOH and HCl may be used to adjust the pH of the aqueous solution to precipitate calcium and magnesium salts.

[0036] In the depicted embodiment, electrodialysis unit 110 representatively consists of several cells in series, with each cell including a basified solution compartment (compartments 210A and 210B illustrated); an acidified solution compartment (compartments 225A and 225B illustrated); and a brine solution compartment (compartments 215A and 215B). FIG. 2 also shows a bipolar membrane (BPM) between a basified solution compartment and an acidified solution compartment (BPM 220A and 220B illustrated). A suitable BPM is a Neosepta BP-1E, commercially available from Ameridia Corp. Also depicted are anion exchange membranes (AEM), such as Neosepta ACS (commercially available from Ameridia Corp.), disposed between a brine compartment and an acidified solution compartment (AEM 230A and 230B illustrated). A cation exchange membrane (CEM) such as Neosepta CMX-S (commercially available from Ameridia Corp.), is disposed adjacent to a brine compartment (CEM 240A and CEM 240B illustrated). Finally, FIG. 2 shows end cap membranes 245A and 245B (such as Nafion® membranes) that separate the membrane stack from electrode solution compartment 250A and electrode solution compartment 250B, respectively.

[0037] Broadly speaking, under an applied voltage provided to electrodialysis unit 110, water dissociation inside the BPM (and the ion-selective membranes comprising a BPM) will result in the transport of hydrogen ions (H+) from one side of the BPM, and hydroxyl ions (OH-) from the opposite side. AEMs/CEMs, as their names suggest, allow the transport of negatively/positively charged ions through the membrane. The properties of these membranes such as electrical resistance, burst strength, and thickness are provided by the manufacturer (*e.g.,* Neosepta ACS and CMX-S are monovalent-anion and monovalent-cation permselective membranes, respectively). In one embodiment, electrodialysis unit 110 includes electrodes 260A and 260B of, for example, nickel manufactured by De Nora Tech

Inc. FIG. 2 also shows electrode solution compartment 250A and electrode solution compartment 250B through which, in one embodiment, a NaOH(aq) solution is flowed. Where electrode 260A is a positively-charged electrode, sodium ions (Na+) will be encouraged to move across cap membrane 245A and where electrode 260B is negatively-charged, sodium ions will be attracted to electrode solution compartment 250B. In one embodiment, the solution compartments between adjacent membranes are filled with polyethylene mesh spacers (e.g., 762 μm thick polyethylene mesh spacers), and these compartments are sealed against leaks using axial pressure and 794 mm thick EPDM rubber gaskets.

[0038] One skilled in the art will appreciate that using electrodialysis unit 110 to produce the acids and bases necessary to create Ca/Mg salts is highly advantageous in environments with ample power but limited raw materials. For example, on a coral atoll electrodialysis unit 110 could be powered by solar panels, allowing people on the atoll to create building materials from nothing but renewable energy and seawater.

[0039] FIG. 3 is an illustration of method 300 for making building materials from an aqueous solution, in accordance with an embodiment of the disclosure. The order in which some or all of process blocks 301-307 appear in method 300 should not be deemed limiting. Rather, one of ordinary skill in the art having the benefit of the present disclosure will understand that some of method 300 may be executed in a variety of orders not illustrated, or even in parallel. Additionally, method 300 may include additional blocks or have fewer blocks than shown, in accordance with the teachings of the present disclosure.

[0040] Block 301 shows receiving the aqueous solution including dissolved ions. In one embodiment, this may include receiving seawater containing dissolved calcium, carbon, and magnesium.

[0041] Block 303 discloses increasing a pH of the aqueous solution so the dissolved ions precipitate from the aqueous solution as salt. In one embodiment, this may involve mixing NaOH with the aqueous solution, while in other embodiments this may include mixing other basic chemicals with the aqueous solution to precipitate calcium or magnesium salts. The NaOH or other base may be supplied by electrodialysis equipment (*see e.g.,* FIG. 2).

[0042] Block 305 illustrates collecting the salt precipitated from the aqueous solution. In one embodiment, salt includes at least one of calcium carbonate or magnesium hydroxide; however, in other embodiments other salts may be precipitated from solution depending on the pH of the solution and processing steps employed.

[0043] Block 307 discloses forming building materials from the salt. In one embodiment, construction aggregate and/or binder material (polymer, clays or the like) is added to the salt in order to form building materials such as bricks/blocks that may be useful for building terrestrial structures such as houses, or ocean structures such as breakwaters and harbors. The construction aggregate may include sand, gravel, crushed stone, or ash.

[0044] In another embodiment, forming the building materials includes adding a first material including silicon to the $CaCO_3$ and sintering the salt and the first material to form cement clinker. This cement clinker may subsequently be ground to form cement. Cement may be used stand-alone to build structures or in conjunction with calcium and magnesium salts.

[0045] FIG. 4 is an illustration of method 400 for making building materials from an aqueous solution, in accordance with an embodiment of the disclosure. The order in which some or all of process blocks 401-407 appear in method 400 should not be deemed limiting. Rather, one of ordinary skill in the art having the benefit of the present disclosure will understand that some of method 400 may be executed in a variety of orders not illustrated, or even in parallel. Additionally, method 400 may include additional blocks or have fewer blocks than shown, in accordance with the teachings of the present disclosure.

[0046] Block 401 shows precipitating calcium salts from an aqueous solution by increasing a pH of the aqueous solution. This may be accomplished by adding NaOH to the aqueous solution. The calcium salts may include calcium carbonate or the like.

[0047] Block 403 discloses mixing the calcium salts with a first material including silicon to form a mixture. This mixture may include other materials to alter the properties of the cement made from method 300. For instance, materials with iron and aluminum may be added along with gypsum. Other minerals/compounds not discussed may also be included in accordance with the teachings of the present disclosure.

[0048] Block 405 illustrates heating the mixture to form cement clinker. This may include heating the mixture to temperatures in excess of 1000 ^oC. More specifically, the mixture may be heated to 1450 ^oC. At these temperatures, the mixture is partially melted/sintered to form nodules of aggregate called clinker. Resultant clinker may be sold as-is since the shelf life of clinker is greater than that of the pulverized cement.

[0049] Block 407 discloses grinding the clinker to make cement. Once ground into a powder/dust the clinker will harden after application of water. Fresh water created through a desalinization process may be used to set/cure the cement and form structures in places where fresh water is not readily available. One skilled in the art will realize that the methods discussed here may be used to form calcium salts, magnesium salts, and cement in any

quantity. Furthermore, the methods may produce a certain percentage of each material depending on the requirements of a particular construction project.

[0050] The above description of illustrated embodiments of the invention, including what is described in the Abstract, is not intended to be exhaustive or to limit the invention to the precise forms disclosed. While specific embodiments of, and examples for, the invention are described herein for illustrative purposes, various modifications are possible within the scope of the invention, as those skilled in the relevant art will recognize.

[0051] These modifications can be made to the invention in light of the above detailed description. The terms used in the following claims should not be construed to limit the invention to the specific embodiments disclosed in the specification. Rather, the scope of the invention is to be determined entirely by the following claims, which are to be construed in accordance with established doctrines of claim interpretation.

CLAIMS

What is claimed is:

1. A method of making building materials from an aqueous solution, comprising:

receiving the aqueous solution including dissolved ions;

increasing a pH of the aqueous solution to precipitate the dissolved ions from the aqueous solution as salt;

collecting the salt precipitated from the aqueous solution; and

forming the building materials from the salt.

2. The method of claim 1, wherein the salt includes at least one of calcium carbonate or magnesium hydroxide, and wherein the aqueous solution includes seawater.

3. The method of claim 1, further comprising adding construction aggregate to the salt prior to forming the building materials.

4. The method of claim 3, wherein the construction aggregate includes at least one of sand, gravel, crushed stone, or ash, and wherein forming the building materials includes compressing the salt and the construction aggregate.

5. The method of claim 1, wherein forming the building materials includes adding a first material including silicon and sintering the salt and the first material to form cement clinker.

6. The method of claim 1, wherein the building materials include at least one of cement, mortar, bricks, or road base.

7. A method of making a building material comprising:

precipitating calcium salts from an aqueous solution by increasing a pH of the aqueous solution;

mixing the calcium salts with a first material including silicon to form a mixture; and

heating the mixture to form cement clinker.

8. The method of claim 7, further comprising mixing the calcium salts with at least one of a second material including aluminum or a third material including iron.

9. The method of claim 7, wherein heating includes sintering at a temperature where tricalcium silicate is formed from the mixture.

10. The method of claim 7, further comprising grinding the cement clinker to form cement, and wherein the mixture has a composition of Portland cement.

11. The method of claim 7, wherein the aqueous solution is seawater and aqueous NaOH is added to the seawater to increase the pH of the aqueous solution and to precipitate the calcium salts.

12. The method of claim 11, wherein the aqueous NaOH is supplied by an electrodialysis unit.

13. A system for making building materials, comprising;

an electrodialysis unit coupled to receive aqueous NaCl, and output aqueous HCl and aqueous NaOH;

a first precipitation unit including a first input and a second input, wherein the first input is coupled to receive an aqueous solution including dissolved ions and the second input is coupled to the electrodialysis unit to receive the aqueous NaOH, wherein in response to receiving the aqueous solution and the aqueous NaOH, the first precipitation unit precipitates calcium salts from the dissolved ions and outputs the aqueous solution; and

a first salt processing unit coupled to receive the calcium salts from the first precipitation unit and to convert the calcium salts into building materials.

14. The system of claim 13, wherein the first salt processing unit is configured to receive a first material including silicon and heat the calcium salts and the first material to form cement clinker.

15. The system of claim 14, wherein the first salt processing unit is configured to receive least one of a second material including aluminum or a third material including iron.

16. The system of claim 15, further comprising a grinding unit to grind the cement clinker to form cement.

17. The system of claim 13, wherein in response to receiving the aqueous NaOH the first precipitation unit precipitates magnesium salts in addition to the calcium salts.

18. The system of claim 13, further comprising a second precipitation unit coupled to receive the aqueous solution from the first precipitation unit and the aqueous NaOH from the electrodialysis unit, wherein in response to receiving the aqueous solution and the aqueous NaOH, the second precipitation unit precipitates magnesium salts.

19. The system of claim 13, wherein the first salt processing unit adds construction aggregate to the calcium salts.

20. The system of claim 13, further comprising a desalination unit coupled to receive the aqueous solution from the first precipitation unit, wherein the desalination unit outputs fresh water.

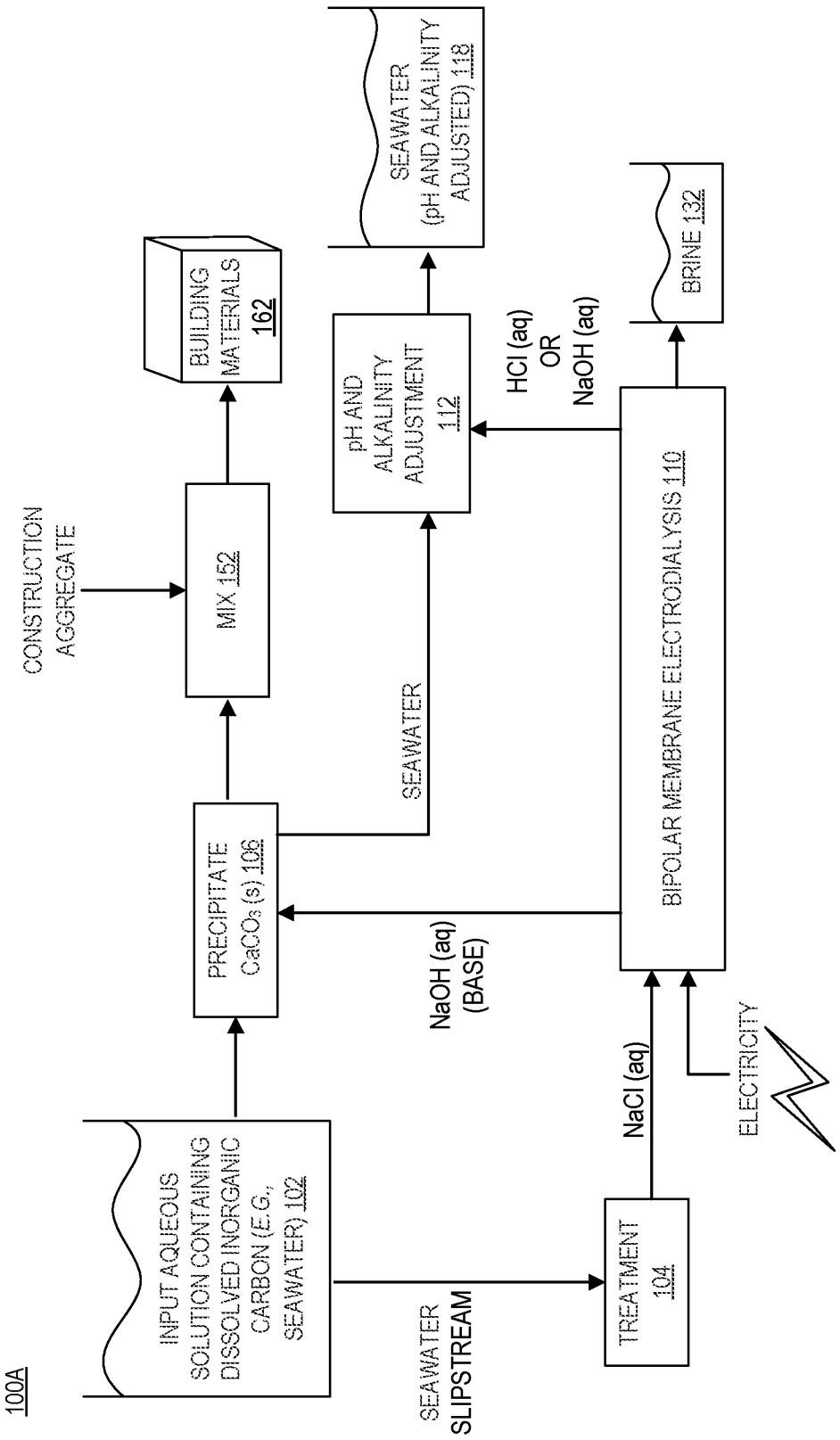

100A
INPUT AQUEOUS SOLUTION CONTAINING DISSOLVED INORGANIC CARBON (E.G., SEAWATER) 102
SEAWATER SLIPSTREAM
TREATMENT 104
NaCl (aq)
ELECTRICITY
BIPOLAR MEMBRANE ELECTRODIALYSIS 110
BRINE 132
HCl (aq) OR NaOH (aq)
pH AND ALKALINITY ADJUSTMENT 112
SEAWATER (pH AND ALKALINITY ADJUSTED) 118
NaOH (aq) (BASE)
PRECIPITATE CaCO3 (s) 106
SEAWATER
MIX 152
CONSTRUCTION AGGREGATE
BUILDING MATERIALS 162

FIG. 1A

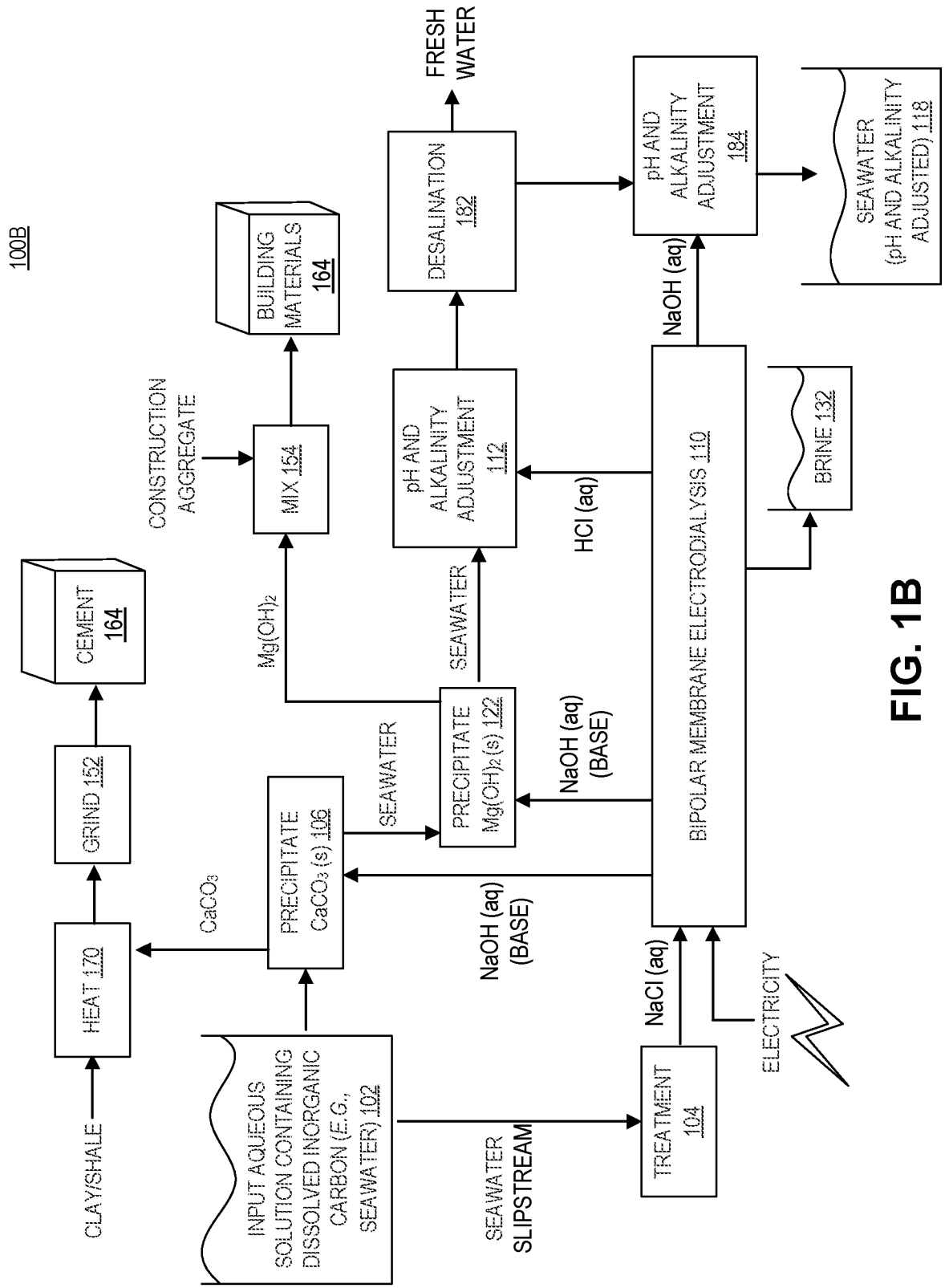

100B
CLAY/SHALE
HEAT 170
GRIND 152
CEMENT 164
INPUT AQUEOUS SOLUTION CONTAINING DISSOLVED INORGANIC CARBON (E.G., SEAWATER) 102
CaCO3
PRECIPITATE CaCO3 (s) 106
SEAWATER
PRECIPITATE Mg(OH)2 (s) 122
Mg(OH)2
CONSTRUCTION AGGREGATE
MIX 154
BUILDING MATERIALS 164
SEAWATER
pH AND ALKALINITY ADJUSTMENT 112
DESALINATION 182
FRESH WATER
HCl (aq)
NaOH (aq) (BASE)
NaOH (aq) (BASE)
BIPOLAR MEMBRANE ELECTRODIALYSIS 110
BRINE 132
NaOH (aq)
pH AND ALKALINITY ADJUSTMENT 184
SEAWATER (pH AND ALKALINITY ADJUSTED) 118
SEAWATER SLIPSTREAM
TREATMENT 104
NaCl (aq)
ELECTRICITY

FIG. 1B

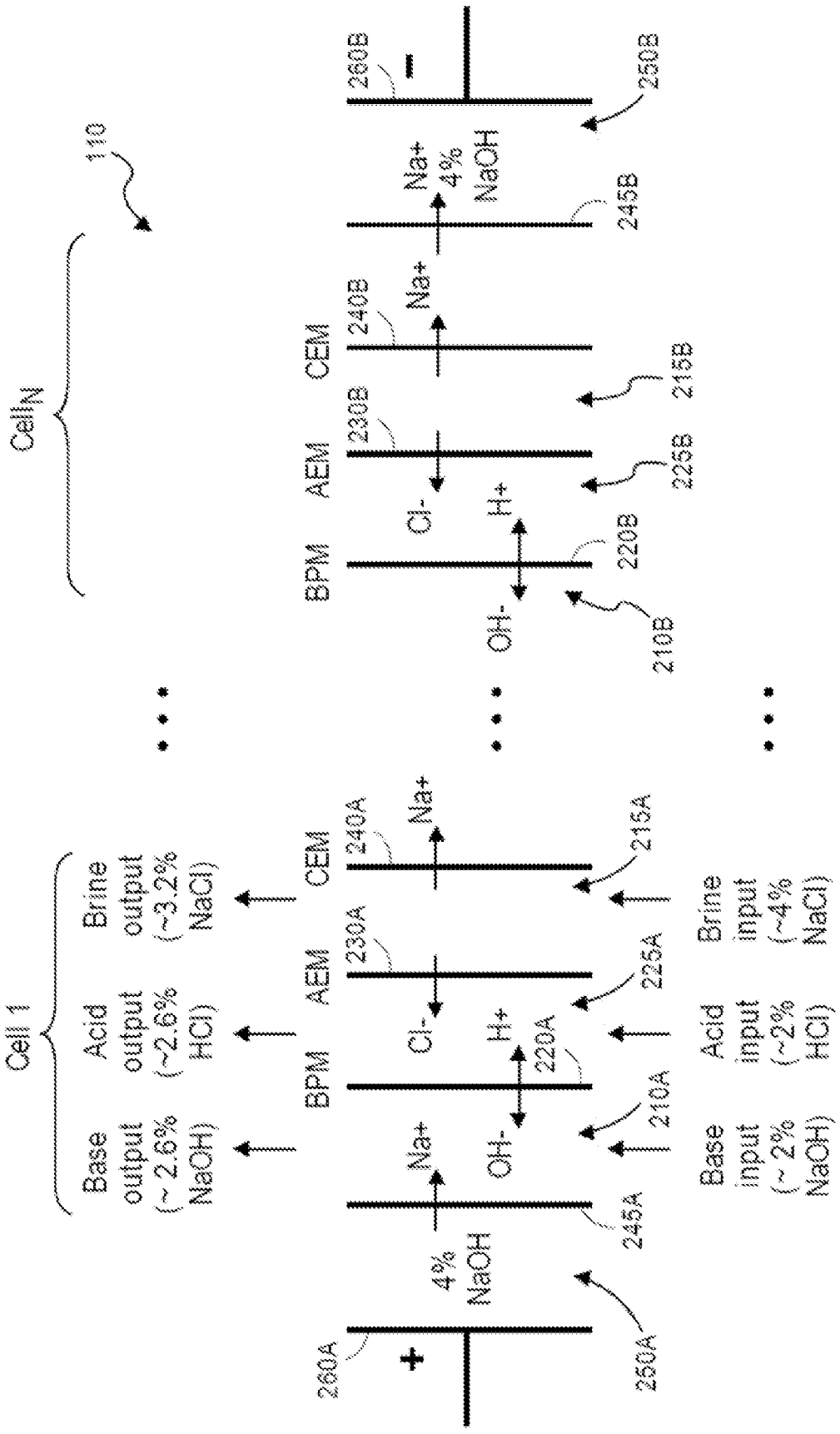

Cell 1
Base output (~ 2.6% NaOH)
Acid output (~2.6% HCl)
Brine output (~3.2% NaCl)
Base input (~ 2% NaOH)
Acid input (~2% HCl)
Brine input (~4% NaCl)
4% NaOH
Na+
OH-
Cl-
H+
BPM
AEM
CEM
260A
250A
245A
210A
220A
225A
230A
240A
215A
Cell N
110
260B
250B
245B
210B
220B
225B
230B
240B
215B

FIG. 2

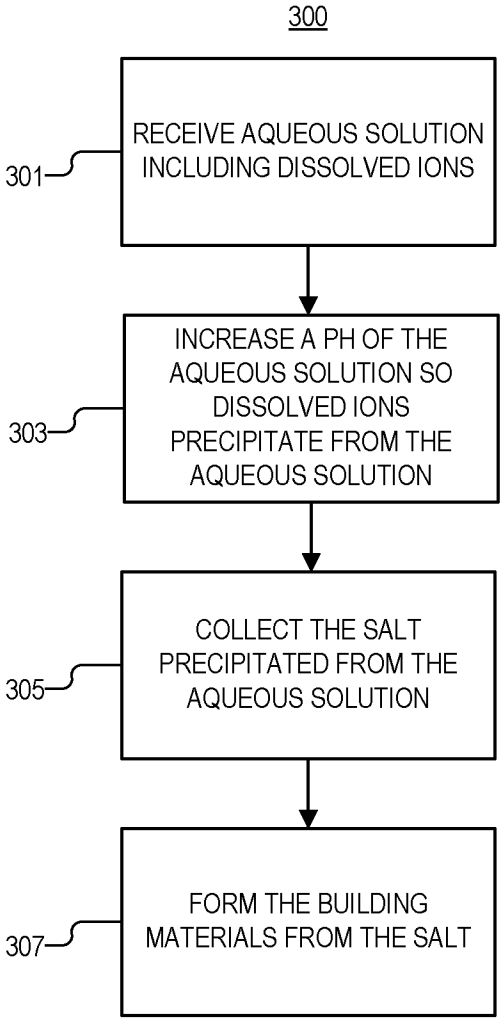

300
RECEIVE AQUEOUS SOLUTION INCLUDING DISSOLVED IONS
301
INCREASE A PH OF THE AQUEOUS SOLUTION SO DISSOLVED IONS PRECIPITATE FROM THE AQUEOUS SOLUTION
303
COLLECT THE SALT PRECIPITATED FROM THE AQUEOUS SOLUTION
305
FORM THE BUILDING MATERIALS FROM THE SALT
307

FIG. 3

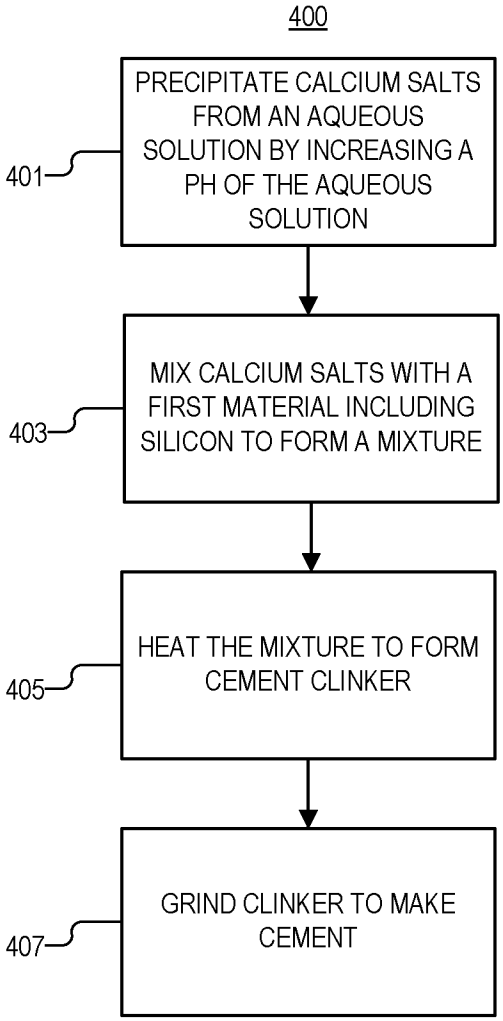

400
PRECIPITATE CALCIUM SALTS FROM AN AQUEOUS SOLUTION BY INCREASING A PH OF THE AQUEOUS SOLUTION
401
MIX CALCIUM SALTS WITH A FIRST MATERIAL INCLUDING SILICON TO FORM A MIXTURE
403
HEAT THE MIXTURE TO FORM CEMENT CLINKER
405
GRIND CLINKER TO MAKE CEMENT
407

FIG. 4

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A. CLASSIFICATION OF SUBJECT MATTER

B01D 53/14(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B01D 53/14; B01D 61/44; B01D 13/02; B01D 63/00; C04B 28/18; C02F 5/02; G06Q 40/00; B01D 61/42

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords:carbon dioxide, calcium carbonate, precipitate, building material, silicon, heat, cement

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 7966250 B2 (CONSTANTZ, B. R. et al.) 21 June 2011 See column 10, lines 30-31; column 15, lines 65-67; and claims 1, 5, 15, 30.	1-4,6,13,17-20
Y		5,7-12,14-16
Y	EP 2236477 A1 (DING, S. J.) 06 October 2010 See claims 1, 2.	5,7-12,14-16
A	WO 2012-050530 A1 (AGENCY FOR SCIENCE, TECHNOLOGY AND RESEARCH) 19 April 2012 See the entire document.	1-20
A	EP 0503589 A1 (YEDA RESEARCH AND DEVELOPMENT COMPANY, LTD.) 16 September 1992 See the entire document.	1-20
A	US 4392959 A (COILLET, D. W.) 12 July 1983 See the entire document.	1-20

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 August 2017 (21.08.2017)	**21 August 2017 (21.08.2017)**

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