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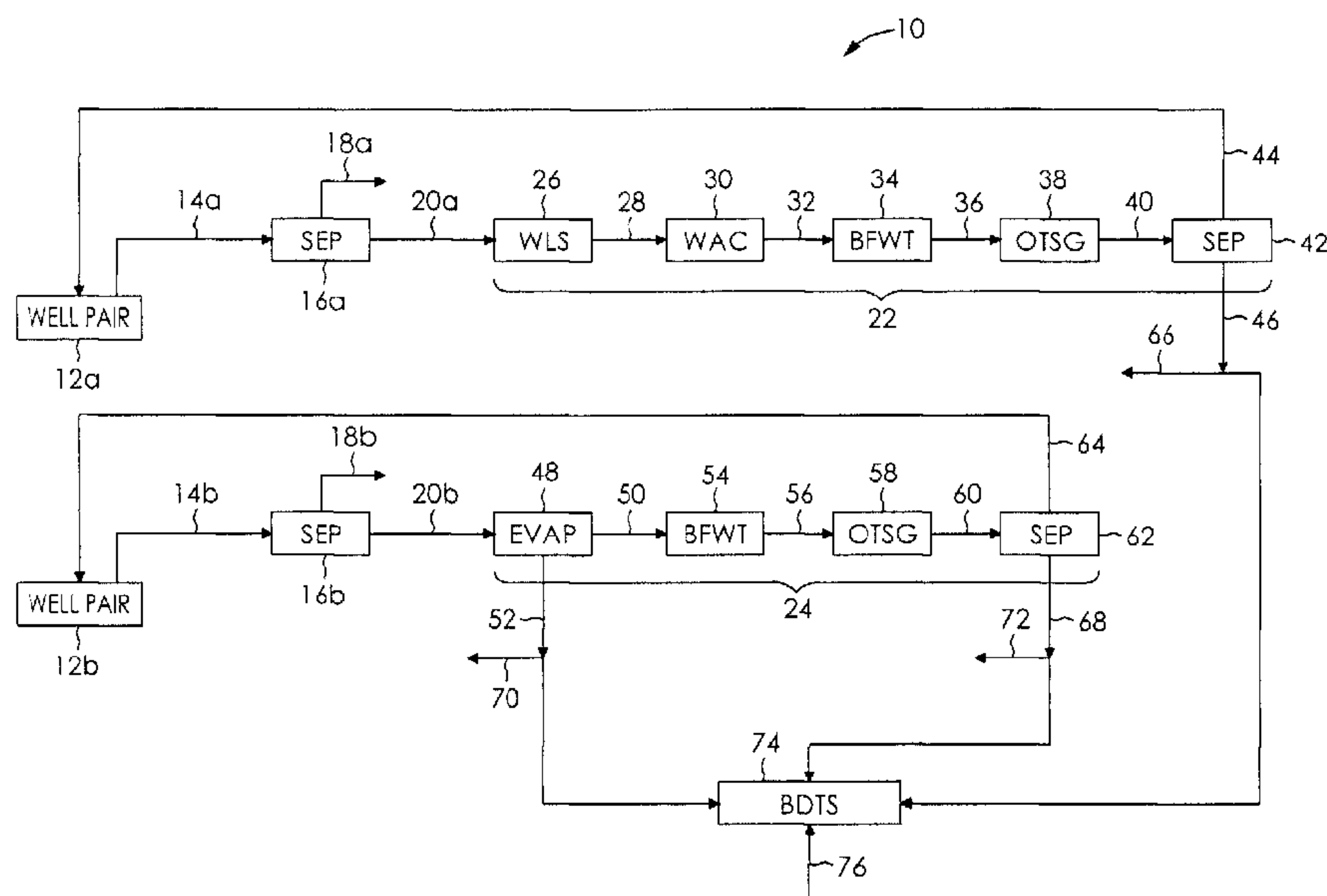
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(54) Title: SOLIDIFICATION OF WASTE BRINE FROM IN SITU HYDROCARBON RECOVERY OPERATIONS WITH
INSULATION MATERIAL



(57) Abrégé/Abstract:

There is provided a process for treating, solidifying and/or stabilizing waste brine, such as waste brine derived from a thermal in situ hydrocarbon recovery operation. The process can include addition of insulation material including calcium silicate to the waste

(57) **Abrégé(suite)/Abstract(continued):**

brine. The process can also involve addition of an open-cell solid material including a solidification reagent to the waste brine. The open-cell solid material has cellular walls defining internal cellular cavities sized and configured to receive part of the waste brine and to allow reactions between the waste brine and the solidification reagent. The process can also include addition of a solidification material to the waste brine, wherein the solidification material includes a solidification reagent for undergoing solidification reactions with components of the waste brine, and fibers for providing structural properties to the waste brine.

ABSTRACT

There is provided a process for treating, solidifying and/or stabilizing waste brine, such as waste brine derived from a thermal in situ hydrocarbon recovery operation. The process can include addition of insulation material including calcium silicate to the waste brine. The process can also involve addition of an open-cell solid material including a solidification reagent to the waste brine. The open-cell solid material has cellular walls defining internal cellular cavities sized and configured to receive part of the waste brine and to allow reactions between the waste brine and the solidification reagent. The process can also include addition of a solidification material to the waste brine, wherein the solidification material includes a solidification reagent for undergoing solidification reactions with components of the waste brine, and fibers for providing structural properties to the waste brine.

SOLIDIFICATION OF WASTE BRINE FROM IN SITU HYDROCARBON RECOVERY OPERATIONS WITH INSULATION MATERIAL

TECHNICAL FIELD

[0001] The technical field generally relates to thermal in situ hydrocarbon recovery operations, and more particularly to techniques for solidifying waste brines generated in such operations.

BACKGROUND

[0002] Thermal in situ hydrocarbon recovery operations generate steam for injection into the hydrocarbon-bearing reservoir in order to heat and reduce the viscosity of the hydrocarbons to facilitate recovery. Production fluids that are recovered from the reservoir are separated into produced hydrocarbons and produced water.

[0003] The produced water is then treated, e.g. in an evaporator, to remove contaminants as an evaporator blowdown stream and provide treated water for use as boiler feed water. The boiler feed water can then be supplied to steam generators that produce steam, which can include wet steam streams. Wet steam streams can further be sent to separators to produce dry steam streams suitable for injection and boiler blowdown streams.

[0004] Evaporator and boiler blowdown streams are generally disposed as waste brines in deep injection wells. The waste brines can also be concentrated in a crystallizer and then dried to form a dried salt residual or the concentrate can be transported by truck for third-party waste management.

[0005] Disposal of solidified waste brines in an on-site landfill would be economically beneficial. Concentrated waste brine can be solidified using a gas-fired dryer. However, the resulting dried brine can be water soluble, and can be difficult to handle in industrial landfills when exposed to water from precipitation. Alternatively, solid waste material can be obtained by adding a solidification

reagent to the waste brine. Examples of solidification reagents typically used are Portland cement, quicklime, hydrated lime, cement kiln dust, silicates, blast furnace slag and fly ash. However, the solidified material is not always stable and generation of contaminated leachate can prevent disposing thereof in a landfill.

[0006] There are various challenges associated with efficient and effective disposal of waste brines produced in thermal in situ hydrocarbon recovery operations.

SUMMARY

[0007] In some implementations, there is provided process for treating waste brine, including:

adding insulation material comprising calcium silicate to the waste brine.

[0008] In some implementations, the insulation material includes pipe insulation.

[0009] In some implementations, the pipe insulation includes waste pipe insulation that has been pre-used in hydrocarbon processing operations prior to addition to the waste brine.

[0010] In some implementations, the insulation material includes at least about 85 wt% calcium silicate.

[0011] In some implementations, the insulation material further includes sodium silicate, magnesium silicate, aluminum silicate, crystalline silica and/or cellulosic fibers.

[0012] In some implementations, the waste brine is derived from a thermal in situ hydrocarbon recovery operation.

[0013] In some implementations, the waste brine is derived from a SAGD operation, a crystallizer blowdown stream, an evaporator blowdown stream, and/or an OTSG blowdown stream.

[0014] In some implementations, there is provided a process for treating waste brine, including:

adding an open-cell solid material comprising at least one solidification reagent to the waste brine.

[0015] In some implementations, the open-cell solid material includes insulation material.

[0016] In some implementations, the insulation includes waste pipe insulation.

[0017] In some implementations, the at least one solidification reagent includes calcium silicate.

[0018] In some implementations, the open-cell solid material has an open-cell structure formed from production thereof as an open-cell-structured foam.

[0019] In some implementations, the open-cell solid material has an open-cell structure formed from grinding of a closed-cell foam.

[0020] In some implementations, the waste brine is derived from a thermal in situ hydrocarbon recovery operation.

[0021] In some implementations, the waste brine is derived from a SAGD operation, a crystallizer blowdown stream, an evaporator blowdown stream, and/or an OTSG blowdown stream.

[0022] In some implementations, there is provided a process for solidifying waste brine, including:

adding an open-cell solid material and at least one solidification reagent to the waste brine;

wherein the open-cell solid material has cellular walls defining internal cellular cavities sized and configured to receive part of the waste brine to allow reactions between the waste brine and the solidification reagent.

[0023] In some implementations, the cellular walls include at least a portion of the solidification reagent.

[0024] In some implementations, the cellular walls include calcium silicate as a solidification reagent.

[0025] In some implementations, the solidification reagent includes one or more reagents that are added to the waste brine as separate components from the open-cell solid material.

[0026] In some implementations, the waste brine is derived from a thermal in situ hydrocarbon recovery operation.

[0027] In some implementations, the waste brine is derived from a SAGD operation, a crystallizer blowdown stream, an evaporator blowdown stream, and/or an OTSG blowdown stream.

[0028] In some implementations, there is provided a process for stabilizing waste brine, including:

adding an open-cell solid material to the waste brine;

wherein the open-cell solid material has cellular walls defining internal cellular cavities sized and configured to receive and retain part of the waste brine.

[0029] In some implementations, the open-cell solid material has an open-cell structure formed from production thereof as an open-cell-structured foam.

[0030] In some implementations, the open-cell solid material has an open-cell structure formed from grinding of a closed-cell foam.

[0031] In some implementations, the open-cell solid material includes insulation material.

[0032] In some implementations, the insulation includes waste pipe insulation.

[0033] In some implementations, the insulation includes calcium silicate.

[0034] In some implementations, the waste brine is derived from a thermal in situ hydrocarbon recovery operation.

[0035] In some implementations, the waste brine is derived from a SAGD operation, a crystallizer blowdown stream, an evaporator blowdown stream, and/or an OTSG blowdown stream.

[0036] In some implementations, there is provided a process for solidifying waste brine derived from a thermal in situ hydrocarbon recovery operation, including:

adding a solidification material to the waste brine, the solidification material comprising:

at least one solidification reagent for undergoing solidification reactions with components of the waste brine; and

fibers for providing structural properties to the waste brine.

[0037] In some implementations, the solidification reagent includes calcium silicate.

[0038] In some implementations, the solidification reagent includes at least about 85 wt% calcium silicate.

[0039] In some implementations, the fibers include glass fibers, synthetic fibers or natural fibers.

[0040] In some implementations, the fibers include synthetic and/or natural cellulosic fibers.

[0041] In some implementations, the waste brine is derived from a thermal in situ hydrocarbon recovery operation.

[0042] In some implementations, the waste brine is derived from a SAGD operation, a crystallizer blowdown stream, an evaporator blowdown stream, and/or an OTSG blowdown stream.

BRIEF DESCRIPTION OF THE DRAWINGS

[0043] Fig 1 is a process flow diagram of a thermal in situ hydrocarbon recovery operation including a water blowdown treatment and solidification system.

[0044] Figs 2 and 3 are process flow diagrams of a waste brine treatment and solidification operation.

[0045] Figs 4a and 4b are process flow diagrams of different modes of waste brine solidification treatment and disposal.

[0046] Fig 5 is a process diagram of a waste brine solidification treatment using pipe insulation material.

DETAILED DESCRIPTION

[0047] Waste brine generated during in situ hydrocarbon recovery operations, e.g. in oil sands SAGD operations, can be treated with a solidification reagent, which can include insulation material comprising calcium silicate, to facilitate disposal thereof in landfills. However, in some implementations, the solidification process can be used for solidifying waste brines from any suitable oil sands brine source, such as basal water desalination or utility water desalination brines, or from other industrial sources. Various aspects, implementations and applications regarding waste brine solidification treatment will be discussed further below.

In situ hydrocarbon recovery operations and production of waste brines

[0048] Fig 1 shows an illustrative example of a thermal in situ bitumen or heavy hydrocarbon recovery operation 10 which can include Steam-Assisted Gravity Drainage (SAGD) where injection-production well pairs are used to exploit a bitumen containing reservoir. Each well pair 12a, 12b includes an injection well

employed to inject steam into the reservoir and a production well to recover condensate and mobilized hydrocarbons as production fluid 14a, 14b. The production fluid 14a, 14b is supplied to an oil-water separator (SEP) 16a, 16b to produce a produced hydrocarbons stream 18a, 18b (e.g., produced bitumen) and produced water 20a, 20b. Diluent can be added to enhance the separation of the oil from the water, and in such scenarios the produced hydrocarbons stream 18a, 18b is diluted.

[0049] Still referring to Fig 1, an illustrative example, water treatment systems for treating produced water and generating steam include a first water treatment train 22 and a second water treatment train 24. The first train 22 receives de-oiled produced water stream 20a and second train 24 receives de-oiled produced water 20b. It should be noted that there may be a single water treatment train or multiple trains that include the same or different treatment units and processes.

[0050] Still referring to Fig 1, in this example system, the first train 22 can include a softening unit receiving the de-oiled produced water stream 20a. The softening unit can include a Warm Line Softener (WLS) 26 as illustrated or a Hot Lime Softener (HLS). A chemical additive that includes lime and other chemicals can be added to the WLS 26 to produce a softened water stream 28 and a WLS sludge. Depending on the operation of the WLS 26, different amounts of divalent cations, such as calcium and magnesium, as well as silica can be removed from the de-oiled produced water stream 20a. The softened water stream 28 can be subjected to additional softening that is particularly directed to reducing divalent cation concentration. For example, the softening unit can further include a cation exchange unit 30 for receiving the softened water stream 28 to produce a further treated water stream 32 further depleted in divalent cations. The cation exchange unit 30 can be a Weak Acid Cation (WAC) exchanger, for example, which can use a sodium based medium to remove the divalent cations. The softened water stream 28 can also be filtered through membrane filters (not illustrated), e.g. microfilters, before entering the cation exchange unit 30.

[0051] The treated water 32 of the first water treatment train 22 can be fed to a first boiler feed water tank (BFWT) 34, from which a first boiler feed water stream 36 can be sent for steam generation to a first Once Through Steam Generator (OTSG) 38. In some example systems, the first boiler feed water stream 36 can be sent to a deaerator to remove non-condensable gases and oxygen from the stream before entering the first OTSG 38. The first OTSG produces wet steam 40 that is sent to a separator 42 for separating into substantially dry steam 44 and a first boiler blowdown (BBD_{WLS}) stream 46 that has a concentrated level of impurities relative to the concentration in the first boiler feed water stream 36. Steam generation has the effect of concentrating impurities in the blowdown stream. For example, an OTSG often produces wet steam including about 20% water and 80% steam and once the water is removed from the wet steam, the impurities concentration in the blowdown can be about five times greater than the concentration in the boiler feed water. The dry steam 44 can be used as the steam injected into the injection well of the well pair 12a.

[0052] Still referring to Fig 1, in this example system, the second water treatment train 24 has an alternative configuration to the first train 22. The second water treatment train 24 can include an evaporator (EVAP) 48 for receiving a second de-oiled produced water stream 20b, which can be identical, similar or different compared to the first de-oiled produced water stream 20a and can come from the same or a different source. For instance, the first de-oiled produced water stream 20a can come from a SAGD well pad operating in a given reservoir area, while the second de-oiled produced water stream 20b can come from a different SAGD well pad or other recovery operation operating in another reservoir area. In some implementations, the produced water stream 20b can be pre-heated before being sent to the evaporator 48. It should also be understood that there can be several evaporators arranged in parallel, and that the evaporators can be, for example, mechanical vapour recompression and/or multiple effect distillation type evaporators. The evaporator 48 produces a distillate stream 50 and an evaporator blowdown (EBD) stream 52. The distillate

stream 50 is depleted in calcium, magnesium, silica and dissolved solids and is a relatively clean, high quality water stream.

[0053] The distillate stream 50 of the second water treatment train 24 can be supplied to a second boiler feed water tank 54. A second boiler feed water stream 56 can be sent from the tank 54 to a second steam generator, which can include a second OTSG 58 and a second separator 62. The second OTSG 58 produces wet steam 60 and the second separator 62 receives the wet steam 60 and produces substantially dry steam 64 and a second boiler blowdown (BBD_{EVAP}) stream 68. The dry steam 64 can be used as the steam injected into the injection well of the well pair 12b.

[0054] In some example systems, a portion of the BBD_{WLS} stream 46 can be disposed of directly or stored as a BBD_{WLS} disposal stream 66. A portion of the EBD stream 52 can be recycled as recycled EBD stream 70 to other processing units. A portion of BBD_{EVAP} stream 68 can also be disposed of directly or stored as a BBD_{EVAP} disposal stream.

[0055] The BBD_{WLS} stream 46, EBD stream 52 and BBD_{EVAP} stream 68 can be sent as waste brines to a blowdown treatment and solidification (BDTS) operation 74 where the streams, either independently or in combination, can be treated with a solidification material 76 resulting in a solid material which can be disposed in a landfill. A portion of the de-oiled produced water 20a, 20b can also be sent as waste brine stream to the BDTS operation 74. The BBD_{WLS} stream 46, EBD stream 52, BBD_{EVAP} stream 68 and/or de-oiled produced water can be stored independently or in combination in holding tank(s) before being sent to the BDTS operation 74.

[0056] *Waste brine treatment and solidification implementations*

[0057] As mentioned above, any one of the BBD_{WLS} stream 46, EBD stream 52 and BBD_{EVAP} stream 68, or any combination thereof, can be sent directly as waste brines to a solidification operation to facilitate their disposal in a landfill. In

some implementations, these blowdown streams can be subjected to additional treatments before the solidification operation itself, as will be now described referring now to Figs 2 and 3.

[0058] In some implementations as illustrated in Fig 2, the BDTS operation 74 can include sending any one of the first and second boiler blowdown streams (BBD_{WLS} , BBD_{EVAP}) and evaporator blowdown stream (EBD), or any combination thereof, collectively referred to as blowdown stream 78, to an brine evaporator 80 to recover a water stream 82 and discharge a concentrated waste water brine stream 84. At this stage, the concentrated waste brine stream 84 is either mixed with a solidification reagent 76 in solidification operation 96 to form a solid waste material or sent to a crystallizer 86. In the crystallizer 86, the concentrated waste brine 84 can be further concentrated to produce water stream 88 and crystallizer waste brine stream 90. As was the case for the concentrated waste brine stream 84, the crystallizer waste brine stream 90 can either be sent to a solidification operation 96 or further fed to other water-removal devices or concentrators 92 to produce an even more concentrated waste brine stream 94. In the solidification operation 96, waste brine stream 84, 90 and/or 94 is mixed with a solidification material 76, which can for example include insulation material including calcium silicate, to form solidified waste material 98 which can be disposed in a landfill 100, for example.

[0059] In some implementations, the waste brine stream which is sent to solidification operation 96 can contain approximately 35 wt% to 65 wt% solids content. Since the total solids content of the concentrated waste brine stream 84 can vary depending on the blowdown stream source (BBD_{WLS} , BBD_{EVAP} or EBD), further concentrating waste brine 84 in crystallizer 86 and other potential water-removal devices or concentrators 92 can be done to reach a minimum weight percentage of total solids in the waste brine to be solidified. In some implementations, the concentrated waste brine 84 is thus further concentrated to reach a minimum content of solids content of approximately 35 wt% in crystallizer waste brine stream 90 or waste brine stream 94. The waste brines generated by

the in situ hydrocarbon recovery operation can be monitored for solids content (e.g. total suspended solids content) and other properties, such as composition, temperature, and so on, and the waste brines can be blended or pre-treated in order to achieve a desired state, such as a minimum total solids concentration of 35 wt%. The pre-treatment of the waste brines and the addition of the solidification reagent can be adjusted depending on the monitored properties.

[0060] Monitoring of the solids content of the waste brines can be performed at different stages of the process. For instance, the solids content of the concentrated waste brine 84 can be measured at the exit of the evaporator 80 or the solids content of the crystallizer waste brine stream 90 can be measured after the crystallizer 86. Monitoring of the solids content can also be performed at different other positions during the process, for example at the exit of any other additional water-removal devices or concentrators 92. The solids content can be measured for any one of the concentrated waste brines either on-line or a brine sample can be collected and analyzed in the lab.

[0061] Referring now to Figs 4a and 4b, different possible ways of adding the solidification material to the waste brine to form a solidified waste material will be described.

[0062] As illustrated in Fig 4a, the solidification material can be added in-line to the concentrated waste brine 84, 90, 94 upstream of the solidification unit 102. Alternatively, as illustrated in Fig 4b, addition of the solidification material to the waste brine can be done directly into the solidification unit 102. In solidification unit 102, the mixture waste brine and solidification material is further blended to form a paste consisting of "solidified" waste material 98 which can further be sent for disposal, e.g. in landfills. It should be noted that the solidified product 98 formed by mixing and reacting the solidification material with the brine is in the form of a paste or slurry and is not fully solid. In other words, the reaction occurring when the solidification material is mixed with the waste brine produces a thickened waste material which will eventually become fully solid after disposal

thereof, for example in a landfill. Thus, it can also be said that the waste material resulting from the mixing is partially solidified. Solidification unit 102 can include an inline mixer or a tank provided with a mixer, for instance a ribbon mixer or a pug mill, which facilitates thorough mixing of the solidification material and the waste brine. Upon thorough mixing, the reagents of the solidification material can be incorporated into the waste brine and reactions between the reagents and the components of the waste brine can occur to promote solidification of the waste brine.

[0063] It should also be noted that the solidification material can include a single component or a mixture of components. When a mixture of components makes up the solidification material, they can be added together or separately to the waste brine. In some implementations, the solidification material can be a mixture of dry components that can be added together to the waste brine in the mixer. In some implementations, the mixer can be designed so that the dry ingredients of the solidification material are wetted before incorporation into the waste brine with reduced or no soak time. Hence, in some implementations the solidification material can be in the form of a liquid or a slurry when added to the waste brine.

[0064] After addition of the solidification material to the waste brine and mixing, the resulting solidified waste material which is in the form of a paste or slurry, can be discharged from the solidification unit 102 through a pipe for disposal into containers for later disposal to the landfill, or can be pumped directly to the landfill where it is left to sit, e.g. in sloped lifts, and where it is allowed to fully solidify. The addition/mixing/discharge process can be run in a continuous, batch or semi-batch mode. When the slurry is disposed of in containers, it can be left to sit therein for several hours during which the slurry can further solidify, before being transported to the landfill. It should be noted that final strength development of the solidified waste material can take several weeks, and there is no specific requirement that final strength be achieved before initial placement in the landfill.

[0065] The solidification process not only allows the formation of solid products which can be easily disposed in landfills, but the chemical reactions between the solidification agent and the waste brine can also allow stabilizing the solidified waste by reducing the amount of material that can be leached therefrom when it is exposed to water. Further detail will be provided below on the solidification/stabilization process itself.

[0066] The nature of the solidification material, which will be described in more detail below, and the quantities thereof to be added to the waste brine to achieve proper solidification, can depend on the waste brine chemistry and process operating parameters. As previously mentioned, the waste brine can originate from different water treatment processes used in the SAGD operation, and, the waste brine chemistry is influenced by these treatments. For instance, the waste brine originating from the first boiler blowdown stream BBD_{WLS} which has been treated with lime softening and ion exchange processes has a concentration in calcium, magnesium and silica which is lower than the concentration of these elements/components in the waste brines originating from evaporator blowdown streams (BBD_{EVAP} or EBD). Also, the amount of organic material present in the waste brines can be different depending on their origin. These differences can affect the type and amount of solidification material that can be used. Hence, in some implementations, testing can be performed to determine the proper quantity of solidification material that is required to solidify a given waste brine. In some implementations, the solidification material can be added in an amount of approximately 0.2 to 0.7 kg per liter of waste brine. Testing can also confirm that the nature of the solidification material is adapted to achieve a proper solidification or can be used to adjust the solidification material recipe.

[0067] In some implementations, testing can include monitoring the properties of the paste waste material discharged from the solidification unit 102. A preliminary visual assessment can be performed followed by one or more further tests including for example a standard concrete industry slump test, a standard Paint Filter test, rheology measurements (such as Unconfined Strength Test) and

hydraulic permeability, to ensure that the desired solidification has occurred. Testing can also be performed on the solidified waste material left to sit for several hours to few days. For instance, the confined compressive strength of the solidified material can be measured with a pocket penetrometer within few hours of mixing and/or after 1 to 7 days. The results of these tests can be used as a solidification indicator to adjust the amounts of solidification formulation added, the types or reagents added, the mixing intensity provided, or other process parameters.

[0068] Unconfined compressive strength and hydraulic conductivity are other properties of the solid waste material that can be determined. They are usually measured on solidified waste material left to sit for few days, e.g. 7, 14 and/or 28 days. The unconfined compressive strength can be measured to determine if the solidified waste material has a desired strength to be able to support loads of materials. In some implementations, the unconfined compressive strength of the solidified waste material can be at least approximately 10 psi. Hydraulic conductivity can be measured to determine the ability of the solidified waste material to conduct water in response to an applied hydraulic gradient and to determine the contaminant leachability. In some implementations, the hydraulic conductivity of the solidified waste material can be approximately $1 \cdot 10^{-5}$ cm/s to $1 \cdot 10^{-6}$ cm/s. In some implementations, it can be approximately $1 \cdot 10^{-6}$ cm/s.

Solidification material

[0069] The waste brine to be solidified is generally in the form of a slurry which contains suspended and dissolved solids, both of organic and mineral nature, including contaminants. Addition of the solidification material into this waste slurry generates a reaction between the waste components and the solidification material resulting in the formation of a solid. Moreover, chemical reactions can arise whereby the contaminants are converted into less soluble and mobile forms. This results in a reduction of the leachability of the waste which is “stabilized”. Therefore, addition of the solidification material can induce two

reactions: solidification which changes the physical nature and handling characteristics of the waste, and stabilization which chemically reduces the hazard potential of the waste. The solidification material can be in various forms and can include various possible reagents and other additives as will be now described in greater detail.

[0070] In some implementations, the solidification material can include solidification reagents capable of undergoing solidification reactions with the components of the waste brine and additives such as fibrous material. The fibrous material can aid producing the solid material and also provide some structural properties to the waste solid material such as reducing the permeability (hydraulic conductivity) for instance. The fibrous material can include glass fibers, synthetic fibers or natural fibers. In some implementations, the fibrous material can include synthetic and/or natural cellulosic fibers. The solidification material can include calcium silicate as one the solidification reagent. Calcium silicate is generally referred to by the chemical compound Ca_2SiO_4 , also known as calcium orthosilicate and sometimes formulated $2\text{CaO} \cdot \text{SiO}_2$. Calcium silicate can also refer to silicic acid calcium salt CaSiO_3 also called calcium metasilicate. Moreover, calcium silicate can be calcium silicate in hydrated or anhydrous form, and it can be in crystalline or amorphous form. Examples of crystalline form of calcium silicate include tobermorite or xonotlite. Calcium silicate is capable of undergoing solidification reactions with the components of the waste brine, for example through the formation of calcium aluminum silicate minerals. In some implementations, calcium silicate in any form can be used in combination with other solidification reagents, such as lime, quicklime, cement kiln dust, calcium carbonate, calcium hydroxide, Portland cement, fly ash, pozzolan, clay, etc., or any combination of these reagents.

[0071] In some implementations, the solidification material which is added to the waste brine to form a solid waste product can include a solid material having an open-cell structure. An open-cell solid material can be a material having cellular walls defining internal cellular cavities. The cellular cavities, or more simply

“cells”, are composed of small nodules that contain voids or hollow spaces. Fluids (gas, liquids) and/or solids can be transferred between the individual spaces. When the solidification material includes a solid open-cell material, the cells can be sized and configured to receive part of the waste brine. The structure of the cells also allows the open-cell material to retain the waste brine, thus impeding leaching once the solid waste is disposed of in a landfill for example. In some implementations, the “open”-cell structure of the open-cell solid material can result from its production process, for example as an open-cell-structured foam. Alternatively, the “open”-cell structure can be obtained by grinding of a closed-cell foam. An example of open-cell solid material includes insulation material, such as pipe insulation material. More detail on insulation material is provided further below.

[0072] In some implementations, the cellular walls of the open-cell solid material can include a solidification reagent. The liquid in the waste brine can flow into the open cells and be trapped therein and the components of the waste brine can react with the solidification reagent included in the open-cell material resulting in solidification of the brine. In some implementations, the open-cell solid material does not include a solidification reagent. In this case, solidification reagent(s) can be added to the waste brine as separate components. Then, the waste brine which contains the solidification reagent(s) can be trapped into the open cells of the open-cell material and undergo solidification within the cells. In other possible implementations, solidification reagents can be included in the cellular walls of the open-cell solid material and also added as separate components to the waste brine. In some implementations, the open-cell solid can be insulation material and the solidification reagent can include calcium silicate.

[0073] In some implementations, the solidification material which is added to the waste brine to form a solid waste product can include an insulation material containing calcium silicate as the open-cell material. The solidification material can also be a mixture of an insulation material containing calcium silicate with other solidification reagents, including for example lime, quicklime, cement kiln

dust, calcium carbonate, calcium hydroxide, Portland cement, fly ash, pozzolan, clay, etc., or any combination of these reagents. The insulation material can be any material known for its insulating properties and containing calcium silicate as a main component. The solidification reagent can thus be any calcium silicate based material used in insulating preformed blocks, preformed pipes, or boards, including for instance for high-temperature pipes or insulating material for fire endurance applications.

[0074] In some implementations, the insulating material can contain at least about 85 wt% calcium silicate. In some implementations, the insulating material can further include fibers, such as cellulosic fibers (natural or synthetic), and further components including for instance sodium silicate, magnesium silicate and/or aluminum silicate, as well as crystalline silica. In some implementations, the insulation material containing calcium silicate can be characterized by a melting point ranging from about 1200°C to about 1500°C.

[0075] The insulating material containing calcium silicate can include pipe insulation material, such as insulation material for high-temperature pipes. In some implementations, the insulation material of the solidification reagent can include material used to insulate pipelines in a hydrocarbon processing operation, such as an oil sands hydrocarbon recovery operation. In some implementations, the solidification reagent can include waste pipe insulation material, i.e. pipe insulation material that has already been used in hydrocarbon processing operation pipelines. Since a significant amount of waste pipe insulation can be generated in oil sands hydrocarbon recovery operations, its re-use as a solidification material can result in a reduction of the amount of waste pipe insulation requiring final disposal. This, in addition to using waste pipe insulation generated on-site as a solidification material rather than buying and transporting reagents, can be economically and environmentally beneficial.

Waste brine solidification with waste pipe insulation

[0076] The various steps that can be implemented in the treatment of waste brine with waste pipe insulation will now be described referring to Fig 5. In step 200, the insulation material which has reached the end of its useful life as pipe insulation in hydrocarbon processing operations is removed from the pipelines and recovered as waste pipe insulation material. This waste material or a part thereof can then be stocked in containers for re-use as reagent for solidifying waste brines generated in the same or a different hydrocarbon processing operation. Since the waste pipe insulation material removed from the pipeline can be in the form of large pieces less suitable for direct addition to the waste brines, a preparation step 210 can be implemented for obtaining solidification material ready for addition of the waste brine. More particularly, the preparation step 210 can include a size reduction treatment of the waste pipe insulation material. In this step, the waste pipe insulation material can be broken up into small particles so as to obtain a material suitable for addition to the waste brine and induce solidification thereof. Any apparatus capable of cutting, grinding, chopping and/or crushing the bulk waste pipe insulation material into small particulate material suitable for addition to the waste brines can be used in the size reduction step. In some implementations, the size reduction can be performed using a wood chipper. The particulate insulation material resulting from step 210 can then be directly sent to the next step 220 and be added to the waste brine or can be stocked for being used later. In some implementations, the particulate insulation material can be mixed with other components, such as other solidification reagents before addition to the waste brine. A suitable solidification material can be prepared for treating a given waste brine by mixing the particles of waste pipe insulation material with other reagents, including for example lime, quicklime, cement kiln dust, calcium carbonate, Portland cement, fly ash, pozzolan, and/or clay. The nature and quantity of any additional solidification reagent can be determined depending on the waste brine to be treated, as mentioned above, by monitoring the properties of the resulting solidified waste material. In some implementations, the solidification material can include at least about 40 wt%

insulation material or at least about 50 wt% insulation material. The solidification material can be added to the brine in amounts varying for example from about 0.2 to about 0.7 kg/L. In some implementations, the amount of solidification material added to the brine can be from about 0.4 to about 0.5 kg/L. It should be noted that the amount of solidification material can vary depending on the waste brine to be treated and/or the strength of the solidified waste to be reached. Monitoring of the properties of the treated waste will allow determining the proper quantities.

[0077] Still referring to Fig 5, in step 220, the particles of waste pipe insulation material or the mixture of these particles with other solidification reagents can be added in-line to the waste brine to be treated upstream of a mixing unit or alternatively directly into the mixing unit. It should be noted that if a mixture of reagents is used for solidifying the waste brine, the various reagents, including the particulate insulation material, can be added together or separately. In some implementations, step 220 includes adding a mixture of the particulate insulation material and at least one other additional solidification reagent, in a dry form, to the waste brine in a tank provided with a mixer. In some implementations, the mixer can be designed so that the dry ingredients are wetted before to be incorporated into the waste brine without a soak time.

[0078] In step 230 the mixture waste brine/solidification reagent(s) is blended to allow incorporation of the solidification reagent(s) into the waste brine to enhance reaction between the solidification reagent(s) and the waste brine components in step 240. The mixing step 230 can be performed in any mixer suitable to thoroughly blend the waste brine and the solidification reagent(s), e.g. a ribbon mixer or a pug mill. In steps 230 and 240, the liquid in the waste brine can flow into the open cells of the insulation material and, then, the components of the waste brine can react with the calcium silicate included in the open-cell resulting in solidification of the brine. If additional solidification reagents are added to the waste brine at the same time as the insulation material, these additional reagents

can also react with the components of the waste brine to further enhance solidification thereof.

[0079] The waste material obtained in step 240 can be in the form of a paste or slurry which can be pumped directly for disposal in a landfill in step 250. Then, in the landfill, the slurry is left to sit, e.g. in sloped lifts, and is allowed to fully solidify. Alternatively, the slurry resulting from step 240 can be discharged from the mixer into disposal containers in step 250. Then, the slurry in the containers can be left to sit therein for several hours to few days during which the slurry can further solidify, before being transported to the landfill.

EXAMPLE

[0080] Bench scale solidification testing was performed on an OTSG blowdown crystallizer concentrate. The concentrate brine was used as received.

[0081] SAMPLES PREPARATION

[0082] Various solidification materials were tested as shown in the Table below. Large pieces of waste pipe insulation material (pre-used pipe insulation) were broken up by hand using a hammer and then reduced to smaller particles using a food processor before addition the waste brine. Unused pipe insulation material was also tested. Unused insulation was added to the waste brines as powder or pulverized. The powder was saw dust produced at the plant from sizing the insulation while the pulverized insulation was crushed/pulverized from scrap insulation parts using a hammer and a food processor. Reagent grade calcium metasilicate powder (CaSiO_3 Meta) from VWR was also tested as a solidification reagent. The solidification material was prepared by mixing the insulation material (waste or unused) with either quicklime or Portland cement.

[0083] SAMPLES ANALYSIS

[0084] All formulations were subjected to compressive strength testing using a pocket penetrometer. This test was used to screen for strength development of

the samples. Pocket penetrometer testing was conducted at various intervals over the first seven days following sample mixing. Pocket penetrometer tests are performed by pushing the penetrometer probe tip about ½ inches into the solidifying material and measuring the resistance force. The resistance scale on the instrument ranges from 0 to 4.5 tons/ft² (t/ft²).

[0085] Unconfined Compressive Strength (UCS) testing was performed on selected samples, following ASTM method D 2216, and after 14 days of cure.

[0086] RESULTS

[0087] The results are presented in the Table below.

[0088] The results show that the waste brine can be solidified using various types of solidification formulations including calcium silicate from different origins (waste insulation, unused insulation, metasilicate).

[0089] Formulations including at least 50 wt% waste pipe insulation, added at various concentrations to the brine, performed well, with penetrometer strength after 7 days of curing generally above 4.5 t/ft². Formulation containing 75 wt% waste pipe insulation (60 g waste pipe insulation and 20 g quicklime), added at a concentration of 0.4 kg/L, showed a penetrometer strength after 7 days of curing of 4 t/ft².

[0090] The results obtained with the formulation including Portland cement and waste pipe insulation seem to indicate lower “reactivity” than a formulation including quicklime and waste pipe insulation. For instance, the formulation containing 60 g waste pipe insulation and 20 g quicklime, added at a concentration of 0.4 kg/L, showed a penetrometer strength after 7 days of curing of 4 t/ft², while the formulation containing 60 g waste pipe insulation and 20 g Portland cement, added at the same concentration of 0.4 kg/L, showed a penetrometer strength after 7 days of curing of 1 t/ft². However, when increasing the proportion of insulation material versus Portland cement and the quantity of solidification formulation, one can observe an increase in the penetrometer

strength after 7 days of curing to 1.5 t/ft^2 (e.g., see the formulation containing 68 g insulation material and 22 g Portland cement used in a concentration of 0.45 kg/L). Moreover, when comparing the two formulations including approximately the same proportions Portland cement / insulation material (23 g / 47 g or 30 g / 60g, i.e. about 33 wt% Portland cement and 67 wt% insulation), but added at different reagent dosages to the waste brine (0.35 and 0.45 kg/L), one can observe that strength developed using a higher quantity of solidification reagents. These results suggest that the solidified waste strength should increase using higher proportions of insulation material and/or a higher quantity of solidification reagents per kg of brine.

[0091] It also worth mentioning that even if the data reported in the table below show that some formulations do not allow reaching a strength of 4.5 tons/ft^2 even after 7 days of the treatment, this does not mean that such a formulation would not allow solidifying the brine after more than 7 days and/or at larger scale. While achieving a maximum strength of 4.5 tons/ft^2 within 7 days of curing would be desirable, formulations which have not reached the 4.5 tons/ft^2 within 7 or fewer days of curing, can still be suitable for some implementations.

Brine	Brine volume (mL)	Reagents (g)							Penetrometer Strength Measurements (t/ft ²)							UCS	
		Reagent dosage (kg/L Brine)	Waste pipe insulation	CaSiO ₃ Meta	Unused insulation powder	Unused insulation pulverized	Quicklime	Portland cement	1	2	3	4	5	6	7	Stress failure (psi)	Strain @ Failure (%)
OTSG blowdown crystallizer concentrate	300	0.48	72				72			4.10	>4.5		>4.5		>4.5	53.3	4.7
	300	0.56	95				72		>4.5	>4.5	>4.5		>4.5		>4.5	69.7	4.1
	357	0.27	48				48		2.0	>4.5		>4.5		>4.5			
	200	0.56		63			48		1.0	3.0		4.5		>4.5			
	278	0.35			48		48		2.75	>4.5		>4.5		>4.5			
	353	0.27				48	48		2.80	>4.5		>4.5		>4.5			
	200	0.41				33	48		0.80	2.0	1.75	1.50	1.60		1.75		
	200	0.40	60				20			2.65		3.50	3.0		4.0		
	200	0.35	47					23	<0.25		Liq	Liq		Liq	Liq		
	200	0.40	60					20	0.75		0.80	0.80		0.90	1.0		
	200	0.45	60					30	0.75		0.70	0.75		0.75	1.0		
	200	0.45	68					22	1.50		1.50	1.50		1.50	1.50		
	200	0.45	45				45		2.80		2.75	2.75		3.0	3.0		
	200	0.45			45		45		3.0		4.0	4.0		4.0	4.0		

CLAIMS

1. A process for treating waste brine, comprising:

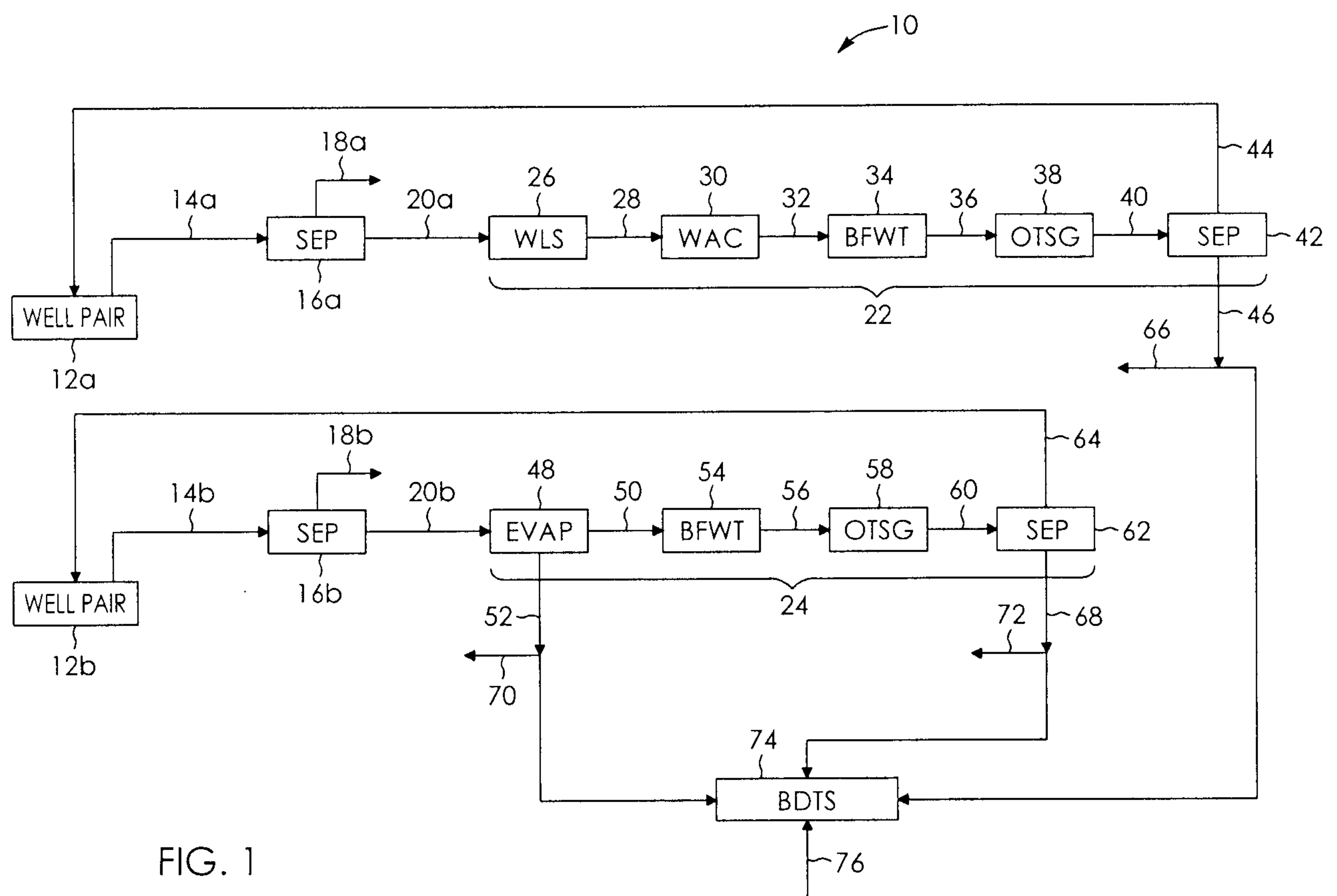
 adding insulation material comprising calcium silicate to the waste brine.
2. The process of claim 1, wherein the insulation material comprises pipe insulation.
3. The process of claim 2, wherein the pipe insulation comprises waste pipe insulation that has been pre-used in hydrocarbon processing operations prior to addition to the waste brine.
4. The process of any one of claims 1 to 3, wherein the insulation material comprises at least about 85 wt% calcium silicate.
5. The process of any one of claims 1 to 4, wherein the insulation material further comprises sodium silicate, magnesium silicate, aluminum silicate, crystalline silica and/or cellulosic fibers.
6. The process of any one of claims 1 to 5, wherein the waste brine is derived from a thermal in situ hydrocarbon recovery operation.
7. The process of any one of claims 1 to 6, wherein the waste brine is derived from a SAGD operation, a crystallizer blowdown stream, an evaporator blowdown stream, and/or an OTSG blowdown stream.
8. A process for treating waste brine, comprising:

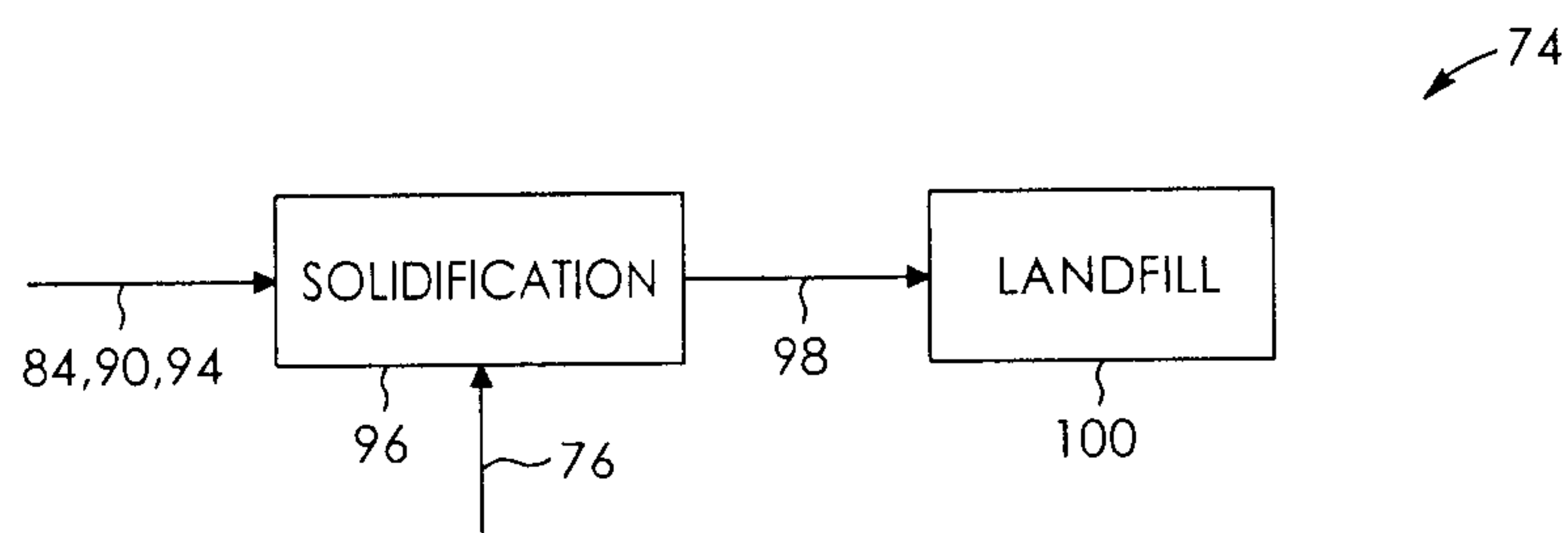
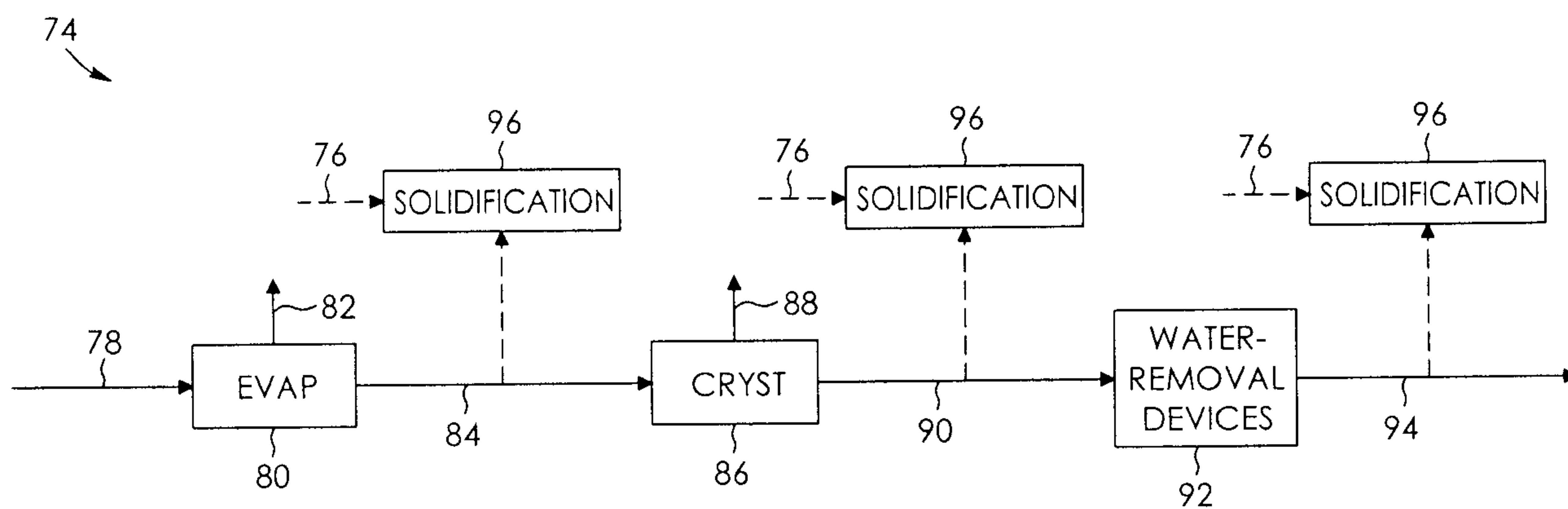
 adding an open-cell solid material comprising at least one solidification reagent to the waste brine.
9. The process of claim 8, wherein the open-cell solid material comprises insulation material.

10. The process of claim 9, wherein the insulation comprises waste pipe insulation.
11. The process of any one of claims 8 to 10, wherein the at least one solidification reagent comprise calcium silicate.
12. The process of any one of claims 8 to 11, wherein the open-cell solid material has an open-cell structure formed from production thereof as an open-cell-structured foam.
13. The process of any one of claims 8 to 11, wherein the open-cell solid material has an open-cell structure formed from grinding of a closed-cell foam.
14. The process of any one of claims 8 to 13, wherein the waste brine is derived from a thermal in situ hydrocarbon recovery operation.
15. The process of any one of claims 8 to 14, wherein the waste brine is derived from a SAGD operation, a crystallizer blowdown stream, an evaporator blowdown stream, and/or an OTSG blowdown stream.
16. A process for solidifying waste brine, comprising:
 - adding an open-cell solid material and at least one solidification reagent to the waste brine;
 - wherein the open-cell solid material has cellular walls defining internal cellular cavities sized and configured to receive part of the waste brine to allow reactions between the waste brine and the solidification reagent.
17. The process of claim 16, wherein the cellular walls comprise at least a portion of the solidification reagent.
18. The process of claim 17, wherein the cellular walls comprise calcium silicate as a solidification reagent.

19. The process of claim 16, wherein the solidification reagent comprises one or more reagents that are added to the waste brine as separate components from the open-cell solid material.
20. The process of any one of claims 16 to 19, wherein the waste brine is derived from a thermal in situ hydrocarbon recovery operation.
21. The process of any one of claims 16 to 20, wherein the waste brine is derived from a SAGD operation, a crystallizer blowdown stream, an evaporator blowdown stream, and/or an OTSG blowdown stream.
22. A process for stabilizing waste brine, comprising:
 - adding an open-cell solid material to the waste brine;
 - wherein the open-cell solid material has cellular walls defining internal cellular cavities sized and configured to receive and retain part of the waste brine.
23. The process of claim 22, wherein the open-cell solid material has an open-cell structure formed from production thereof as an open-cell-structured foam.
24. The process of claim 22, wherein the open-cell solid material has an open-cell structure formed from grinding of a closed-cell foam.
25. The process of any one of claims 22 to 24, wherein the open-cell solid material comprises insulation material.
26. The process of claim 25, wherein the insulation comprises waste pipe insulation.
27. The process of claim 25 or 26, wherein the insulation comprises calcium silicate.
28. The process of any one of claims 22 to 27, wherein the waste brine is derived from a thermal in situ hydrocarbon recovery operation.

29. The process of any one of claims 22 to 28, wherein the waste brine is derived from a SAGD operation, a crystallizer blowdown stream, an evaporator blowdown stream, and/or an OTSG blowdown stream.
30. A process for solidifying waste brine derived from a thermal in situ hydrocarbon recovery operation, comprising:
- adding a solidification material to the waste brine, the solidification material comprising:
 - at least one solidification reagent for undergoing solidification reactions with components of the waste brine; and
 - fibers for providing structural properties to the waste brine.
31. The process of claim 30, wherein the solidification reagent comprises calcium silicate.
32. The process of claim 31, wherein the solidification reagent comprises at least about 85 wt% calcium silicate.
33. The process of any one of claims 30 to 32, wherein the fibers comprise glass fibers, synthetic fibers or natural fibers.
34. The process of claim 33, wherein the fibers comprise synthetic and/or natural cellulosic fibers.
35. The process of any one of claims 30 to 34, wherein the waste brine is derived from a thermal in situ hydrocarbon recovery operation.
36. The process of any one of claims 30 to 35, wherein the waste brine is derived from a SAGD operation, a crystallizer blowdown stream, an evaporator blowdown stream, and/or an OTSG blowdown stream.





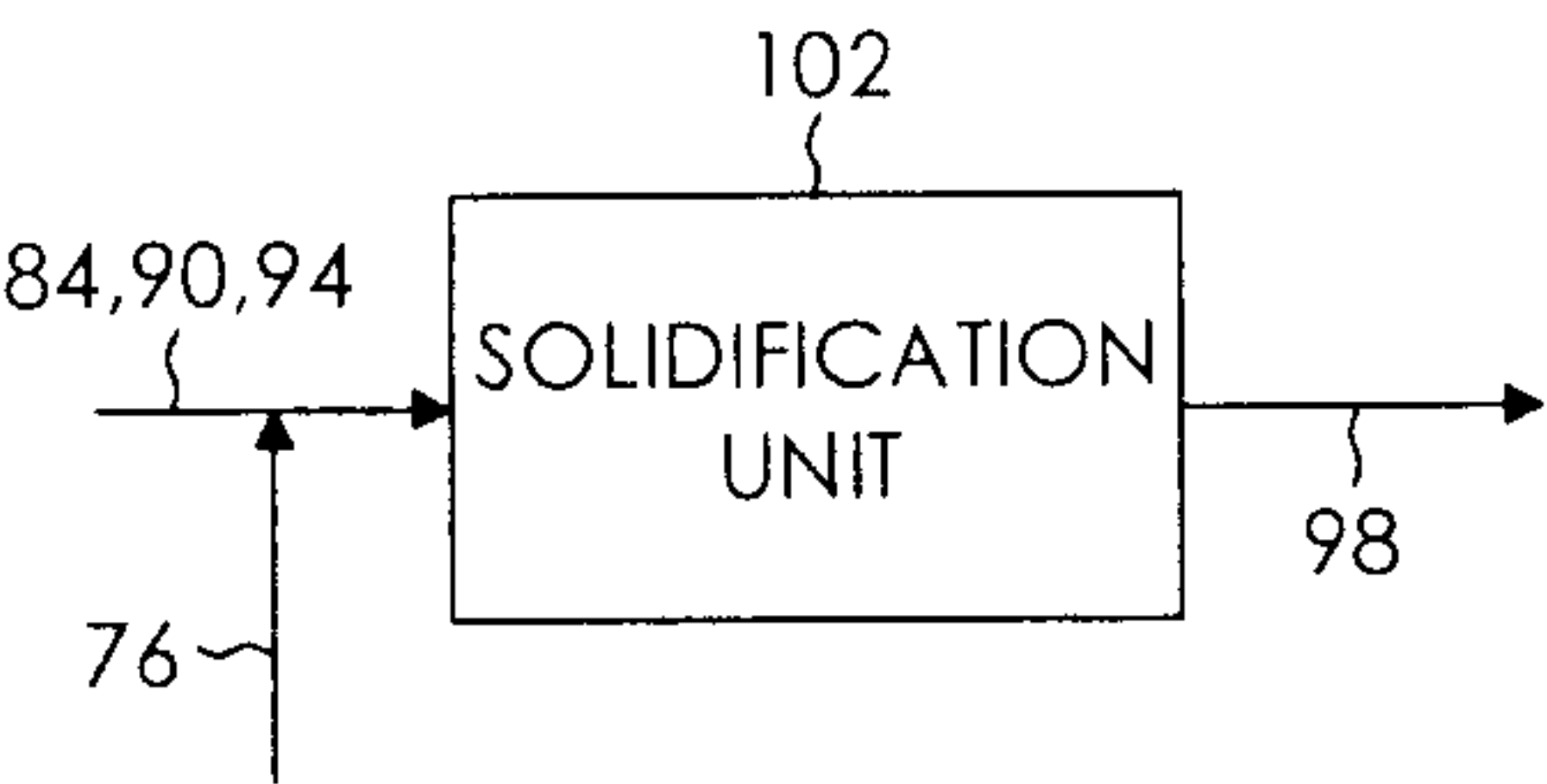


FIG. 4a

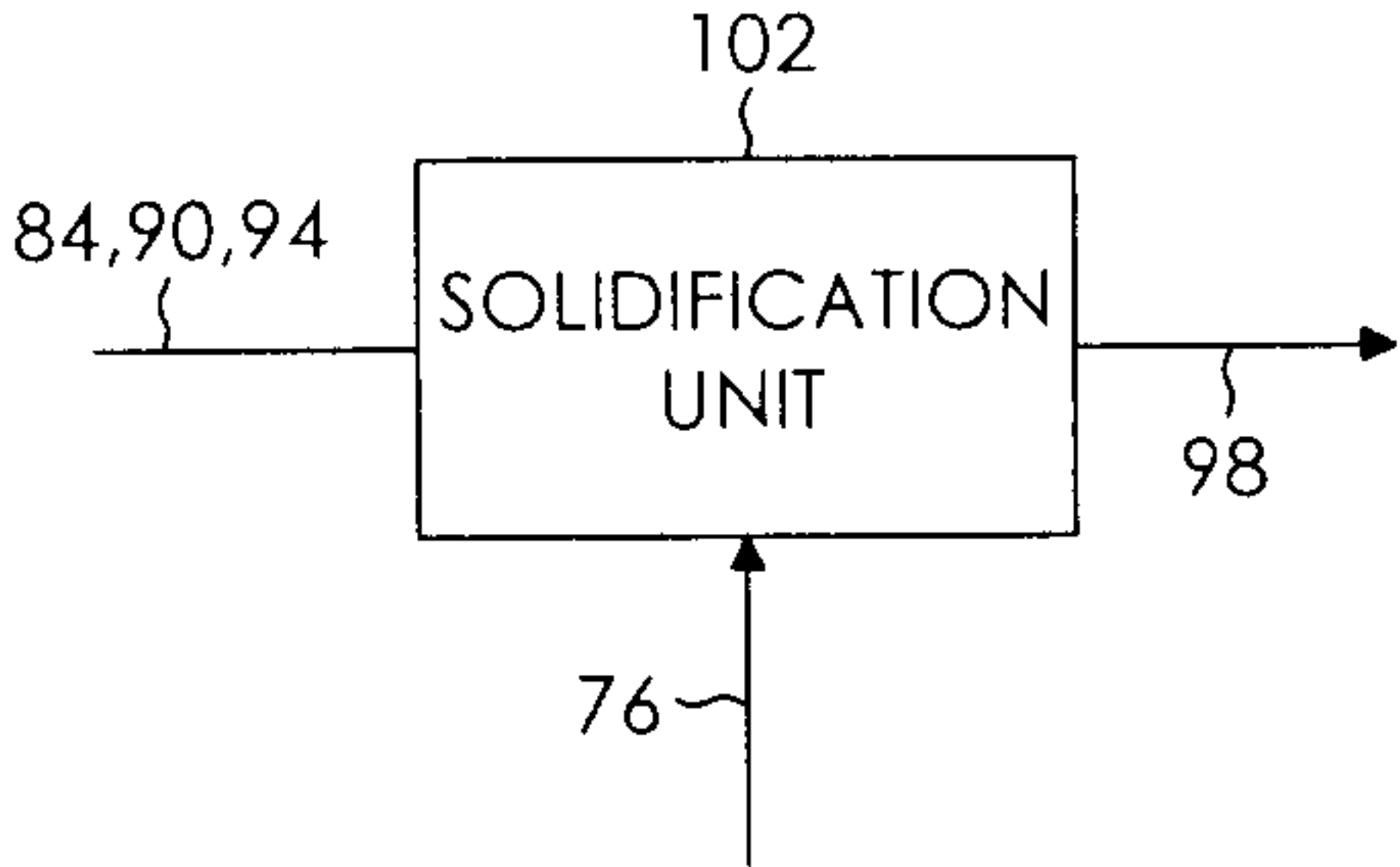


FIG. 4b

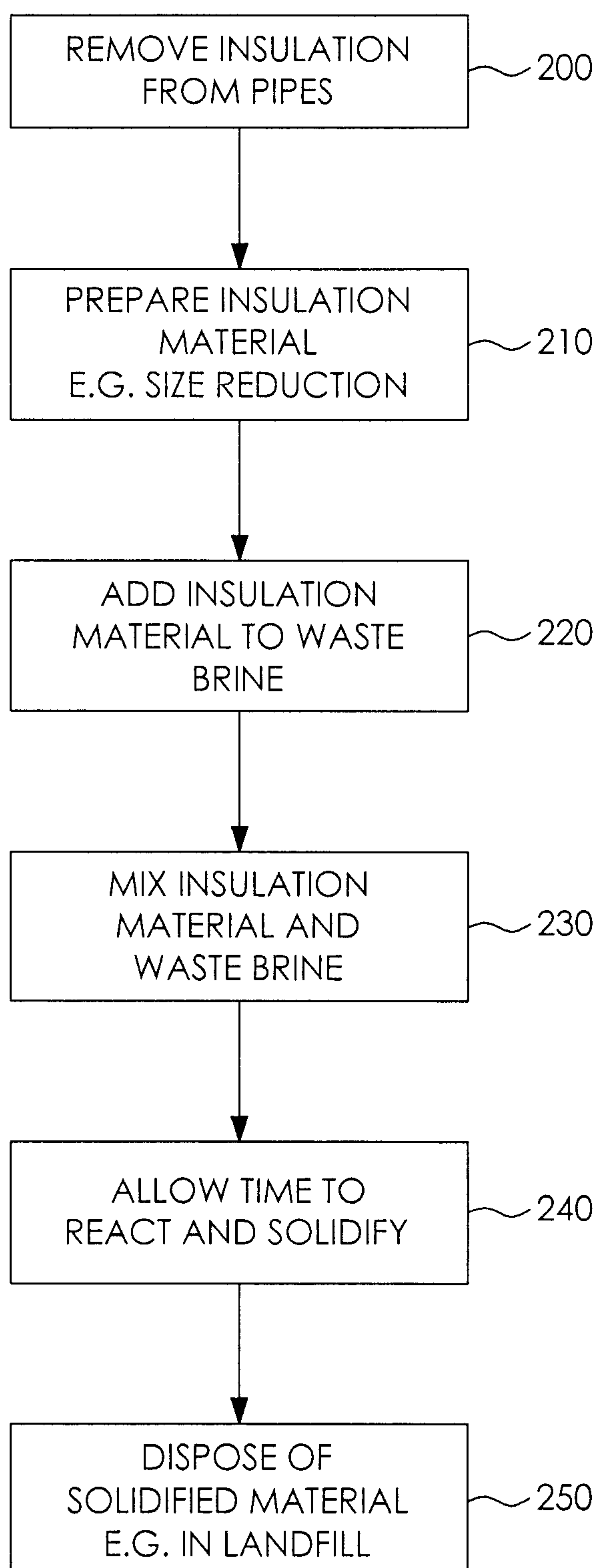


FIG. 5

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