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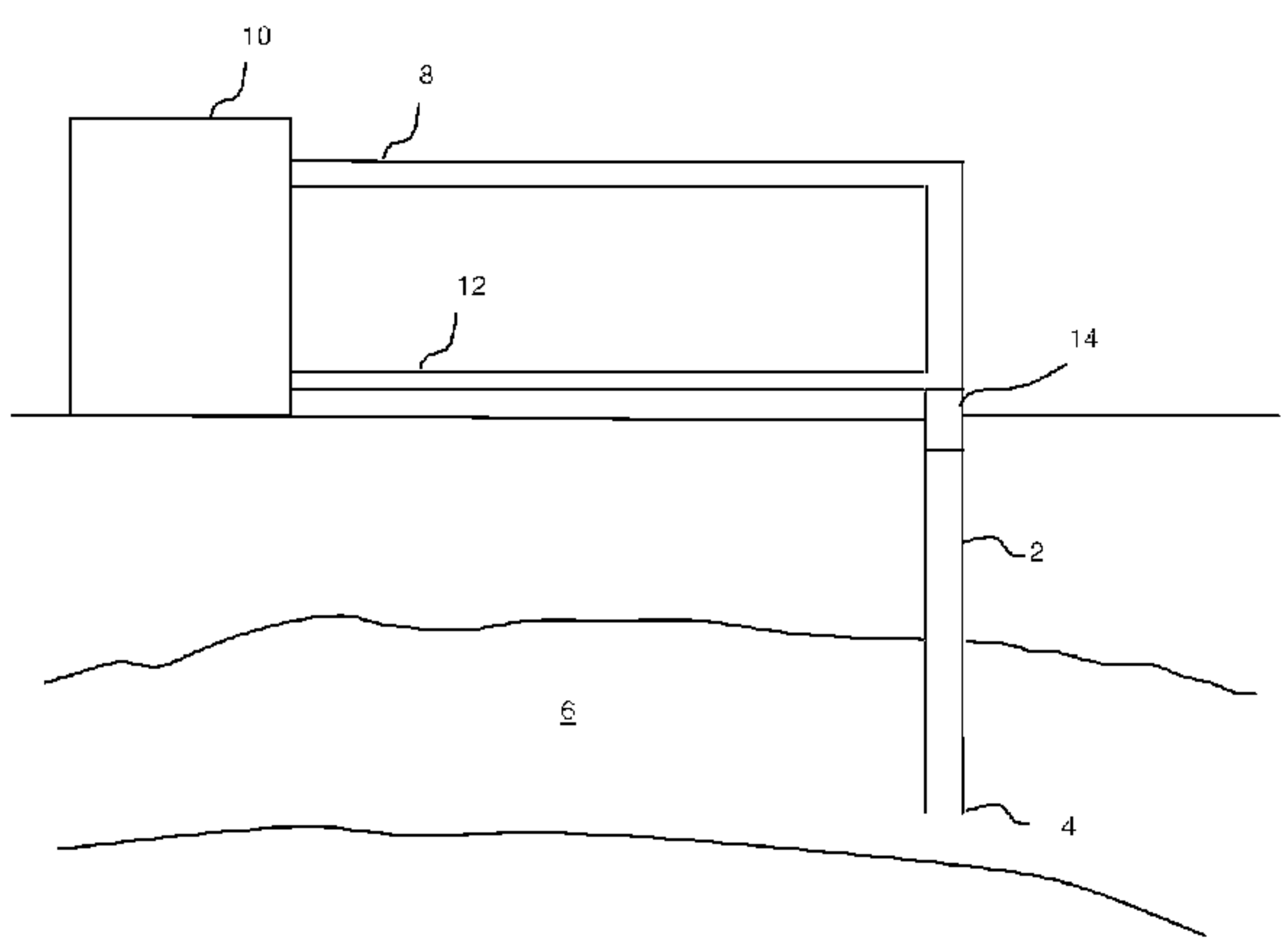
(72) Inventeurs/Inventors:
DE KOEIJER, GELEIN, NO;
BORCH, JAN HENRIK, NO

(73) Propriétaire/Owner:
STATOIL PETROLEUM AS, NO

(74) Agent: SMART & BIGGAR

(54) Titre : PROCEDE POUR LE STOCKAGE DE COMPOSITIONS DE DIOXYDE DE CARBONE DANS DES FORMATIONS GEOLOGIQUES SOUTERRAINES ET AGENCEMENT DESTINE A ETRE UTILISE DANS DE TELS PROCEDES

(54) Title: A METHOD FOR STORING CARBON DIOXIDE COMPOSITIONS IN SUBTERRANEAN GEOLOGICAL FORMATIONS AND AN ARRANGEMENT FOR USE IN SUCH METHODS



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A method and arrangement are proposed for injecting CO_2 into a subterranean aquifer for storage therein. In order to reduce the effects of water evaporation from brine in the aquifer when dry CO_2 is injected into the aquifer, the CO_2 is supplied mixed with a salt-lean fluid, i.e. a fluid that contains a low concentration of ions that can precipitate out as salts. The mixing may take place at the wellhead, with the CO_2 salt-lean fluids supplied via separate low-grade material pipelines. The proportion of CO_2 and salt-lean fluid in the mixture is such as to obtain a CO_2 composition that is saturated with salt-lean fluid at the site of injection into the aquifer. By injecting saturated or "wet" CO_2, less water is evaporated from the brine and the salt precipitation is greatly reduced, so keeping the pore spaces clear and providing an increased accessible pore volume for CO_2 storage.

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(71) Applicant (*for all designated States except US*): **STATOIL PETROLEUM AS** [NO/NO]; NO-4035 Stavanger (NO).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): **DE KOEIJER, Gelein** [NO/NO]; c/o Statoil ASA, NO-4035 Stavanger (NO). **BORCH, Jan Henrik** [NO/NO]; c/o Statoil ASA, NO-4035 Stavanger (NO).

(74) Agent: **ZACCO NORWAY AS**; P.O. Box 2003 Vika, Haakon VII's gt. 2, NO-0125 Oslo (NO).

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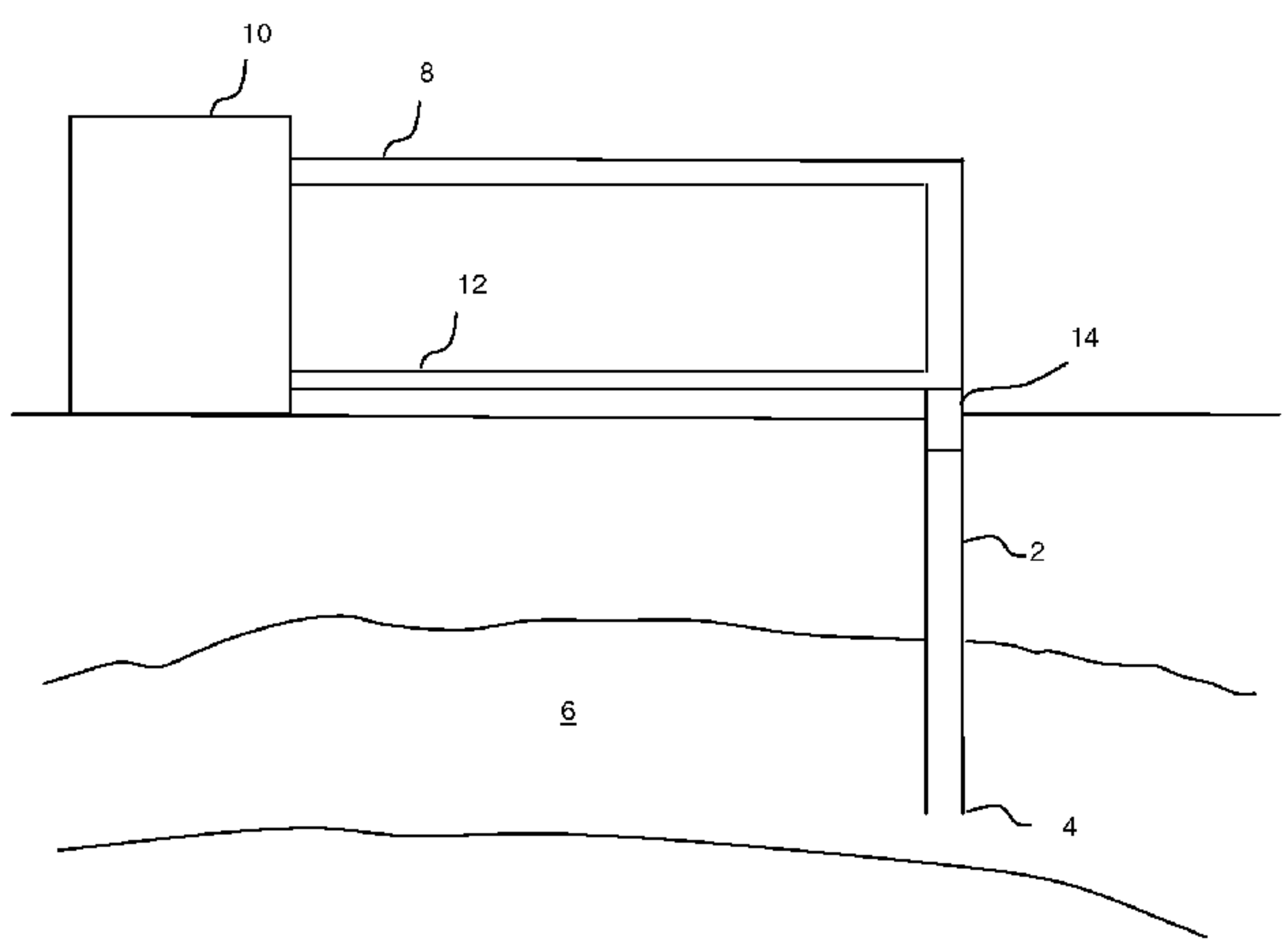

Fig. 1

(57) Abstract: A method and arrangement are proposed for injecting CO_2 into a subterranean aquifer for storage therein. In order to reduce the effects of water evaporation from brine in the aquifer when dry CO_2 is injected into the aquifer, the CO_2 is supplied mixed with a salt- lean fluid, i.e. a fluid that contains a low concentration of ions that can precipitate out as salts. The mixing may take place at the wellhead, with the CO_2 salt-lean fluids supplied via separate low-grade material pipelines. The proportion of CO_2 and salt-lean fluid in the mixture is such as to obtain a CO_2 composition that is saturated with salt-lean fluid at the site of injection into the aquifer. By injecting saturated or "wet" CO_2, less water is evaporated from the brine and the salt precipitation is greatly reduced, so keeping the pore spaces clear and providing an increased accessible pore volume for CO_2 storage.

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A Method for storing carbon dioxide compositions in subterranean geological formations and an arrangement for use in such methods

The invention relates to methods for introducing carbon dioxide (CO_2) into subterranean geological formations, specifically aquifers, and to arrangements for use in such methods.

The increase of CO_2 in the atmosphere is thought to have a major effect on global climate. It is therefore desirable to reduce the emission of anthropogenic CO_2 into the atmosphere. In addition to the development of low CO_2 emission power plants, energy-saving automobiles and the increased use of renewable energy sources, the permanent storage of CO_2 in subterranean geological formations can be an important means for reducing net CO_2 emission.

An extensive review of existing CO_2 Capture and Storage (CCS) projects and technology is given in the IPCC Special report on Carbon Dioxide Capture and Storage (Carbon Dioxide Capture and Storage, IPCC, 2005, editors: Metz et al., Cambridge University Press, UK; also available at: http://www.ipcc.ch). The paper SPE 127096 "An overview of active large-scale CO_2 storage projects", I. Wright et al. presented at the 2009 SPE International Conference on CO_2 capture, Storage and Utilization held in San Diego, California, USA 2-4 November 2009 provides a more recent update on existing large-scale CO_2 storage projects. Of the commercial scale projects reviewed in these documents, the most significant in terms of cumulative volume injected are the Sleipner and In Salah projects.

The Sleipner CCS Project is located 250 km off the Norwegian coast and is operated by Statoil. It is a commercial scale project for the storage of CO_2 in a subterranean aquifer in the Utsira formation at a depth of 800-1000m below the sea surface. CO_2 produced during natural gas processing is captured and subsequently injected underground into the brine-saturated unconsolidated sandstone formation. CO_2 injection started in October 1996 and by 2008, more than ten million tons of CO_2 had been injected at a rate of approximately 2700 tons per day. A shallow long-reach well is used to take the CO_2 2.4 km away from the producing wells and platform area. The injection site is placed beneath a local dome of the top Utsira formation.

The In Salah CCS Project is an onshore project for the production of natural gas from a gas reservoir located in a subterranean aquifer. The aquifer is located in the Sahara desert. The reservoir is in a carboniferous sandstone formation, 2000 m deep; it is only 20 m thick, and of low permeability. Natural gas containing up to 10% of CO_2 is produced. CO_2 is separated, and subsequently re-injected into the water-filled parts of the reservoir.

A known problem of CO_2 sequestration in aquifers, particularly saline aquifers is the risk of salt precipitation, which can impair the injection of CO_2. Salts are normally dissolved in formation water and can precipitate and form solids under certain conditions. When dry liquid or supercritical CO_2, also known as “dense state” CO_2, is injected into such formations, the water in the brine dissolves in the CO_2. As water is removed into the CO_2 stream, salt concentration increases, eventually reaching the solubility limit and giving rise to salt precipitation. The precipitated solids reduce the pore space available to the fluids, in some cases blocking the pore throats in the sedimentary rock. This impairs permeability near the wellbore, preventing fluid movement through the pores and may hinder any further injection of CO_2. This phenomenon occurs at the CO_2 injection points in and close to the borehole.

The book "CO_2 Capture Project, a technical basis for carbon dioxide storage" edited by Cal Cooper, ISBN 978-1-872691-48-0, suggests injecting fresh water prior to the CO_2 injection, in order to flush brine from the injection point. A further proposal is to use high injection rates in order to overcome the capillary forces with high fluid pressures. This latter proposal is limited by the supply of CO_2, the surface facility specifications and, of course, the fracture gradient of the cap rock.

The paper "Optimization of Residual Gas and Solubility Trapping for CO_2 Storage in Saline Aquifers" by Long Nghiem et al. presented at the 2009 Society of Petroleum Engineers Reservoir Simulation Symposium in Texas, USA, 2-4 February 2009 proposes the use of a water injector above the CO_2 injector to accelerate and increase residual gas an solubility trapping in low-permeability aquifers. The water flows downwards and meets the CO_2, which flows upwards in the reservoir. The quantities of water required are considerable.

Two further publications, JP 3258340 A and WO 08/058298 propose the dissolution of CO_2 in water to generate carbonated water prior to its injection into a subterranean reservoir. In both cases, the quantities of water required are substantial.

In view of the above described state of the art it is an object of the present invention to provide an alternative method and arrangement for the permanent storage of CO_2 in aquifers where the risk of salt precipitation when injecting substantially pure CO_2 is high.

It is a further object of the present invention to provide a method and arrangement which allow for a more efficient use of the storage capacity of aquifers for permanent storage of CO_2.

The scope of the invention is defined by the appended independent claims. Preferred embodiments of the invention are defined by the dependent claims.

According to one embodiment, there is provided a method of introducing a CO_2 composition into a subterranean aquifer for storage of CO_2 therein, the method comprising the steps of: providing a supply of a mixture of a CO_2 composition and a salt-lean fluid, wherein the CO_2 composition is compressed to assume a liquid or supercritical state at the site of injection, passing the mixture downwards via a shaft and injecting the mixture from the shaft into the aquifer, wherein the proportions of the CO_2 composition and the salt-lean fluid in the mixture is such as to obtain a CO_2 composition that is between 50% oversaturated and 50% under-saturated with the salt-lean fluid at the site of injection of the mixture into the aquifer.

By injecting a CO_2 composition that is saturated with a salt-lean fluid, and thus no longer dry, less water will be evaporated from the formation water at the site of injection. Hence, less salt will precipitate out and the pathways in the pore structure will be less obstructed by salt precipitates and the accessible pore volume will be considerably larger than when CO_2 is injected in a dry state.

In accordance with a preferred embodiment of the present invention, there is provided a supply of a salt-lean fluid and a separate supply of a CO_2 composition, wherein the rate of supply of each of the salt-lean fluid and the CO_2 composition is such as to obtain a CO_2 composition that is substantially saturated with the salt-lean fluid at the site of injection of said mixture into the aquifer. By separating the supplies of the salt-lean fluid and the dry CO_2 composition, the preferred low-grade material pipeline can be used without risk of corrosion.

Preferably, the required proportion of salt-lean fluid 5 and CO_2 composition can be obtained by mixing the two supplies in a static mixer located at or close to the shaft.

In accordance with a particularly advantageous embodiment of the present invention, the proportions of the CO_2 composition and the salt-lean fluid in the mixture is n such as to obtain a CO_2 composition that is between 50% oversaturated and 50% under-saturated, preferably between 10% oversaturated and 10% under-saturated, and most preferably between 5% oversaturated and 5% under-saturated with said salt-lean fluid at the site of injection of the mixture into the aquifer.

Advantageously, and in order to obtain a substantial reduction in the amount of precipitated salts at the injection site, the salt-lean fluid comprises less than 50% of the salinity of the formation water into which the CO_2 is injected, where the salinity is expressed in mass percent. In other words, the concentration of salts in the salt-lean fluid is preferably less than half of that of the formation water. In accordance with a preferred embodiment, the salt lean fluid has a salinity that is less than 25% of the salinity of the formation water.

The quantity of water or other salt-lean fluids required to saturate the CO_2 are not particularly high. It is thus an advantage of the present invention when the supply of salt-lean fluid and the supply of CO_2 composition m are both obtained as secondary or side products from a processing plant. In addition, when the salt-lean fluid undergoes a costly treatment prior to discharge, such as biological treatment or demineralization, these costs can be offset by recycling this fluid at the CO_2 injection well.

According to another embodiment, there is provided an arrangement for introducing a CO_2 composition into an aquifer, the arrangement comprising: a well including a shaft having an injection port for the injection of a CO_2 composition into the aquifer, a first conduit for supplying a CO_2 composition which is compressed to assume a liquid or supercritical state at the site of injection, the first conduit being connected to a wellhead portion of the shaft, a second conduit for supplying a salt-lean fluid, the second conduit being connected to a wellhead portion of the shaft, wherein the rate of flow of the CO_2 composition and the salt-lean fluid is such as to form a CO_2 composition that is between 50% oversaturated and 50% under-saturated with the salt-lean fluid at the site of injection of the mixture into the aquifer.

The proportions of salt lean fluid and CO_2 composition can be more accurately controlled in a particularly advantageous embodiment of the present invention when the arrangement comprises a mixer arranged at a wellhead portion of the shaft for mixing the CO_2 composition and the salt-lean fluid to form a CO_2 composition that is substantially saturated with the salt-lean fluid at the site of injection of the mixture into the aquifer. The mixer is preferably a static mixer that mixes by creating turbulence through a pressure drop rather than by the use of moving parts.

Advantageously, the arrangement further comprises a processing plant connected to the first and second conduits for providing a source of the substantially dry CO_2 composition and the salt-lean fluid. Salt-lean fluids, such as drainage water, are conventionally discharged from such processing plants in quantities that are entirely adequate to saturate the CO_2 composition. Recycling this fluid with the CO_2 composition provides a convenient and particularly advantageous way of increasing the CO_2 sequestration quantities.

Figure 1 schematically shows an arrangement for introducing CO_2 into a subterranean reservoir in accordance with the present invention.

An "aquifer", within the context of the present invention shall be understood as being an underground layer of water-bearing permeable rock or unconsolidated materials (gravel, sand, silt, or clay). An aquifer, within the context of the present invention, may also be referred to as a "reservoir".

A "site of injection", within the context of the present invention, shall be understood as being a position adjacent an opening of an injection port, through which opening CO_2 is injected into an aquifer; said position being outside an outer surface of the conduit or well.

The present invention relates to methods for storing CO_2 in subterranean geological formations, in particular, in subterranean aquifers.

The CO_2 injected is preferably a CO_2 composition compressed to assume a liquid or supercritical state, also referred to as dense phase, at the site of injection, i.e., at reservoir conditions. The compressed gas may include CO_2 and additional compounds or impurities, such as lower alkanes, nitrogen and oxygen. These impurities preferably amount to less than 50%wt, 40%wt, 30%wt, 20%wt, 10%wt, 5%wt, 2%wt, most preferably to less than 1%wt, based on total compressed gas weight. The terms "CO_2 composition" and "CO_2", according to the invention, and depending on the context, may relate to the above described mixtures of CO_2.

The invention shall now be explained with reference to the appended figure.

Figure 1 shows an arrangement for introducing CO_2 into an aquifer according to the present invention. A shaft 2 is provided to transport CO_2 from a level substantially above surface into a reservoir 6 within a subterranean formation. The shaft 2 may be in form of a tube disposed within the casing of a well. Alternatively, the casing of the well itself may constitute the shaft 2. The distal end of the shaft 2 terminates within the reservoir 6 in an injection port 4. CO_2 is injected via the shaft 2 into the reservoir 8 under controlled pressure and temperature and is a liquid or supercritical fluid at the injection port 4. In the illustrated embodiment, the well is a vertical well, however, it will be understood by those skilled in the art that it could alternatively be an inclined or deviated well or have a substantially vertical, or inclined upper (proximal) portion and a substantially horizontal distal portion. The well shaft 2 is connected at a proximal or wellhead end via a pipeline 8 to a processing plant 10 which produces CO_2 as a side or secondary product. For example, the processing plant may be a natural gas processing plant. In such a plant, the CO_2 is separated from the natural gas then conventionally compressed and dehydrated and before being transported via pipeline 8 to the well-head. The CO_2 obtained in this way may be pure CO_2 or may alternatively contain specific levels of contaminants, including the lower alkanes, methane, ethane, propane and butane. The pipeline 8 supplying the CO_2 is conventionally of mild steel (carbon steel) and would be subject to corrosion if CO_2 were not dehydrated first. This CO_2 dehydration thus avoids the need for a stainless steel pipeline over distances that can number many hundreds of kilometres.

In accordance with the present invention, a second pipeline 12 joins the shaft 2 at the wellhead and provides a source of salt-lean fluid. A "salt-lean fluid" in the context of the invention is a fluid containing low concentrations of ions that can precipitate. The salt concentration in the salt-lean fluid is preferably defined with reference to the salt concentration or salinity of the formation water, i.e. the water or brine already present at the injection site. Preferably the salt concentration of such a fluid is less than 50% of the salt concentration of the formation water and most preferably less than 25% of the salt concentration of the formation water. Examples of suitable salt-lean fluids include an aqueous fluid, such as water with a salt concentration of less than 1%wt. Another possibility is propylene glycol, also known as methyl ethylene glycol or MEG. Processing plants that produce CO_2 as a side product commonly have salt-lean fluid streams for various types of treatments. Examples of such streams are the knock-off water from the CO_2 compression train, wash water and steam condensate.

This salt-lean fluid is mixed with the CO_2 in the wellhead, preferably with a static mixer 14 provided there. The wellhead, shaft 2 and mixer 14 are typically made of high-grade stainless steel and thus are not subject to corrosion by the fluid-CO_2 mixture or "wet" CO_2 composition. In addition to the mixer 14, the shaft 2 may be provided with a compressor (not shown) upstream or downstream of the mixer 14 for adjusting the pressure of the CO_2-fluid mixture.

The proportion of salt-lean fluid to CO_2 mixed together is such as to provide salt-lean fluid saturated CO_2 at the injection site. In other words, the mixture is such that the CO_2 is around the saturation point or substantially saturated with the salt-lean fluid at the temperature and pressure prevailing in the reservoir at the point of injection.

The exact proportions of CO_2 and salt-lean fluid will thus depend on the conditions prevailing in each reservoir. For example, in the Sleipner project in which CO_2 is stored at a depth of between 800 and 1000 below sea level, the pressure and temperature in the reservoir are around 29°C and 74 bar. In deeper reservoirs, such as at the Snøhvit project located in the Barents Sea offshore Norway at a depth of 2600m below sea level, the prevailing pressure and temperature are considerably higher. Clearly the proportion of salt-lean fluid to CO_2 composition to obtain saturation will be higher at these higher temperature an pressures. It is possible to model the prevailing conditions at the injection site of any particular reservoir. Hence it is possible to set the required proportions at the well head.

While the ideal state is saturated CO_2, some margin is possible. Thus the CO_2 may be between 10% oversaturated and 10% under-saturated with the salt-lean fluid, preferably 10% oversaturated and 5% under-saturated with the salt-lean fluid and most preferably 5% oversaturated and 2% under-saturated with the salt-lean fluid. In any event, the mixture is not a liquid in which CO_2 is dissolved, but rather fluid-saturated or “wet” CO_2.

Since the CO_2 injected into the aquifer 6 is no longer dry, less water will be evaporated from the brine and consequently less salt will precipitate out. As a result, the pathways in the pore structure will be less obstructed by salt precipitates and the accessible pore volume will be considerably larger than when CO_2 is injected in a dry state. In addition, the quantities of water or other salt-lean fluids required to saturate the CO_2 are such that these fluids can be obtained entirely from the CO_2 source processing plant. When these fluids are subject to costly treatments, such as biological treatment or demineralization, these costs can be offset by the recycling of this fluid at the CO_2 injection well to increase the levels of CO_2 sequestration.

While the above description has centered on the arrangement illustrated in Fig. 1 with two separate pipelines supplying a CO_2 composition and a salt-lean fluid and a mixer at the wellhead to achieve the desired saturation or “wetness” of the CO_2 composition, it will be understood that the CO_2 composition and salt-lean fluid could be mixed upstream of the wellhead and supplied via a high-grade, corrosion-resistant pipeline to the well. In some cases, it may even be advantageous to pipe a “wet” CO_2 composition directly from the processing plant, i.e. omit the dehydration step, or modify this process in the plant to obtain the desired proportions of CO_2 composition and salt-lean fluid

Claims

1. A method of introducing a CO_2 composition into a subterranean aquifer for storage of CO_2 therein, said method comprising the steps of:

providing a supply of a mixture of a CO_2 composition and a salt-lean fluid, wherein the CO_2 composition is compressed to assume a liquid or supercritical state at the site of injection,

passing said mixture downwards via a shaft and injecting said mixture from said shaft into said aquifer,

wherein the proportions of said CO_2 composition and said salt-lean fluid in said mixture is such as to obtain a CO_2 composition that is between 50% oversaturated and 50% under-saturated with said salt-lean fluid at the site of injection of said mixture into said aquifer.

2. A method as claimed in claim 1, wherein the step of providing said supply of said mixture includes:

providing a supply of a salt-lean fluid and a separate supply of a CO_2 composition, wherein the rate of supply of each of said salt-lean fluid and said CO_2 composition is such as to obtain a CO_2 composition that is substantially saturated with said salt-lean fluid at the site of injection of said mixture into said aquifer.

3. A method as claimed in claim 2, further comprising the step of providing said supply of a salt-lean fluid and said separate supply of a CO_2 composition to a static mixer located at or close to said shaft.

4. A method of claim 3, wherein said step of providing said supplies of a salt-lean fluid and a CO_2 composition includes providing two separate pipelines for each supply, said pipelines terminating at said mixer.

5. A method of any one of claims 1 to 4, wherein the proportions of said CO_2 composition and said salt-lean fluid in said mixture is such as to obtain a CO_2 composition that is between 10% oversaturated and 10% under-saturated with said salt-lean fluid at the site of injection of said mixture into said aquifer.

6. A method according to claim 5, wherein said CO_2 composition is between 5% oversaturated and 5% under-saturated with said salt-lean fluid at the site of injection of said mixture into said aquifer.

7. A method according to any one of claims 1 to 6, wherein said salt-lean fluid has a salt concentration that is less than 50% of the salt concentration of formation water present in said aquifer at the site of injection.

8. A method according to claim 7, wherein said salt-lean fluid has a salt concentration that is less than 25% of the salt concentration of said formation water.

9. A method according to any one of claims 1 to 8, wherein the step of providing a supply of a salt-lean fluid and providing a supply of a CO_2 composition

includes obtaining said salt-lean fluid and CO_2 composition as side products from a processing plant.

10. An arrangement for introducing a CO_2 composition into an aquifer, said arrangement comprising:

a well including a shaft having an injection port for the injection of a CO_2 composition into the aquifer,

a first conduit for supplying a CO_2 composition which is compressed to assume a liquid or supercritical state at the site of injection, said first conduit being connected to a wellhead portion of said shaft,

a second conduit for supplying a salt-lean fluid, said second conduit being connected to a wellhead portion of said shaft,

wherein the rate of flow of said CO_2 composition and said salt-lean fluid is such as to form a CO_2 composition that is between 50% oversaturated and 50% under-saturated with said salt-lean fluid at the site of injection of said mixture into said aquifer.

11. An arrangement as claimed in claim 10, further comprising a mixer arranged at a wellhead portion of said shaft for mixing said CO_2 composition and said salt-lean fluid to form said CO_2 composition that is substantially saturated with said salt-lean fluid at the site of injection of said mixture into said aquifer.

12. An arrangement as claimed in claim 11, wherein said mixer is a static mixer.

13. An arrangement as claimed in any one of claims 10 to 12, wherein the proportions of said CO_2 composition

and said salt-lean fluid in said mixture is such as to obtain a CO_2 composition that is between 10% oversaturated and 10% under-saturated with said salt-lean fluid at the site of injection of said mixture into said aquifer.

14. An arrangement as claimed in claim 13, wherein said CO_2 composition is between 10% oversaturated and 5% under-saturated with said salt-lean fluid at the site of injection of said mixture into said aquifer.

15. An arrangement as claimed in claim 13, wherein said CO_2 composition is between 5% oversaturated and 2% under-saturated with said salt-lean fluid at the site of injection of said mixture into said aquifer.

16. An arrangement as claimed in any one of claims 10 to 15, further comprising a processing plant connected to said first and second conduits for providing a source of a substantially dry CO_2 composition and a salt-lean fluid.

17. An arrangement as claimed in any one of claims 10 to 16, wherein said salt-lean fluid comprises less than 5%wt of salts.

18. An arrangement as claimed in claim 17, wherein said salt-lean fluid comprises less than 2%wt of salts.

19. An arrangement as claimed in claim 17, wherein said salt-lean fluid comprises less than 1%wt of salts.

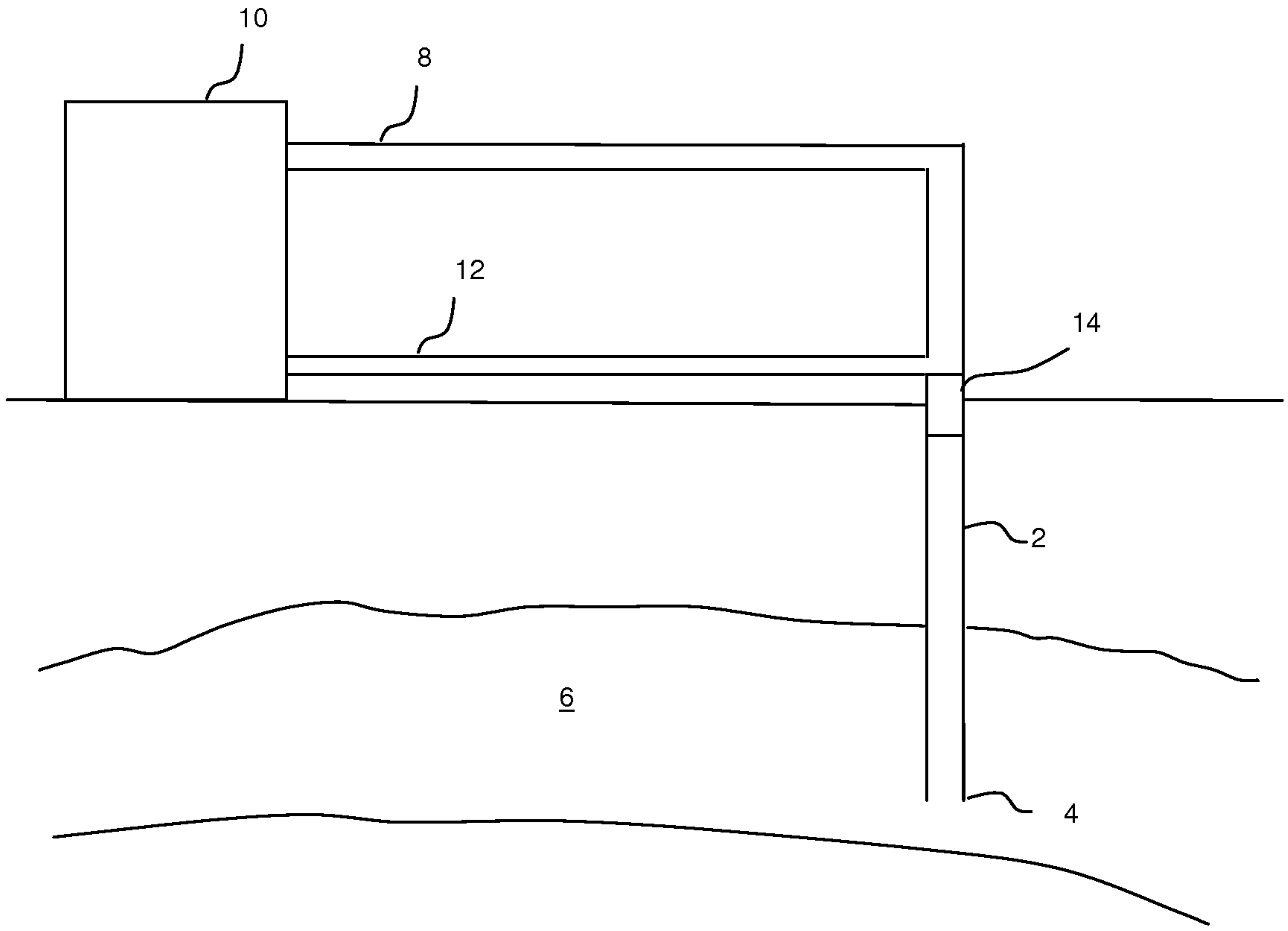
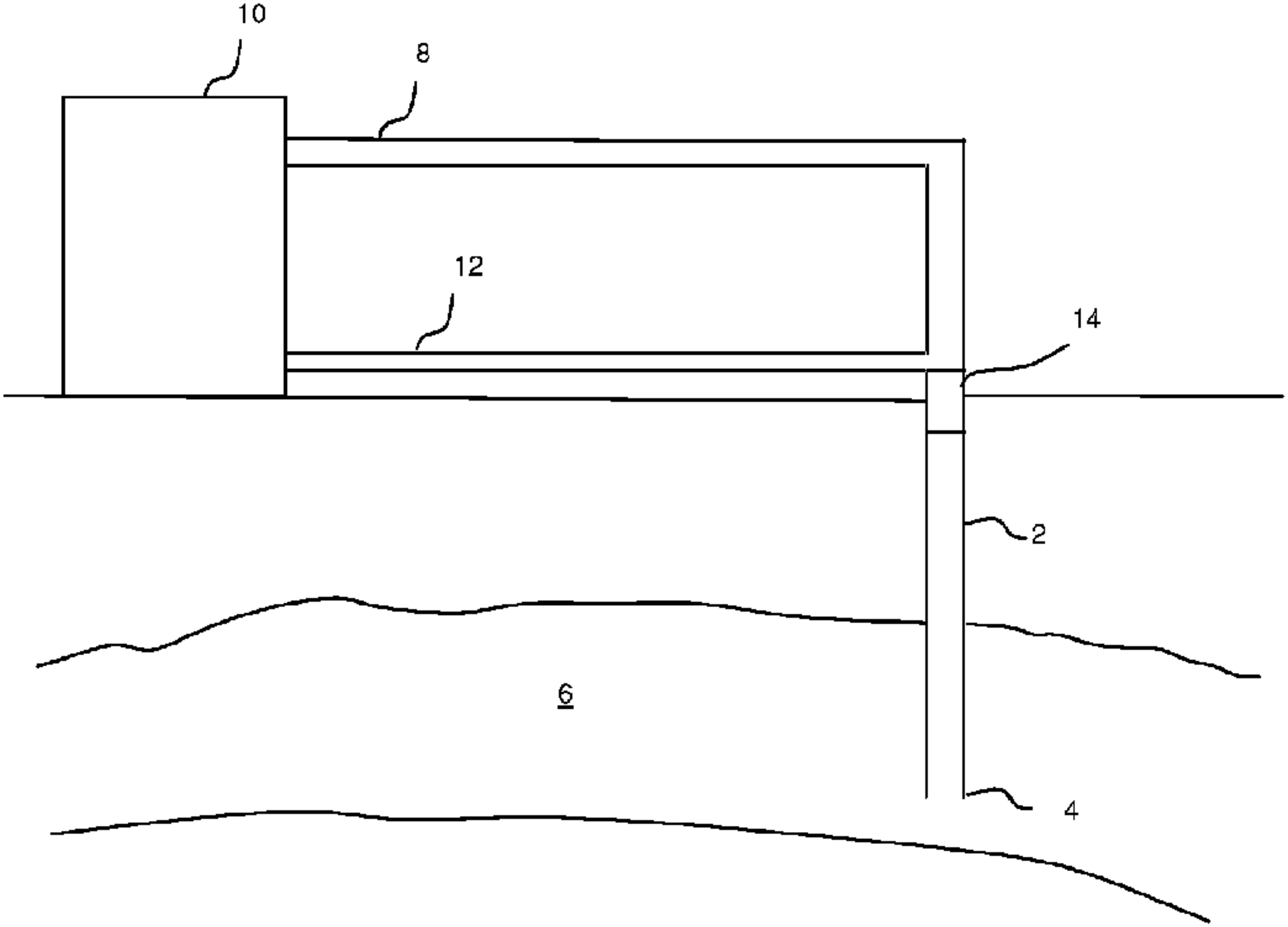


Fig. 1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