



(51) International Patent Classification:

Not classified

SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

(21) International Application Number:

PCT/US2023/083135

Published:

— without international search report and to be republished upon receipt of that report (Rule 48.2(g))

(22) International Filing Date:

08 December 2023 (08.12.2023)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

18/077,619 08 December 2022 (08.12.2022) US

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(81) Designated States (unless otherwise indicated, for every

kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every

kind of regional protection available): ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE,

(54) Title: PORTABLE SYSTEM TO CAPTURE AND STORE LIQUID CARBON DIOXIDE

(57) Abstract: A hydraulic fracturing operation is performed in a wellbore formed in a subterranean zone. A wellhead is installed at an entrance to the wellbore. Liquid CO₂ is flowed through a pipeline located at a surface and fluidically coupled to the wellhead. The liquid CO₂ is flowed into the wellbore through the wellhead to perform the hydraulic fracturing. The hydraulic fracturing operation including flowing of the liquid CO₂ through the pipeline to the wellhead is stopped. A portion of the liquid CO₂ is withdrawn from within the pipeline into a liquid CO₂ storage container, which is a portable system designed to capture and store liquid CO₂ and that is fluidically coupled to the pipeline at the surface.



PORTABLE SYSTEM TO CAPTURE AND STORE LIQUID CARBON DIOXIDE**CLAIM OF PRIORITY**

[0001] This application claims priority to U.S. Patent Application No. 18/077,619 filed on December 8, 2022, the entire contents of which are hereby
5 incorporated by reference.

TECHNICAL FIELD

[0002] This disclosure relates to using carbon dioxide (CO₂), specifically liquid CO₂, in hydraulic fracturing operations.

BACKGROUND

10 [0003] Hydraulic fracturing is a technique to stimulate production of hydrocarbons through the wellbore and to safely extract energy from an underground well. Hydraulic fracturing operations involve injecting fluids (e.g., liquids and materials such as proppants) at high pressure into a wellbore formed in a subterranean zone (e.g., a formation, a portion of a formation, multiple
15 formations). The fluids are injected at high pressure to create small fractures in the subterranean zone. The proppants keep the fractures in the open position. By doing so, hydrocarbon entrapped in the subterranean zone flows into the wellbore through the fractures. In some instances, the fluids injected into the wellbore include carbon dioxide (CO₂). Chemical interaction between the CO₂ and the
20 subterranean zone, specifically the rock formation, especially under high pressure, can alter the pore structure of the rock matrix and aid in the dissolution of the rock matrix and in the migration of minerals.

[0004] In some instances, CO₂ in liquid state is used as one of the injection fluids. Liquid CO₂ is a fluid state of CO₂ in which the CO₂ is maintained at low
25 temperatures (e.g., -34.4 °C) and high pressure (e.g., 1.406 MPa). Compared to gaseous CO₂, liquid CO₂ is easier to transport.

SUMMARY

[0005] This specification describes technologies relating to a portable system to capture and store liquid CO₂, e.g., liquid CO₂ used in hydraulic fracturing
30 operations.

[0006] Certain aspects of the subject matter described here can be implemented as a method. A hydraulic fracturing operation is performed in a wellbore formed in a subterranean zone. A wellhead is installed at an entrance to the wellbore. Liquid CO₂ is flowed through a pipeline located at a surface and fluidically coupled to the wellhead. The liquid CO₂ is flowed into the wellbore through the wellhead to perform the hydraulic fracturing. The hydraulic fracturing operation including flowing of the liquid CO₂ through the pipeline to the wellhead is stopped. A portion of the liquid CO₂ is withdrawn from within the pipeline into a liquid CO₂ storage container that is fluidically coupled to the pipeline at the surface.

[0007] An aspect combinable with any other aspect includes the following features. After withdrawing the portion of the liquid CO₂ from the pipeline, the liquid CO₂ storage container is de-coupled from the pipeline. The liquid CO₂ storage container filled with the portion of the liquid CO₂ is transported away from the wellbore.

[0008] An aspect combinable with any other aspect includes the following features. The withdrawn portion of the liquid CO₂ is stored in the liquid state while transporting the liquid CO₂ storage container.

[0009] An aspect combinable with any other aspect includes the following features. To store the withdrawn portion of the liquid CO₂ in the liquid state, a temperature and a pressure of the liquid CO₂ container is maintained at a temperature and a pressure, respectively, at which CO₂ remains in liquid state.

[0010] An aspect combinable with any other aspect includes the following features. To flow the liquid CO₂ into the wellbore through the wellhead to perform the hydraulic fracturing, multiple liquid CO₂ containers, each carrying liquid CO₂, are coupled to an inlet of the pipeline. An outlet of the pipeline is coupled to the wellhead. A booster pump fluidically coupled to the pipeline is operated to flow the liquid CO₂ from the multiple liquid CO₂ containers to the wellhead.

[0011] An aspect combinable with any other aspect includes the following features. Each liquid CO₂ container is fluidically coupled to a manifold trailer fluidically coupled to the inlet of the pipeline.

[0012] An aspect combinable with any other aspect includes the following features. To withdraw a portion of the liquid CO₂ within the pipeline into a liquid CO₂ storage container fluidically coupled to the pipeline at the surface, a check valve is fluidically coupled to the pipeline at a location between the multiple
5 liquid CO₂ containers and the wellhead. The check valve is operated to isolate a portion of the pipeline between the check valve and the wellhead. The portion of the liquid CO₂ within the isolated portion of the pipeline is withdrawn.

[0013] An aspect combinable with any other aspect includes the following features. A pipeline pump is fluidically coupled to the check valve and the liquid
10 CO₂ container into which the portion of the liquid CO₂ is withdrawn. The pipeline pump is operated to draw the portion of the liquid CO₂ into the liquid CO₂ container.

[0014] Certain aspects of the subject matter described here can be implemented as a method that includes multiple steps. In step (a), a cemented
15 liner of a first stage in a wellbore is perforated. In step (b), after perforating the cemented liner, slickwater fluid is flowed into the wellbore to initiate and propagate a fracture in the wellbore. In step (c), after initiating and propagating the fracture, proppant slurry is flowed into the wellbore. In step (d), after flowing proppant slurry into the wellbore, liquid CO₂ is flowed into the wellbore. After
20 flowing the liquid CO₂ into the wellbore, a portion of the liquid CO₂ is withdrawn into a liquid CO₂ container. The liquid CO₂ is maintained in the liquid state in the liquid CO₂ container.

[0015] An aspect combinable with any other aspect includes the following features. To maintain the liquid CO₂ in the liquid state, the liquid CO₂ container is
25 insulated to maintain a temperature and a pressure of the liquid CO₂ container at a temperature and a pressure, respectively, at which CO₂ remains in liquid state.

[0016] An aspect combinable with any other aspect includes the following features. To flow the liquid CO₂ into the wellbore, the liquid CO₂ is flowed into the wellbore through a pipeline located at a surface and fluidically coupled to the
30 wellhead.

[0017] An aspect combinable with any other aspect includes the following features. To flow the liquid CO₂ through the pipeline, multiple liquid CO₂

containers, each carrying liquid CO₂, are coupled to an inlet of the pipeline. An outlet of the pipeline is coupled to the wellhead. A booster pump, which is fluidically coupled to the pipeline, is operated to flow the liquid CO₂ from the multiple liquid CO₂ containers to the wellhead.

5 [0018] An aspect combinable with any other aspect includes the following features. To withdraw a portion of the liquid CO₂ into the liquid CO₂ storage container, a check valve is fluidically coupled to the pipeline at a location between the multiple liquid CO₂ containers and the wellhead. The check valve is operated to isolate a portion of the pipeline between the check valve and the wellhead. The
10 portion of the liquid CO₂ within the isolated portion of the pipeline is withdrawn.

[0019] An aspect combinable with any other aspect includes the following features. A pipeline pump is fluidically coupled to the check valve and the liquid CO₂ container into which the portion of the liquid CO₂ is withdrawn. The pipeline pump is operated to draw the liquid CO₂ within the isolated portion of the
15 pipeline.

[0020] An aspect combinable with any other aspect includes the following features. Steps (a)-(d) form a fracturing stage. The hydraulic fracturing stage is stopped before withdrawing the portion of the liquid CO₂ into the liquid CO₂ container. After withdrawing the portion of the liquid CO₂ into the liquid CO₂
20 container, steps (a)-(d) are performed in a second, subsequent hydraulic fracturing stage.

[0021] The details of one or more implementations of the subject matter described in this specification are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages of the subject matter
25 will become apparent from the description, the drawings, and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] FIG. 1 is schematic diagram showing injecting different hydraulic fracturing fluids into a wellhead of a wellbore.

[0023] FIG. 2 is a schematic diagram showing injecting liquid CO₂ into the
30 wellhead of FIG. 1.

[0024] FIG. 3 is a flowchart of an example of a process of withdrawing liquid CO₂ that is injected into the wellhead of the wellbore.

[0025] Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0026] Use of liquid CO₂ as one of the hydraulic fracturing fluids can enhance the efficiency of hydraulic fracturing operation. In addition, the injected CO₂ can be trapped in the subterranean zone and thereby be sequestered. Such sequestration of CO₂ can have positive environmental impact. Liquefying CO₂ and maintaining liquefied CO₂ in liquid form can necessitate the use of specialized equipment, e.g., equipment with appropriate insulation depending on the saturation temperature and pressure. Moreover, when implemented in hydraulic fracturing operations, the liquid CO₂ flows through equipment including flow equipment such as pipelines, valves, pumps, and the like. Continuous contact of such equipment with the liquid CO₂ can cause damage to the equipment due to the low temperature and high pressure of the liquid CO₂. One technique to reduce the continuous contact of the equipment with the liquid CO₂ is to bleed the CO₂ to the atmosphere. However, not only does doing so result in wastage of liquid CO₂, but the addition of CO₂ to the atmosphere also creates a negative environmental impact.

[0027] This disclosure describes technologies relating to a portable system to capture and store liquid CO₂, specifically liquid CO₂ used as in hydraulic fluids. Implementing the techniques described here can limit a need to vent CO₂ to the atmosphere, thereby creating a positive environmental impact. Implementing the techniques here can also reduce a contact time between hydraulic fracturing equipment and liquid CO₂. Such reduction in contact time can reduce damage to and increase the life of the equipment. The CO₂ captured using the techniques described here is maintained in liquid form, allowing the liquid CO₂ to be transported to different locations for storage or re-use.

[0028] FIG. 1 is schematic diagram showing injecting different hydraulic fracturing fluids into a wellhead of a wellbore. Hydraulic fracturing operations can be performed in a pad of wells, the pad including four wells. The fracturing operations are performed in an alternating fashion in two wells at a time. In a hydraulic fracturing set up, a wellbore 100 is formed in a subterranean zone (not

shown). A wellhead 102 (e.g., a Christmas tree with valves and pipeline fittings) is installed at the surface of the Earth at an inlet to the wellbore. Multiple pipelines are connected to the wellhead to flow different hydraulic fracturing fluids into the wellbore 100. For example, a first pipeline 104 flows slurry, which is a mixture of a fluid and proppants. A second pipeline 106 flows slickwater. A third pipeline 108 can flow liquid CO₂. Other pipelines to flow other hydraulic fracturing fluids or fluids for other well operations can be fluidically coupled to the wellhead.

[0029] In an example hydraulic fracturing sequence in two adjacent wells, a perforation gun is run into the wellbore 100 to perforate a cemented liner of the first stage in a first well (e.g., the wellbore 100). Then, slickwater fluid is flowed through the second pipeline 106 to initiate and propagate the fracture in the first well. Then, proppant slurry is flowed through the first pipeline 104 into the first well. Then, liquid CO₂ is flowed through the third pipeline 108 into the first well. The hydraulic fracturing operations described here represent a first stage of hydraulic fracturing. While the pumping steps (i.e., pumping the slickwater fluid, pumping the proppant slurry and pumping the liquid CO₂) are being conducted, the perforation step (i.e., running the perforation gun to perforate the cemented liner) is performed in the second well. Then, the pumping operations are performed in the second well. The sequence of operations is repeated for each hydraulic fracturing stage in an alternating fashion between the two wells.

[0030] FIG. 2 is a schematic diagram showing injecting liquid CO₂ into the wellhead 102. FIG. 2 schematically shows multiple equipment used to flow liquid CO₂ for hydraulic fracturing. For example, the liquid CO₂ is injected through the third pipeline 108 into the wellhead 102. The liquid CO₂ can be transported to the well site, e.g., to an inlet 202 of the third pipeline 108, with an outlet 204 of the third pipeline 108 connected to the wellhead 102. The location of the inlet 202 shown in FIG. 2 can be different in different implementations. For example, the liquid CO₂ can be transported in multiple containers (e.g., a first container 206a, a second container 206b, a third container 206c or more or fewer containers). Each container can be a tanker driven to the well site. At the well site, each container can be fluidically coupled to a manifold trailer 208 (e.g., a manifold) that can receive fluidic inlet connections from the multiple containers and include one fluidic outlet

connection to the inlet 202 of the third pipeline 108. A booster pump 210 can be fluidically coupled to the manifold trailer 208 and to the inlet 202 of the third pipeline 108 to draw the liquid CO₂ from the multiple containers into the inlet 202 of the third pipeline 108.

5 [0031] A liquid CO₂ pump truck 212, which includes pumping equipment to pump the liquid CO₂ drawn from the multiple containers, is fluidically coupled to the third pipeline 108. The liquid CO₂ pump truck 212 is operated to flow the liquid CO₂ through the third pipeline 108 towards the wellhead 102. In some implementations, a valve 214 can be fluidically connected to the liquid CO₂ pump
10 truck 212 and to the booster pump 210. The valve 214 can be operated to control a quantity of liquid CO₂ drawn from the multiple containers into the liquid CO₂ truck 212.

[0032] In some implementations, a flowmeter 216 is fluidically coupled to the third pipeline 108 downstream of the valve 214. The flowmeter 216 can be
15 used to measure a volumetric flow rate of the liquid CO₂ through the third pipeline 108. Operations of the liquid CO₂ pump truck 212 or the booster pump 210 or both can be controlled based on measurements obtained from the flowmeter 216.

[0033] In some implementations, a check valve 218 is fluidically coupled to the third pipeline 108 upstream of the outlet 204 of the third pipeline 108 (e.g.,
20 downstream of the flowmeter 216). The check valve 218 can permit flow of the liquid CO₂ through the third pipeline 108 towards the outlet 204 of the third pipeline 108, and can prevent flow of the liquid CO₂ in the opposite direction towards the inlet 202 of the third pipeline 108.

[0034] When flow of the liquid CO₂ through the third pipeline 108 into the
25 wellbore 100 through the wellhead 102 is stopped, then a quantity of liquid CO₂ remains in the third pipeline 108, specifically between the inlet 202 and the outlet 204. The fluidic properties of the liquid CO₂ (namely, the low temperature and high pressure) can have damaging effects on the equipment through which the liquid CO₂. Moreover, unless the temperature and pressure are maintained, the liquid CO₂
30 can transition to a different state or phase.

[0035] To avoid these drawbacks, in some implementations, a portion of the liquid CO₂ can be withdrawn from within the third pipeline 108 and collected in a

portable liquid CO₂ container 220. The container 220 can be an insulated tank that can maintain a temperature of the liquid CO₂ at a temperature at which the liquid CO₂ remains in the same state/phase as when the liquid CO₂ was initially introduced into the third pipeline 108. In some implementations, the liquid CO₂ container 220 can be connected to refrigeration systems to maintain the liquid CO₂ at the low temperatures mentioned above.

[0036] The liquid CO₂ container 220 can be fluidically coupled to the third pipeline 108 to withdraw the portion of the liquid CO₂. For example, a check valve 222 can be fluidically coupled to the third pipeline 108 upstream of the check valve 218 and, in some implementations, upstream of the flowmeter 216. When hydraulic fracturing operations are being performed, the check valve 222 can permit the flow of the liquid CO₂ downstream of the check valve 222, and seal flow of the liquid CO₂ to the liquid CO₂ container 220. When hydraulic fracturing operations are stopped, the check valve 222 can switch operational states to seal the flow of the liquid CO₂ downstream of the check valve 222, and to divert flow of the liquid CO₂ into the liquid CO₂ container 220. In this manner, the check valve 222 can be operated to isolate a portion of the third pipeline 108 in which the liquid CO₂ resides. The isolated portion can be a length of the third pipeline 108 from the multiple liquid CO₂ containers to the check valve 222. Alternatively or in addition, the isolated portion can be a length of the third pipeline 108 from the check valve 222 to the outlet 204 attached to the wellhead 102. In some implementations, the entire length of the third pipeline 108 from the inlet 202 to the outlet 204 can be isolated to withdraw portions of the liquid CO₂ from the entire length of the third pipeline 108.

[0037] In some implementations, a pipeline pump 224 can be fluidically coupled between the check valve 222 and the liquid CO₂ container 220. When the check valve 222 is in the operational state that diverts flow of the liquid CO₂ into the liquid CO₂ container 220, the pipeline pump 224 can be operated to draw the liquid CO₂ from the third pipeline 108 and to pump the drawn liquid CO₂ into the liquid CO₂ container 220. Alternatively or in addition, the pipeline pump 224 can pressurize the liquid CO₂ in the liquid CO₂ container 220 to a pressure at which the

liquid CO₂ remains in the same state/phase as when the liquid CO₂ was initially introduced into the third pipeline 108.

[0038] In an example operation of withdrawing the portion of the liquid CO₂ into the liquid CO₂ container 220, after the booster pump 210 and/or the CO₂ pump truck 212 pumps the liquid CO₂ from the multiple containers into the third pipeline 108, the pumps are shut-in. The check valve 218 is closed. The multiple containers are also closed. The check valve 222 is opened and the pipeline pump 224 is run. Once the liquid CO₂ container 220 fills to a desired level, the pipeline pump 224 is shut-in and the check valve 222 is closed. This example operation is repeated as desired, e.g., after each fracturing stage.

[0039] FIG. 3 is a flowchart of an example of a process 300 of withdrawing liquid CO₂ that is injected into the wellhead of the wellbore. In some implementations, the process 300 can be performed by an operator, e.g., a hydraulic fracturing equipment operator. At 300, a cemented liner of a first stage in a wellbore is perforated. Next, at 304, slickwater fluid is flowed into the wellbore. Next, at 306, proppant slurry is flowed into the wellbore. Next, at 308, liquid CO₂ is flowed into the wellbore. Next, at 310, a portion of the liquid CO₂ is withdrawn into a portable container. Next, at 312, the liquid CO₂ is maintained in the liquid state in the portable container, e.g., by using necessary insulation, refrigeration and pressurization.

[0040] After withdrawing the liquid CO₂ into the container, the container can be separated, i.e., de-coupled from the pipeline from which the liquid CO₂ was withdrawn. The insulation and refrigeration can maintain the temperature of the liquid CO₂. The container can be sealed appropriately to maintain the pressure of the liquid CO₂. The container, de-coupled from the pipeline, can be transported to any location, e.g., a location away from the wellbore, while the liquid CO₂ is maintained in the same state as it was when introduced into the pipeline. The liquid CO₂ can be stored at that location. Alternatively, the container can be coupled to different equipment, e.g., hydraulic fracturing equipment at a different well site, to flow the liquid CO₂ out of the container into the other equipment.

[0041] In some implementations, the liquid CO₂ can be replaced with supercritical CO₂. In the supercritical state, CO₂ has viscosity like gas and density

like water. In such implementations, the liquid CO₂ container 220 can be modified to maintain the CO₂ in the supercritical state. For example, the CO₂ container can be fitted with airtight blender, high pressure pump and manifold trucks that can maintain the CO₂ in supercritical condition. Remaining equipment described here
5 can also be similarly modified to accommodate supercritical CO₂ in place of liquid CO₂.

[0042] Thus, particular implementations of the subject matter have been described. Other implementations are within the scope of the following claims.

CLAIMS

1. A method comprising:

while performing a hydraulic fracturing operation in a wellbore formed in a subterranean zone, a wellhead installed at an entrance to the wellbore, flowing,
5 through a pipeline located at a surface and fluidically coupled to the wellhead, liquid CO₂ into the wellbore through the wellhead to perform the hydraulic fracturing;

stopping the hydraulic fracturing operations including stopping flow of the liquid CO₂ through the pipeline to the wellhead; and

10 withdrawing a portion of the liquid CO₂ within the pipeline into a liquid CO₂ storage container fluidically coupled to the pipeline at the surface.

2. The method of claim 1, further comprising:

after withdrawing the portion of the liquid CO₂ from the pipeline, de-
15 coupling the liquid CO₂ storage container from the pipeline; and

transporting the liquid CO₂ storage container filled with the portion of the liquid CO₂ away from the wellbore.

3. The method of claim 2, further comprising storing the withdrawn portion of the
20 liquid CO₂ in liquid state while transporting the liquid CO₂ storage container.

4. The method of claim 3, wherein storing the withdrawn portion of the liquid CO₂ in the liquid state comprises maintaining a temperature and a pressure of the liquid CO₂ container at a temperature and a pressure, respectively, at which CO₂
25 remains in liquid state.

5. The method of claim 1, wherein flowing the liquid CO₂ into the wellbore through the wellhead to perform the hydraulic fracturing comprises:

coupling a plurality of liquid CO₂ containers, each carrying liquid CO₂, to an
30 inlet of the pipeline, an outlet of the pipeline coupled to the wellhead; and

operating a booster pump fluidically coupled to the pipeline to flow the liquid CO₂ from the plurality of liquid CO₂ containers to the wellhead.

6. The method of claim 5, further comprising fluidically coupling each liquid CO₂ container to a manifold trailer fluidically coupled to the inlet of the pipeline.

- 5 7. The method of claim 5, wherein withdrawing a portion of the liquid CO₂ within the pipeline into a liquid CO₂ storage container fluidically coupled to the pipeline at the surface comprises:

fluidically coupling a check valve to the pipeline at a location between the plurality of liquid CO₂ containers and the wellhead;

- 10 operating the check valve to isolate a portion of the pipeline between the check valve and the wellhead; and

withdrawing the portion of the liquid CO₂ within the isolated portion of the pipeline.

- 15 8. The method of claim 7, further comprising:

fluidically coupling a pipeline pump to the check valve and the liquid CO₂ container into which the portion of the liquid CO₂ is withdrawn; and

operating the pipeline pump to draw the portion of the liquid CO₂ into the liquid CO₂ container.

20

9. A method comprising:

(a) perforating a cemented liner of a first stage in a wellbore;

(b) after perforating the cemented liner, flowing slickwater fluid into the wellbore to initiate and propagate a fracture in the wellbore;

- 25 (c) after initiating and propagating the fracture, flowing proppant slurry into the wellbore;

(d) after flowing proppant slurry into the wellbore, flowing liquid CO₂ into the wellbore;

- 30 after flowing the liquid CO₂ into the wellbore, withdrawing a portion of the liquid CO₂ into a liquid CO₂ container; and

maintaining the liquid CO₂ in the liquid CO₂ container in a liquid state.

10. The method of claim 9, wherein maintaining the liquid CO₂ in the liquid state comprises insulating the liquid CO₂ container to maintain a temperature and a pressure of the liquid CO₂ container at a temperature and a pressure, respectively, at which CO₂ remains in liquid state.

5

11. The method of claim 9, wherein flowing the liquid CO₂ into the wellbore comprises flowing, through a pipeline located at a surface and fluidically coupled to the wellhead, the liquid CO₂ into the wellbore through the wellhead.

10 12. The method of claim 11, wherein flowing the liquid CO₂ through the pipeline comprises:

coupling a plurality of liquid CO₂ containers, each carrying liquid CO₂, to an inlet of the pipeline, an outlet of the pipeline coupled to the wellhead; and

15 operating a booster pump fluidically coupled to the pipeline to flow the liquid CO₂ from the plurality of liquid CO₂ containers to the wellhead.

13. The method of claim 12, wherein withdrawing a portion of the liquid CO₂ into the liquid CO₂ container comprises:

20 fluidically coupling a check valve to the pipeline at a location between the plurality of liquid CO₂ containers and the wellhead;

operating the check valve to isolate a portion of the pipeline between the check valve and the wellhead; and

withdrawing the portion of the liquid CO₂ within the isolated portion of the pipeline.

25

14. The method of claim 13, further comprising:

fluidically coupling a pipeline pump to the check valve and the liquid CO₂ container into which the portion of the liquid CO₂ is withdrawn; and

30 operating the pipeline pump to draw the portion of the liquid CO₂ into the liquid CO₂ container.

15. The method of claim 9, wherein steps (a)-(d) comprise a hydraulic fracturing stage, wherein the method further comprises:

stopping the hydraulic fracturing stage before withdrawing the portion of the liquid CO₂ into the liquid CO₂ container; and

5 after withdrawing the portion of the liquid CO₂ into the liquid CO₂ container, performing steps (a)-(d) in a second, subsequent hydraulic fracturing stage.

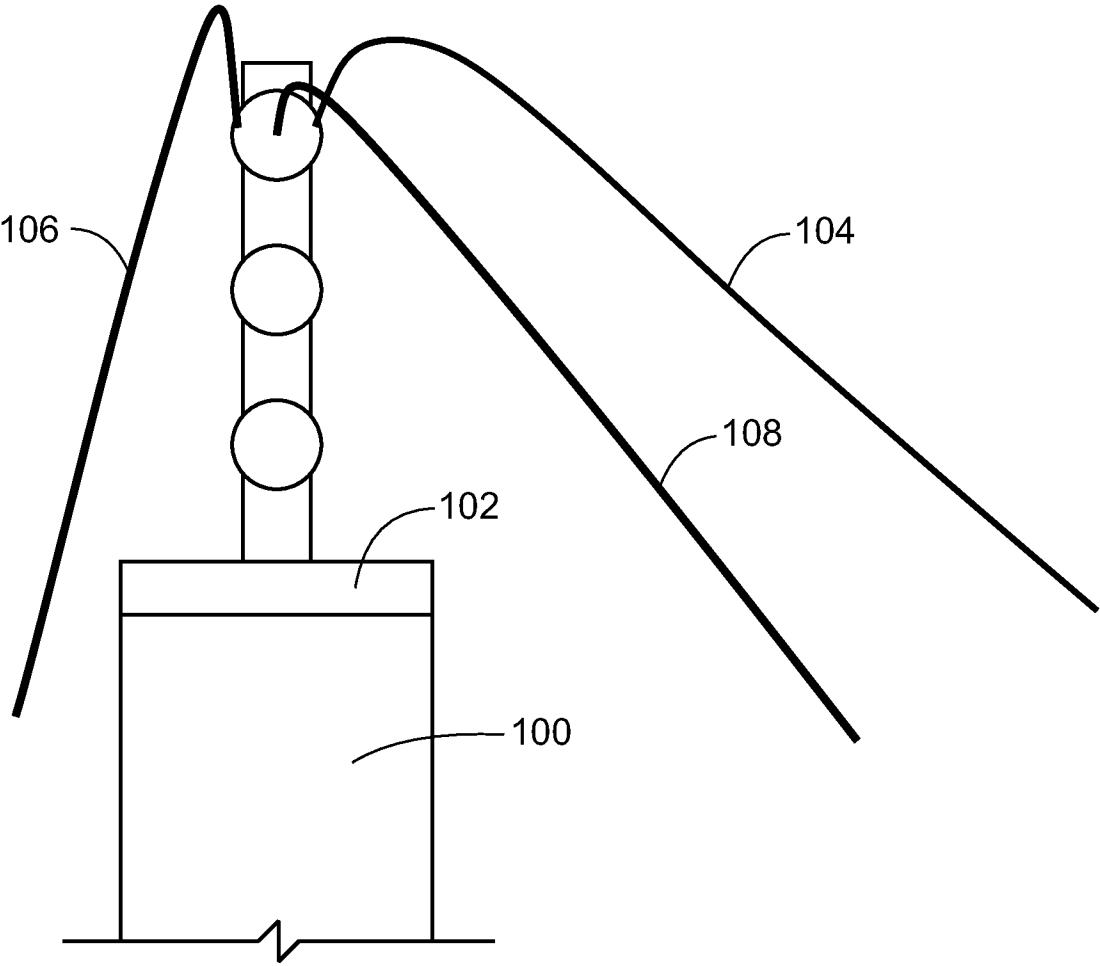


FIG. 1

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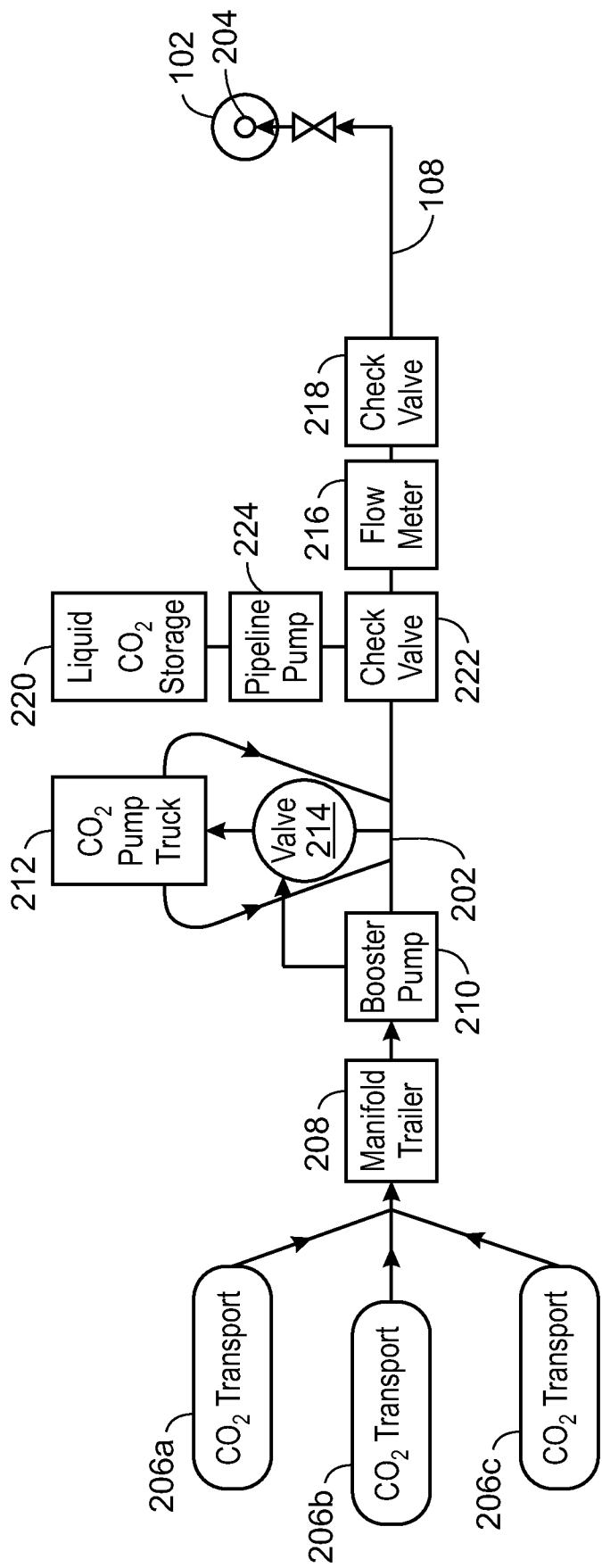


FIG. 2

3/3

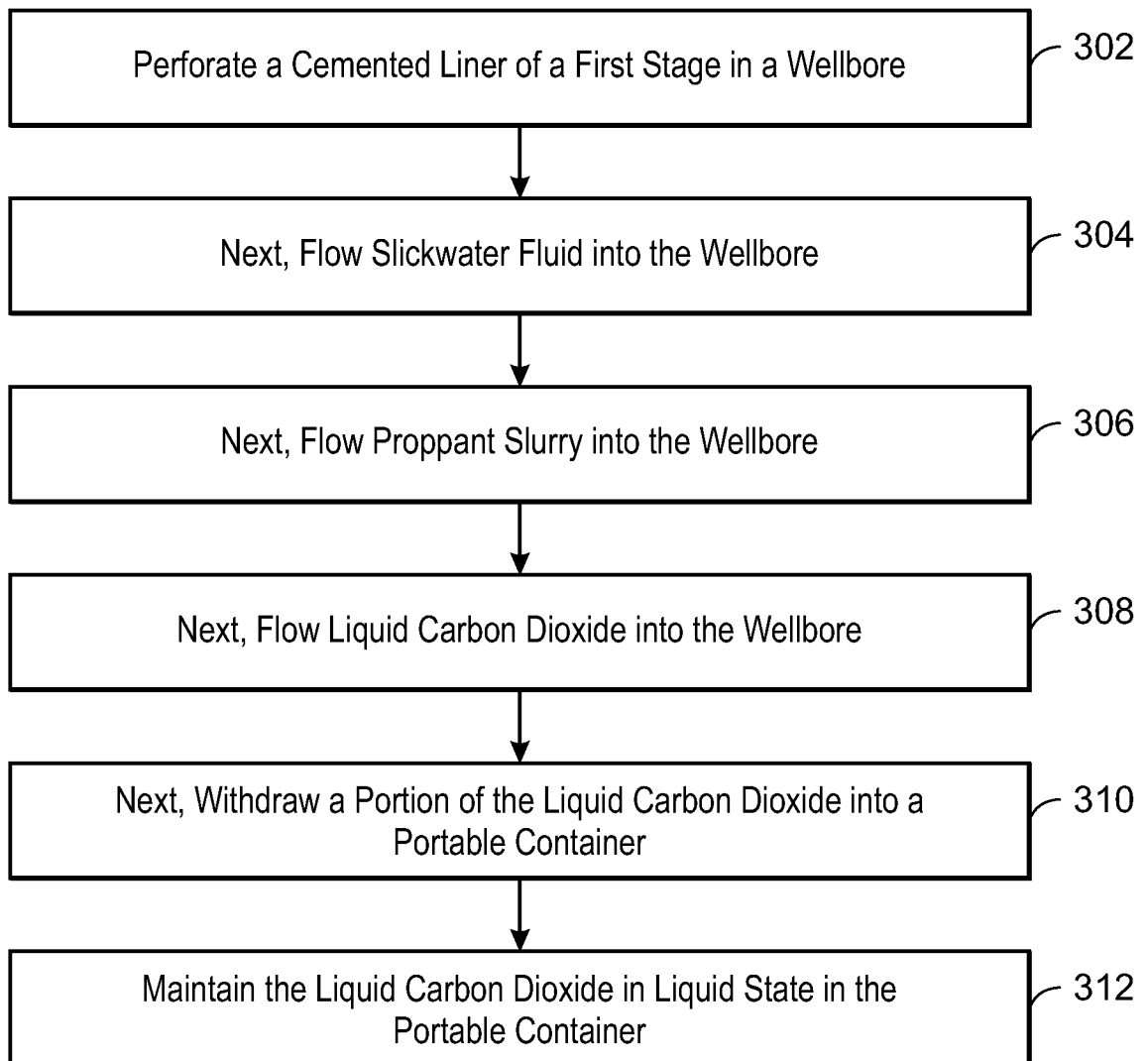
300


FIG. 3