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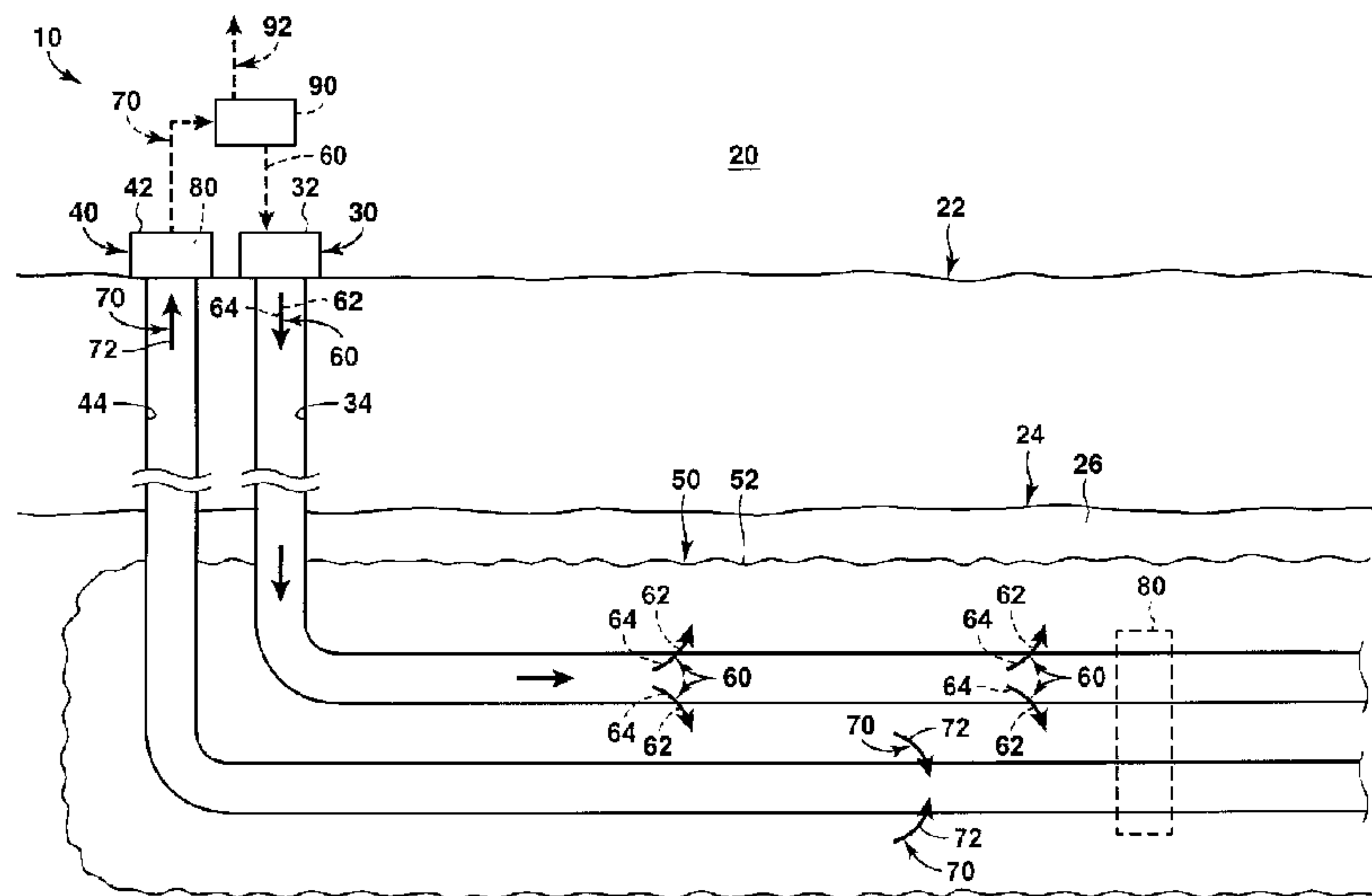
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(54) Title: THERMAL RECOVERY METHODS FOR RECOVERING VISCOUS HYDROCARBONS FROM A
SUBTERRANEAN FORMATION



(57) Abrégé/Abstract:

Thermal recovery methods for recovering viscous hydrocarbons from a subterranean formation. The thermal recovery methods include performing a plurality of injection cycles. Each injection cycle in the plurality of injection cycles includes injecting a heated solvent vapor stream into a heated chamber that extends within the subterranean formation and fluidly contacting the viscous hydrocarbons with the heated solvent vapor stream to generate mobilized viscous hydrocarbons. Each injection cycle also includes injecting a steam stream into the heated chamber. The thermal recovery methods further include producing a chamber liquid and/or mobilized viscous hydrocarbons from the subterranean formation.

Abstract of the Disclosure

Thermal recovery methods for recovering viscous hydrocarbons from a subterranean formation. The thermal recovery methods include performing a plurality of injection cycles. Each injection cycle in the plurality of injection cycles includes injecting a heated solvent vapor stream into a heated chamber that extends within the subterranean formation and fluidly contacting the viscous hydrocarbons with the heated solvent vapor stream to generate mobilized viscous hydrocarbons. Each injection cycle also includes injecting a steam stream into the heated chamber. The thermal recovery methods further include producing a chamber liquid and/or mobilized viscous hydrocarbons from the subterranean formation.

THERMAL RECOVERY METHODS FOR RECOVERING VISCOUS HYDROCARBONS FROM A SUBTERRANEAN FORMATION

Field of the Disclosure

5 The present disclosure is directed generally to thermal recovery methods of recovering viscous hydrocarbons from a subterranean formation and more particularly to thermal recovery methods that sequentially inject a heated solvent vapor stream and a steam stream into the subterranean formation.

Background of the Disclosure

10 Hydrocarbons often are utilized as fuels and/or as chemical feedstocks for manufacturing industries. Hydrocarbons naturally may be present within subterranean formations, which also may be referred to herein as reservoirs and/or as hydrocarbon reservoirs. Such hydrocarbons may occur in a variety of forms, which broadly may be categorized herein as conventional hydrocarbons and unconventional hydrocarbons. A process utilized to remove a given
15 hydrocarbon from a corresponding subterranean formation may be selected based upon one or more properties of the hydrocarbon and/or of the subterranean formation.

 Examples of hydrocarbon production techniques that may be utilized to produce viscous hydrocarbons from a subterranean formation include thermal recovery processes. Thermal recovery processes generally inject a thermal recovery stream, at an elevated temperature, into
20 the subterranean formation. The thermal recovery stream contacts the viscous hydrocarbons, within the subterranean formation, and heats, dissolves, and/or dilutes the viscous hydrocarbons, thereby generating mobilized viscous hydrocarbons. The mobilized viscous hydrocarbons generally have a lower viscosity than a viscosity of the naturally occurring viscous hydrocarbons at the native temperature and pressure of the subterranean formation and may be pumped and/or

flowed from the subterranean formation. A variety of different thermal recovery processes have been utilized, including cyclic steam stimulation processes, solvent-assisted cyclic steam stimulation processes, steam flooding processes, solvent-assisted steam flooding processes, steam-assisted gravity drainage processes, solvent-assisted steam-assisted gravity drainage processes, heated vapor extraction processes, liquid addition to steam to enhance recovery processes, and/or near-azeotropic gravity drainage processes.

Thermal recovery processes may differ in the mode of operation and/or in the composition of the thermal recovery stream. However, all thermal recovery processes rely on injection of the thermal recovery stream into the subterranean formation, at the elevated temperature, and thermal contact between the thermal recovery stream and the subterranean formation heats the subterranean formation.

In thermal recovery processes, such as heated vapor extraction, that utilize a solvent, or a hydrocarbon solvent, as the thermal recovery stream, solvent loss to the subterranean formation may increase production costs and/or limit production economies. As an example, a decrease in an amount of solvent needed to produce viscous hydrocarbons from the subterranean formation may cause a corresponding decrease in production costs as long as the savings associated with the decrease in solvent utilization is not offset by a corresponding increase in energy consumption.

In addition, recovered solvent generally is separated from the viscous hydrocarbons and re-injected into the subterranean formation, and increases in a volume of the solvent recycled also may increase production costs and/or limit production economies. As another example, a decrease in the volume of solvent produced from the subterranean formation may permit a

.corresponding decrease in surface facility size required for solvent separation, recovery, and re-injection, also decreasing production costs.

Historically, thermal recovery processes may utilize solvent inefficiently within the subterranean formation, leading to increased solvent loss to the subterranean formation and/or
5 increased production of solvent from the subterranean formation. Thus, there exists a need for improved thermal recovery methods for recovering viscous hydrocarbons from a subterranean formation.

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Summary of the Disclosure

Thermal recovery methods for recovering viscous hydrocarbons from a subterranean formation. The thermal recovery methods include performing a plurality of injection cycles. Each injection cycle in the plurality of injection cycles includes injecting a heated solvent vapor
5 stream into a heated chamber that extends within the subterranean formation. The heated solvent vapor stream is injected via an at least substantially horizontal region of an injection well that extends within the heated chamber and for a heated solvent vapor injection time period. Each injection cycle also includes fluidly contacting the viscous hydrocarbons with the heated solvent vapor stream to generate a chamber liquid and/or mobilized viscous hydrocarbons. Each
10 injection cycle further includes injecting a steam stream into the heated chamber. The steam stream is injected via the at least substantially horizontal region of the injection well and for a steam injection time period. The thermal recovery methods further include producing the chamber liquid and/or the mobilized viscous hydrocarbons from the subterranean formation. The producing may be performed during at least one injection cycle of the plurality of injection
15 cycles.

Brief Description of the Drawings

Fig. 1 is a schematic representation of examples of a hydrocarbon production system that may be utilized with methods according to the present disclosure.

Fig. 2 is a plot illustrating recovery factor as a function of time for eight different injection strategies.

Fig. 3 is a plot illustrating cumulative solvent-to-oil ratio as a function of recovery factor for the injection strategies of Fig. 2.

Fig. 4 is a flowchart depicting methods, according to the present disclosure, for recovering viscous hydrocarbons from a subterranean formation.

Fig. 5 is a schematic transverse cross-sectional view of a heated chamber illustrating a portion of the method of Fig. 4.

Fig. 6 is a schematic transverse cross-sectional view of a heated chamber illustrating a portion of the method of Fig. 4.

Fig. 7 is a schematic transverse cross-sectional view of a heated chamber illustrating a portion of the method of Fig. 4.

Fig. 8 is a schematic transverse cross-sectional view of a heated chamber illustrating a portion of the method of Fig. 4.

Detailed Description and Best Mode of the Disclosure

Figs. 1-8 provide examples of hydrocarbon production systems 10, of portions of hydrocarbon production systems 10, and/or of methods 100, according to the present disclosure. Elements that serve a similar, or at least substantially similar, purpose are labeled with like numbers in each of Figs. 1-8, and these elements may not be discussed in detail herein with reference to each of Figs. 1-8. Similarly, all elements may not be labeled in each of Figs. 1-8, but reference numerals associated therewith may be utilized herein for consistency. Elements, components, and/or features that are discussed herein with reference to one or more of Figs. 1-8 may be included in and/or utilized with any of Figs. 1-8 without departing from the scope of the present disclosure. In general, elements that are likely to be included in a particular embodiment are illustrated in solid lines, while elements that are optional are illustrated in dashed lines. However, elements that are shown in solid lines may not be essential and, in some embodiments, may be omitted without departing from the scope of the present disclosure.

Fig. 1 is a schematic representation of examples of a hydrocarbon production system 10 that may be utilized with methods 100, according to the present disclosure. As illustrated in Fig. 1, hydrocarbon production system 10 includes an injection well 30 and a production well 40. Injection well 30 and production well 40 extend within a subterranean formation 24 that includes viscous hydrocarbons 26. Injection well 30 and production well 40 also may extend, or may be referred to herein as extending, between a surface region 20 and subterranean formation 24 and/or within a subsurface region 22.

Injection well 30 includes an injection wellhead 32 and an injection wellbore 34. Similarly, production well 40 includes a production wellhead 42 and a production wellbore 44.

During operation of hydrocarbon production system 10, injection well 30 may be utilized to provide, to supply, and/or to inject an injectant stream 60 into subterranean formation 24. Injectant stream 60 may include a heated solvent vapor stream 62 and/or a steam stream 64. Injectant stream 60 may interact with, contact, physically contact, fluidly contact, mix with, and/or heat viscous hydrocarbons 26, within subterranean formation 24, thereby producing, generating, and/or forming mobilized viscous hydrocarbons 72 within the subterranean formation. The mobilized viscous hydrocarbons may form a portion of a chamber liquid 70, which also may include a condensed fraction of injectant stream 60, such as a condensed fraction of the heated solvent vapor stream and/or a condensed fraction of the steam stream. Chamber liquid 70, including mobilized viscous hydrocarbons 72, may flow, under the influence of gravity, to production well 40, which may produce the chamber liquid and/or the mobilized viscous hydrocarbons from the subterranean formation.

Injection of injectant stream 60 into the subterranean formation and production of chamber liquid 70 from the subterranean formation may produce and/or generate a heated chamber 50 within the subterranean formation. The heated chamber may grow, with time, such as may be responsive to continued injection of the injectant stream and/or continued production of the chamber liquid. Heated chamber 50 and subterranean formation 24 may form and/or define an interface region 52 therebetween.

As schematically illustrated in dashed lines in Fig. 1, hydrocarbon production system 10 may include one or more sensors 80. Sensors 80, when present, may be adapted, configured, designed, constructed, and/or programmed to monitor and/or determine any suitable property of hydrocarbon production system 10, including subterranean formation 24, heated chamber 50, and/or chamber liquid 70. As an example, sensors 80 may be configured to monitor a

composition variable of chamber liquid 70. The composition variable may indicate a solvent content, a water content, a viscous hydrocarbon content, and/or a mobilized viscous hydrocarbon content of chamber liquid 70 that is produced via production well 40. As additional examples, sensors 80 may be configured to monitor any suitable temperature, pressure, chemical composition, chemical property, and/or physical property of any suitable portion of hydrocarbon production system 10 and/or of streams that may flow within the hydrocarbon production system. Additional examples of variables that may be monitored by sensors 80 are disclosed herein.

As also schematically illustrated in dashed lines in Fig. 1, hydrocarbon production system 10 may include surface facilities 90. Surface facilities 90 also may be referred to herein as separation facilities 90 and may be adapted, configured, designed, and/or constructed to receive chamber liquid 70 that is produced from subterranean formation 24 and to separate the received chamber liquid into a produced hydrocarbon stream 92 and injectant stream 60. As such, the presence of surface facilities 90 may facilitate recycling, or re-injection, of the portion of the injectant stream that is produced from the subterranean formation with the produced chamber liquid.

As discussed in more detail herein with reference to methods 100 of Fig. 4, hydrocarbon production system 10 may be utilized to perform a plurality of injection cycles. In each injection cycle, a heated solvent vapor stream initially may be injected into the subterranean formation. The heated solvent vapor stream may fluidly contact viscous hydrocarbons within the subterranean formation, thereby generating mobilized viscous hydrocarbons. Subsequent to injection of the heated solvent vapor stream for a heated solvent vapor injection time period, a steam stream may be injected into the subterranean formation for a steam injection time period.

The steam stream generally will have a higher temperature, and a higher concentration of thermal energy, when compared to the corresponding properties of the heated solvent vapor stream. Stated another way, a steam temperature, at which the steam stream has a given vapor pressure, may be greater than a solvent vapor temperature, at which the heated solvent vapor stream has the same given vapor pressure. In addition, a heat capacity and/or a heat of vaporization of the steam stream may be greater than a heat capacity and/or a heat of vaporization of the heated solvent vapor stream. As such, injection of the steam stream into subterranean formation 24 and/or into heated chamber 50 may vaporize condensed solvent that comes into contact with the steam stream.

This vaporization of condensed solvent may provide several benefits over thermal recovery processes that inject the heated solvent vapor stream but that do not subsequently, and cyclically, inject the steam stream. As an example, vaporization of the condensed solvent within the heated chamber, thereby re-forming the heated solvent vapor stream within the heated chamber, may improve and/or increase supply of the heated solvent vapor stream to interface region 52. This may improve the efficiency of solvent utilization within the subterranean formation and/or may decrease a volume of condensed solvent produced from the subterranean formation and provided to surface facilities 90. As another example, vaporization of the condensed solvent within the heated chamber may decrease a potential for loss of the condensed solvent within the heated chamber by providing a driving force for production of the condensed solvent from the subterranean formation via production well 40.

With the above in mind, Fig. 2 is a plot illustrating a recovery factor as a function of time for eight different injection strategies. As indicated as “Base” in Fig. 2, these injection strategies include a base, baseline, and/or control condition, in which the heated solvent vapor stream

continuously is injected into the subterranean formation. The illustrated injection strategies further include seven experimental conditions in which heated solvent vapor and steam are sequentially injected for various relative timeframes. The recovery factor refers to a cumulative production of viscous hydrocarbons from the subterranean formation, and all plots are
5 normalized to the base condition. A higher recovery factor generally is considered to indicate improved recovery of viscous hydrocarbons from the subterranean formation relative to a lower recovery factor. The experimental conditions include:

- 1) a 30.30 condition, in which each injection cycle includes 30 days of heated solvent vapor injection followed by 30 days of steam injection;
- 10 2) a 1.1 condition, in which each injection cycle includes 1 day of heated solvent vapor injection followed by 1 day of steam injection;
- 3) a 30.3 condition, in which each injection cycle includes 30 days of heated solvent vapor injection followed by 3 days of steam injection;
- 4) a 10.1 condition, in which each injection cycle includes 10 days of heated
15 solvent vapor injection followed by 1 day of steam injection;
- 5) a 30.2 condition, in which each injection cycle includes 30 days of heated solvent vapor injection followed by 2 days of steam injection;
- 6) a 15.1 condition, in which each injection cycle includes 15 days of heated solvent vapor injection followed by 1 day of steam injection; and
- 20 7) a 30.1 condition, in which each injection cycle includes 30 days of heated solvent vapor injection followed by 1 day of steam injection.

As may be seen from Fig. 2, injection strategies that inject the heated solvent vapor stream and the steam stream for comparable time periods (e.g., the 30.30 and 1.1 conditions)

exhibit a decrease in the recovery factor as a function of time when compared to injection strategies that inject the heated solvent vapor stream for a significantly longer amount of time when compared to the steam stream (e.g., the 30.3, 10.1, 30.2, 15.1, and 30.1 conditions). In general, viscous hydrocarbons may be converted more effectively to mobilized viscous hydrocarbons by the heated solvent vapor stream when compared to the steam stream. With this in mind, it is postulated that, in the 30.30 and 1.1 conditions, the steam injection time period is sufficient to facilitate flow of the steam stream to the interface region between the heated chamber and the subterranean formation. In contrast, for the experimental conditions in which the heated solvent vapor injection time is significantly greater than the steam injection time, it is postulated that the steam stream, or at least a majority of the steam stream, does not reach the interface region.

Fig. 3 is a plot illustrating cumulative solvent-to-oil ratio as a function of recovery factor for the experimental conditions and/or injection strategies of Fig. 2. The cumulative solvent-to-oil ratio is a ratio of a volume of solvent utilized to produce a given volume of oil. A lower cumulative solvent-to-oil ratio generally is considered to indicate an improved efficiency of solvent utilization and/or lower solvent costs.

As may be seen from Fig. 3, for recovery factors greater than approximately 5%, there is a systematic decrease in cumulative solvent-to-oil ratio as an injection time ratio is decreased, with the injection time ratio being a ratio of the heated solvent vapor injection time period to the steam injection time period. This may be evidenced by the systematic decrease in the cumulative solvent-to-oil ratio when moving from the base case (for which the injection time ratio arguably is infinite) to the 30.1 experimental condition (30:1 injection time ratio) to the 30.2 and 15.1

experimental conditions (15:1 injection time ratio) to the 30.3 and 10.1 experimental conditions (10:1 injection time ratio) to the 30.30 and 1.1 experimental conditions (1:1 injection time ratio).

Fig. 3 also illustrates that the cumulative solvent-to-oil ratio also may be impacted, to some extent, not only by an absolute magnitude of the injection time ratio but also by a magnitude of the heated solvent vapor injection time period and/or by a magnitude of the steam injection time period. This impact may be evidenced by the difference between the 30.30 and 1.1 conditions in Fig. 3.

The combination of Figs. 2-3 illustrates that the methods disclosed herein, which cyclically inject both heated solvent vapor and steam, may be utilized to improve the cumulative solvent-to-oil ratio when compared to methods that inject a heated solvent vapor stream but do not inject a steam stream (i.e., the base condition of Figs. 2-3). However, this improvement in the cumulative solvent-to-oil ratio may be balanced against a decrease in recovery factor with time, at least for methods that utilize relatively lower injection time ratios.

Fig. 4 is a flowchart depicting methods 100, according to the present disclosure, for recovering viscous hydrocarbons from a subterranean formation. Methods 100 may include forming one or more wells at 105 and include injecting a heated solvent vapor stream at 110 and fluidly contacting viscous hydrocarbons with the heated solvent vapor stream at 115. Methods 100 also may include condensing the heated solvent vapor stream at 120, accumulating chamber liquid at 125, monitoring a liquid level variable at 130, and/or ceasing injection of the heated solvent vapor stream at 135. Methods 100 also include injecting a steam stream at 140 and may include ceasing injection of the steam stream at 145 and/or draining mobilized viscous hydrocarbons at 150. Methods 100 further include producing a produced fluid stream at 155 and may include reducing a volume of chamber liquid at 165, maintaining a target operating pressure

at 170, and/or monitoring a composition variable at 175. Methods 100 also include repeating the methods for a plurality of injection cycles at 180.

Forming one or more wells at 105 may include forming any suitable type, number, and/or configuration of well in any suitable manner. The well may form a portion of a hydrocarbon production system, such as hydrocarbon production system 10 of Fig. 1. Examples of the well include an injection well and/or a production well. The injection well, when formed, may include a horizontal, or an at least substantially horizontal, region and/or portion. Similarly, the production well, when formed, may include a horizontal, or at least substantially horizontal, region and/or portion. As illustrated in Fig. 1, the horizontal region of the production well may extend below, vertically below, and/or at a greater depth within the subterranean formation when compared to the horizontal region of the injection well. Figs. 5-8 are schematic cross-sectional views illustrating examples of injection wells 30 and/or production wells 40 that may be formed during the forming at 105.

Injecting the heated solvent vapor stream at 110 may include injecting any suitable heated solvent vapor stream into the subterranean formation and/or into a heated chamber that extends within the subterranean formation. The injecting at 110 may include injecting with, via, and/or utilizing the injection well and/or the horizontal region of the injection well.

The injecting at 110 also may include injecting for a heated solvent vapor injection time period. Examples of the heated solvent vapor injection time period include heated solvent vapor injection time periods of at least 0.1 days, at least 0.25 days, at least 0.5 days, at least 1 day, at least 2 days, at least 3 days, at least 4 days, at least 5 days, at least 6 days, at least 8 days, at least 10 days, at least 15 days, at least 20 days, at least 25 days, and/or at least 30 days. Additional examples of the heated solvent vapor injection time period include heated solvent

vapor injection time periods of at most 45 days, at most 40 days, at most 35 days, at most 30 days, at most 25 days, at most 20 days, at most 15 days, at most 10 days, and/or at most 5 days.

The heated solvent vapor stream may have and/or define any suitable composition or chemical composition that includes at least 50 weight percent nonaqueous species, which also
5 may be referred to herein as a solvent. The nonaqueous species non-negligibly solubilizes and/or dissolves the viscous hydrocarbons and may include a hydrocarbon, or a hydrocarbon solvent, examples of which are disclosed herein. As an example, the heated solvent vapor stream may consist of, or consist essentially of the nonaqueous species. As another example, the heated solvent vapor stream may include at least a threshold fraction of the nonaqueous species.
10 Examples of the threshold fraction of nonaqueous species include threshold fractions of at least 50 weight percent (wt%), at least 51 wt%, at least 60 wt%, at least 70 wt%, at least 80 wt%, at least 90 wt%, at least 95 wt%, and/or at least 99 wt%. As more specific examples, the heated solvent vapor stream and/or the nonaqueous species may include, consist of, and/or consist essentially of one or more of a hydrocarbon, a hydrocarbon solvent, an alkane, an alkene, an
15 alkyne, an aliphatic compound, a naphthenic compound, an aromatic compound, an olefinic compound, natural gas condensate, liquefied petroleum gas, and/or a crude oil refinery stream.

The heated solvent vapor stream also may include water and/or steam. As an example, the heated solvent vapor stream may include an azeotropic, or a near-azeotropic, mixture of hydrocarbon solvent and water. Under these conditions, a solvent molar fraction of the
20 hydrocarbon solvent in the near-azeotropic mixture may be 70%-130% of an azeotropic molar fraction of the near-azeotropic mixture at the target operating pressure within the heated chamber.

It is within the scope of the present disclosure that a bubble point temperature of the heated solvent vapor stream at the target operating pressure within the heated chamber may be less than a bubble point temperature of the steam stream at the target operating pressure within the heated chamber. As such, and as discussed in more detail herein, the injecting at 140 may
5 facilitate vaporization of condensed solvent within the heated chamber.

It is within the scope of the present disclosure that the injecting at 110 may be performed in a manner that is similar to that of more conventional solvent-based thermal recovery processes. As examples, the injecting at 110 may be performed in a manner that is similar to, or may be performed as part of, a heated vapor extraction process, an azeotropic heated vapor
10 extraction process, and/or a near-azeotropic heated vapor extraction process.

The injecting at 110 is illustrated schematically in Fig. 5. As illustrated therein, an injectant stream 60, in the form of a heated solvent vapor stream 62, may be injected into subterranean formation 24 and/or into heated chamber 50 via an injection well 30.

Fluidly contacting viscous hydrocarbons with the heated solvent vapor stream at 115 may
15 include fluidly contacting to produce and/or generate mobilized viscous hydrocarbons within the heated chamber. This may be accomplished in any suitable manner. As examples, the fluidly contacting at 115 may include one or more of diluting the viscous hydrocarbons with the heated solvent vapor stream to generate the mobilized viscous hydrocarbons, dissolving the viscous hydrocarbons in the heated solvent vapor stream to generate the mobilized viscous hydrocarbons,
20 and/or heating the viscous hydrocarbons with the heated solvent vapor stream to generate the mobilized viscous hydrocarbons.

The fluidly contacting at 115 also is schematically illustrated in Fig. 5. Therein, heated solvent vapor stream 62 may flow, within the heated chamber, to an interface region 52 between

the heated chamber and the subterranean formation, may interact with viscous hydrocarbons 26 that are present within subterranean formation 24, and may generate a chamber liquid 70. Chamber liquid 70 may include and/or be mobilized viscous hydrocarbons 72 and/or condensed solvent 78.

5 Condensing the heated solvent vapor stream at 120 may include condensing the heated solvent vapor stream to produce and/or form condensed solvent and/or to form the chamber liquid that includes both the condensed solvent and the mobilized viscous hydrocarbons. The condensing at 120 may be facilitated by, responsive to, and/or a result of the fluidly contacting at 115. As an example, and as discussed, the fluidly contacting at 115 may include heating the
10 viscous hydrocarbons to generate the mobilized viscous hydrocarbons. Under these conditions, heating of the viscous hydrocarbons may be accompanied by a corresponding decrease in a temperature of the heated solvent vapor stream, thereby causing the heated solvent vapor stream to release its heat of condensation and transition from the vapor phase to the liquid phase.

 Additionally or alternatively, the condensing at 120 may be facilitated by, responsive to,
15 and/or a result of thermal and/or fluid contact between the heated solvent vapor stream and subterranean strata that extends within the heated chamber. As an example, thermal and/or fluid contact between the heated solvent vapor stream and the subterranean strata may facilitate thermal energy transfer from the heated solvent vapor stream to the subterranean strata, thereby causing the heated solvent vapor stream to condense on the subterranean strata and generate the
20 condensed solvent.

 Accumulating chamber liquid at 125 may include accumulating the chamber liquid within the heated chamber. This may include accumulating the chamber liquid, which may include both the condensed solvent and the mobilized viscous hydrocarbons, to form a chamber

liquid pool within the heated chamber. Additionally or alternatively, the accumulating at 125 may include accumulating the chamber liquid such that, or until, the at least substantially horizontal region of the injection well is at least partially immersed, is immersed, is completely immersed, is at least partially covered, is covered, and/or is completely covered by the chamber liquid and/or within the chamber liquid pool.

Stated another way, the accumulating at 125 may include accumulating such that the at least substantially horizontal region of the injection well is below, or is a threshold distance below, an upper surface of the chamber liquid pool. Examples of the threshold distance include threshold distances of at least 0.5 meters, at least 1 meter, at least 2 meters, at least 3 meters, at least 4 meters, at most 8 meters, at most 6 meters, and/or at most 4 meters.

The accumulating at 125 may be accomplished in any suitable manner. As an example, methods 100 may include ceasing the producing at 160, such as to bring about, or facilitate, the accumulating at 125. As another example, methods 100 may include regulating a production rate of a produced chamber liquid that is produced during the producing at 155 to bring about, or facilitate, the accumulating at 125. As a more specific example, the accumulating at 125 may include increasing the production rate of the produced chamber liquid responsive to the upper surface of the chamber liquid pool being above, or being greater than the threshold distance above, the at least substantially horizontal region of the injection well. As another more specific example, the accumulating at 125 may include decreasing the production rate of the produced chamber liquid responsive to the upper surface of the chamber liquid pool being below, or being less than the threshold distance above, the at least substantially horizontal region of the injection well.

The accumulating at 125 is schematically illustrated in Fig. 6. As illustrated therein, the accumulating at 125 may include accumulating chamber liquid 70 within heated chamber 50 such that the at least substantially horizontal region of injection well 30 is immersed within the chamber liquid and/or within a chamber liquid pool 74. The accumulating at 125 is illustrated in
5 Fig. 6 by the progression from an upper surface 76 of chamber liquid pool 74 being below injection well 30, as illustrated in dashed lines, to the upper surface of the chamber liquid pool approaching the injection well, as illustrated in dash-dot lines, to the upper surface of the chamber liquid pool being above the injection well, as illustrated in solid lines.

Monitoring the liquid level variable at 130 may include monitoring any suitable liquid
10 level variable that may be associated with and/or indicative of a location of the upper surface of the chamber liquid pool within the heated chamber. When methods 100 include the monitoring at 130, the accumulating at 125 may be performed based, at least in part, on the liquid level variable. As an example, the accumulating at 125 may include increasing a height of a liquid level of the chamber liquid pool and/or a depth of the chamber liquid pool, within the heated
15 chamber, until the monitoring at 130 indicates that the at least substantially horizontal region of the injection well is immersed within the chamber liquid. Examples of the liquid level variable include one or more of a pressure within the heated chamber, a pressure differential within the heated chamber, a pressure differential between the injection well and the production well, a pressure differential between two different depths within the heated chamber, a temperature
20 within the heated chamber, a temperature differential within the heated chamber, a production temperature of the produced fluid stream, a temperature differential between a temperature of the heated solvent vapor stream and a temperature of the produced fluid stream, a temperature differential between the temperature of the produced fluid stream and a bubble point temperature

of the heated solvent vapor stream, a temperature differential between the temperature of the produced fluid stream and a dew point temperature of the heated solvent vapor stream, a comparison between the temperature within the heated chamber and an estimated bubble point temperature of the chamber liquid, a change in a production temperature of mobilized viscous hydrocarbons, the production temperature of the mobilized viscous hydrocarbons, and/or a water-to-hydrocarbon ratio within the produced chamber liquid.

10 Ceasing injection of the heated solvent vapor stream at 135 may be performed with any suitable timing within methods 100 and/or in any suitable manner. As an example, the ceasing at 135 may include ceasing injection of the heated solvent vapor stream subsequent to the heated solvent vapor injection time period and/or subsequent to performing the injecting at 110 for the heated solvent vapor injection time period. As another example, the ceasing at 135 may include ceasing injection of the heated solvent vapor stream prior to the steam injection time period and/or prior to initiation of the injecting at 140.

15 Injecting the steam stream at 140 may include injecting the steam stream via the at least substantially horizontal region of the injection well and/or into the heated chamber. The injecting at 140 may include injecting the steam stream subsequent to performing the injecting at 110, injecting the steam stream subsequent to the heated solvent vapor injection time period, and/or injecting the steam stream for a steam injection time period.

20 It is within the scope of the present disclosure that the injecting at 140 may include vaporizing, or injecting the steam stream to vaporize, at least a fraction of the condensed solvent that is present within the heated chamber. Additionally or alternatively, the injecting at 140 may include vaporizing, or injecting the steam stream to vaporize, at least a fraction of the chamber liquid that may extend within the heated chamber and/or that may define the chamber liquid

pool. This may include vaporizing the condensed solvent and/or the chamber liquid to produce and/or generate vaporized solvent.

As discussed herein, the heated chamber may include and/or define an interface region that extends between the heated chamber and a remainder of the subterranean formation. Under these conditions, the injecting at 140 may include injecting the steam stream to facilitate, or provide a motive force for, flow of the heated solvent vapor stream and/or the vaporized solvent toward and/or into contact with the interface region.

This is illustrated schematically in Fig. 7. As illustrated therein, injection of a steam stream 64 into heated chamber 50 via injection well 30 may increase a pressure within a region 54 of heated chamber 50 that is proximal to injection well 30 and/or may vaporize condensed solvent within region 54. This increased pressure may cause heated solvent vapor stream 62 and/or vaporized solvent 66 to flow toward interface region 52, thereby increasing an effectiveness of the injected solvent in recovering viscous hydrocarbons 26 from the subterranean formation. Additionally or alternatively, the injecting at 140 may include flushing condensed solvent 78 from heated chamber 50, facilitating flow of the condensed solvent from the heated chamber, and/or facilitating condensation of the heated solvent vapor stream within the interface region. As discussed herein, the steam injection time may be selected such that region 54 does not extend into contact with interface region 52 and/or such that injected solvent, in the form of heated solvent vapor stream 62, vaporized solvent 66, and/or condensed solvent 78, contacts interface region 52 to a greater extent when compared to steam stream 64.

When methods 100 include the accumulating at 125, the injecting at 140 additionally or alternatively may include injecting, or initiating the injecting, subsequent to the accumulating at 125 and/or subsequent to the at least substantially horizontal region of the injection well being

immersed within the chamber liquid. Stated another way, the accumulating at 125 may be performed prior to the injecting at 140. Under these conditions, the injecting at 140 may include injecting such that the steam stream contacts, directly contacts, flows through, and/or bubbles through at least a region of the chamber liquid pool. Additionally or alternatively, the injecting
5 at 140 may include injecting such that the steam stream vaporizes at least a fraction of the chamber liquid, such as the condensed solvent, from the chamber liquid pool. When methods 100 include the accumulating at 125, methods 100 further may include maintaining the at least substantially horizontal region of the injection well immersed within the chamber pool during the injecting at 140, during the steam injection time period, during at least a substantial
10 fraction of the steam injection time period, during a majority of the steam injection time period, and/or during an entirety of the steam injection time period.

This is illustrated schematically in Fig. 8. As illustrated therein, injection well 30 may be immersed within chamber liquid pool 74 during the injecting at 140. As such, the injecting at 140 may include contacting steam stream 64 with chamber liquid 70 within chamber liquid
15 pool 74. This contact between the steam stream and the chamber liquid may facilitate thermal energy transfer from the steam stream to the chamber liquid, vaporization of condensed solvent 78 from the chamber liquid, and/or generation of vaporized solvent 66.

It is within the scope of the present disclosure that methods 100 may transition between the injecting at 110 to the injecting at 140 based upon any suitable criteria. As an example, the
20 heated solvent vapor injection time period may be a predetermined, or fixed, heated solvent vapor injection time period. Under these conditions, methods 100 may transition from the injecting at 110 to the injecting at 140 subsequent to, or subsequent to expiration of, the heated solvent vapor injection time period.

Additionally or alternatively, the heated solvent vapor injection time period may be determined and/or established based, at least in part, upon one or more properties and/or variables that may be determined and/or measured during methods 100. Stated another way, methods 100 may transition from the injecting at 110 to the injecting at 140 based, at least in part, on the one or more properties and/or variables. Examples of the one or more properties and/or variables include a change in a production rate of mobilized viscous hydrocarbons from the subterranean formation during the producing at 155; in the production rate, or a magnitude of the production rate, of the mobilized viscous hydrocarbons; in a concentration of solvent in the mobilized viscous hydrocarbons produced from the subterranean formation; in the concentration, or a magnitude of the concentration, of the solvent, and/or in a temperature within the heated chamber.

The steam injection time period may have any suitable duration. As examples, the steam injection time period may be at least 0.1 days, at least 0.25 days, at least 0.5 days, at least 0.75 days, at least 1 day, at least 1.5 days, at least 2 days, at least 3 days, at least 4 days, at least 5 days, at least 6 days, at least 8 days, at least 10 days, and/or at least 15 days. Additionally or alternatively, the steam injection time period may be at most 15 days, at most 10 days, at most 8 days, at most 6 days, at most 5 days, at most 4 days, at most 3 days, at most 2 days, and/or at most 1 day.

Additionally or alternatively, the heated solvent vapor injection time period and the steam injection time period may have any suitable relative magnitude. As an example, method 100 may define an injection time ratio of the heated solvent vapor injection time period to the steam injection time period. Examples of the injection time ratio include injection time ratios of at least 1, at least 2, at least 3, at least 4, at least 5, at least 6, at least 8, at least 10, at least 15, at

least 20, at least 25, at least 30, at least 40, and/or at least 50. Additionally or alternatively, the injection time ratio may be at most 100, at most 80, at most 60, at most 50, at most 40, at most 30, at most 25, at most 20, at most 15, and/or at most 10. The injection time ratio may be selected to prevent, or to decrease a potential for, fluid contact between the steam stream and the interface region.

Additionally or alternatively, methods 100 may define an injection mass ratio. As an example, the injecting at 110 may include injecting a mass of heated solvent vapor, the injecting at 140 may include injecting a mass of steam, and the injection mass ratio may be a ratio of the mass of heated solvent vapor to the mass of steam. The injecting at 110 and the injecting at 140 may be performed such that the injection mass ratio has any suitable value, or magnitude. As examples, the injection mass ratio may be at least 1, at least 1.25, at least 1.5, at least 2, at least 3, at least 4, at least 6, at least 8, at least 10, at least 12.5, at least 15, at least 20, at least 25, and/or at least 30. Additionally or alternatively, the injection mass ratio may be at most 100, at most 80, at most 60, at most 50, at most 40, at most 30, at most 25, at most 20, at most 15, and/or at most 10.

The injecting at 140 may include injecting a steam stream with any suitable composition. As an example, the steam stream may include, may consist of, and/or may consist essentially of steam and/or water. As another example, the steam stream may include, have, and/or define at least a threshold fraction of steam. Examples of the threshold fraction of steam include threshold fractions of at least 51 wt%, at least 60 wt%, at least 70 wt%, at least 80 wt%, at least 90 wt%, at least 95 wt%, and/or at least 99 wt%.

Ceasing injection of the steam stream at 145 may include ceasing supply of the steam stream to the subterranean formation and/or to the heated chamber via the injection well. Stated another way, the ceasing at 145 may include ceasing the injecting at 140.

5 The ceasing at 145 may be performed subsequent to the steam injection time period and/or prior to the repeating at 180. Stated another way, and within a given injection cycle of the plurality of injection cycles, the ceasing at 145 may be performed prior to performing the injecting at 110 for a subsequent injection cycle of the plurality of injection cycles.

10 Draining mobilized viscous hydrocarbons at 150 may include draining the mobilized viscous hydrocarbons under the influence of gravity. This may include draining the mobilized viscous hydrocarbons toward and/or into a lower region of the heated chamber that includes the at least substantially horizontal region of the production well. Additionally or alternatively, the draining at 150 may include draining the mobilized viscous hydrocarbons toward and/or into the production well. This is illustrated schematically in Figs. 5-8, with the arrows indicating drainage of chamber liquid 70, including mobilized viscous hydrocarbons 72 thereof, toward
15 production well 40.

Producing the produced fluid stream at 155 may include producing the chamber liquid, the mobilized viscous hydrocarbons, and/or the condensed solvent from the heated chamber and/or from the subterranean formation. This may include producing with, via, and/or utilizing the production well, or the at least substantially horizontal region of the production well. The
20 chamber liquid may be produced from the subterranean formation as a produced chamber liquid. Similarly, the mobilized viscous hydrocarbons may be produced from the subterranean formation as produced mobilized viscous hydrocarbons, and/or the condensed solvent may be produced from the subterranean formation as produced condensed solvent.

The producing at 155 may be performed with any suitable timing and/or sequence during methods 100. As an example, the producing at 155 may be performed during at least one injection cycle of the plurality of injection cycles. As another example, the producing at 155 may be performed during each injection cycle of the plurality of injection cycles. As yet another example, the producing at 155 may be performed during at least a portion of the heated solvent vapor injection time period, during an entirety of the heated solvent vapor injection time period, during the injecting at 110, during the fluidly contacting at 115, during at least a portion of the steam injection time period, during an entirety of the steam injection time period, and/or during the injecting at 140. Stated another way, it is within the scope of the present disclosure that methods 100 may include continuously performing the producing at 155 or intermittently performing the producing at 155. When methods 100 include intermittently performing the producing at 155, methods 100 may include ceasing the producing at 160 prior to the injecting at 140 and/or during the injecting at 140, such as to facilitate the accumulating at 125, when performed.

As discussed herein, the at least substantially horizontal region of the production well may extend within the heated chamber and below the at least substantially horizontal region of the injection well. It is within the scope of the present disclosure that the at least substantially horizontal region of the production well and the at least substantially horizontal region of the injection well may define any suitable spacing, or average spacing, therebetween. In addition, and when methods 100 include the forming at 105, the forming at 105 may include forming such that the at least substantially horizontal region of the production well and the at least substantially horizontal region of the injection well have and/or define the average spacing. Examples of the average spacing include average spacings of at least 1 meter, at least 2 meters,

at least 3 meters, at least 4 meters, at least 5 meters, at most 10 meters, at most 8 meters, at most 5 meters, at most 4 meters, at most 3 meters, and/or at most 2 meters.

Reducing the volume of chamber liquid at 165 may include reducing the volume of chamber liquid within, or that defines, the chamber liquid pool. Stated another way, the reducing
5 at 165 may include reducing the volume of chamber liquid within the heated chamber. This may include reducing such that the at least substantially horizontal region of the injection well extends above, or is not immersed in, the chamber liquid pool.

The reducing at 165 may be performed at any suitable time and/or with any suitable sequence during methods 100. As an example, methods 100 may include performing the
10 reducing at 165 subsequent to performing the injecting at 140. As another example, and within each injection cycle of the plurality of injection cycles, methods 100 may include performing the reducing at 165 prior to performing the injecting at 110.

Maintaining the target operating pressure at 170 may include maintaining the target operating pressure in, or within, the heated chamber. This may include performing the injecting
15 at 110 at, or to maintain, the target operating pressure and/or performing the injecting at 140 at, or to maintain, the target operating pressure. Additionally or alternatively, the maintaining at 170 may include selectively varying a temperature of the heated solvent vapor stream and/or a temperature of the steam stream to maintain the target operating pressure within the heated chamber.

20 Monitoring the composition variable at 175 may include monitoring any suitable composition variable that may be associated with a solvent content of the produced chamber liquid. Examples of the composition variable include a density of the produced chamber liquid,

a viscosity of the produced chamber liquid, and/or a chemical composition of the produced chamber liquid.

When methods 100 include the monitoring at 175, methods 100 also may include selectively regulating the injecting at 110 based, at least in part, on the monitoring at 175. As an
5 example, methods 100 may include selectively regulating an injection rate of the heated solvent vapor stream based, at least in part, on the composition variable. This may include selectively increasing the injection rate of the heated solvent vapor stream responsive to a decrease in the solvent content of the produced chamber liquid and/or selectively increasing the injection rate of the heated solvent vapor stream responsive to an increase in the solvent content of the produced
10 chamber liquid.

When methods 100 include the monitoring at 175, methods 100 also may include selectively regulating the injecting at 140 based, at least in part, on the monitoring at 175. As an example, methods 100 may include selectively regulating an injection rate of the steam stream based, at least in part, on the composition variable. This may include selectively increasing the
15 injection rate of the steam stream responsive to an increase in the solvent content of the produced chamber liquid and/or selectively decreasing the injection rate of the steam stream responsive to a decrease in the solvent content of the produced chamber liquid.

When methods 100 include the monitoring at 175, methods 100 also may include selectively regulating the producing at 155 based, at least in part, on the monitoring at 175. As
20 an example, methods 100 may include selectively regulating a production rate of the chamber liquid based, at least in part, on the composition variable. This may include selectively increasing the production rate of the chamber liquid to decrease the volume of chamber liquid

within the heated chamber and/or selectively decreasing the production rate of the chamber liquid to increase the volume of the chamber liquid within the heated chamber.

Repeating the methods for the plurality of injection cycles at 180 may include repeating at least the injecting at 110, the fluidly contacting at 115, and the injecting at 140 during each of the plurality of injection cycles. Stated another way, methods 100 may include sequentially performing the injecting at 110, the fluidly contacting at 115, and the injecting at 140 for a plurality of distinct injection cycles. The repeating at 180 also may include repeating the producing at 155 during each of the plurality of injection cycles.

It is within the scope of the present disclosure that methods 100 may include transition from a given injection cycle of the plurality of injection cycles to a subsequent injection cycle of the plurality of injection cycles based upon any suitable criteria. As an example, methods 100 may transition from the given injection cycle to the subsequent injection cycle responsive to completion of the injecting at 140 and/or responsive to expiration of the steam injection time period. As another example, methods 100 may include ceasing the injecting at 140, and/or transitioning from the given injection cycle to the subsequent injection cycle, responsive to the composition variable associated with the solvent content of the produced chamber liquid indicating less than a threshold solvent content within the produced chamber liquid.

It also is within the scope of the present disclosure that methods 100 may include modifying the injecting at 110 and/or the injecting at 140 in a given injection cycle of the plurality of injection cycles relative to a prior injection cycle of the plurality of injection cycles. As an example, and as discussed herein, performing methods 100 may cause the heated chamber to grow, or expand, with time. As such, and responsive to an increase in a volume of the heated chamber, methods 100 may include increasing the injection time ratio in the given injection

cycle relative to the prior injection cycle. As additional examples, methods 100 may include modifying the injection time ratio in the given injection cycle relative to the prior injection cycle based, at least in part, on a change in a production rate of mobilized viscous hydrocarbons, on the production rate of mobilized viscous hydrocarbons, on a change in a concentration of solvent in the mobilized viscous hydrocarbons produced from the subterranean formation, on the concentration of the mobilized viscous hydrocarbons produced from the subterranean formation, on a temperature within the heated chamber, on a change in a production temperature of the mobilized viscous hydrocarbons, and/or on the production temperature of the mobilized viscous hydrocarbons.

In the present disclosure, several of the illustrative, non-exclusive examples have been discussed and/or presented in the context of flow diagrams, or flow charts, in which the methods are shown and described as a series of blocks, or steps. Unless specifically set forth in the accompanying description, it is within the scope of the present disclosure that the order of the blocks may vary from the illustrated order in the flow diagram, including with two or more of the blocks (or steps) occurring in a different order and/or concurrently.

As used herein, the term “and/or” placed between a first entity and a second entity means one of (1) the first entity, (2) the second entity, and (3) the first entity and the second entity. Multiple entities listed with “and/or” should be construed in the same manner, i.e., “one or more” of the entities so conjoined. Other entities may optionally be present other than the entities specifically identified by the “and/or” clause, whether related or unrelated to those entities specifically identified. Thus, as a non-limiting example, a reference to “A and/or B,” when used in conjunction with open-ended language such as “comprising” may refer, in one embodiment, to A only (optionally including entities other than B); in another embodiment, to B only (optionally

including entities other than A); in yet another embodiment, to both A and B (optionally including other entities). These entities may refer to elements, actions, structures, steps, operations, values, and the like.

As used herein, the phrase “at least one,” in reference to a list of one or more entities
5 should be understood to mean at least one entity selected from any one or more of the entities in the list of entities, but not necessarily including at least one of each and every entity specifically listed within the list of entities and not excluding any combinations of entities in the list of entities. This definition also allows that entities may optionally be present other than the entities specifically identified within the list of entities to which the phrase “at least one” refers, whether
10 related or unrelated to those entities specifically identified. Thus, as a non-limiting example, “at least one of A and B” (or, equivalently, “at least one of A or B,” or, equivalently “at least one of A and/or B”) may refer, in one embodiment, to at least one, optionally including more than one, A, with no B present (and optionally including entities other than B); in another embodiment, to at least one, optionally including more than one, B, with no A present (and optionally including
15 entities other than A); in yet another embodiment, to at least one, optionally including more than one, A, and at least one, optionally including more than one, B (and optionally including other entities). In other words, the phrases “at least one,” “one or more,” and “and/or” are open-ended expressions that are both conjunctive and disjunctive in operation. For example, each of the expressions “at least one of A, B, and C,” “at least one of A, B, or C,” “one or more of A, B, and
20 C,” “one or more of A, B, or C,” and “A, B, and/or C” may mean A alone, B alone, C alone, A and B together, A and C together, B and C together, A, B and C together, and optionally any of the above in combination with at least one other entity.

As used herein the terms “adapted” and “configured” mean that the element, component, or other subject matter is designed and/or intended to perform a given function. Thus, the use of the terms “adapted” and “configured” should not be construed to mean that a given element, component, or other subject matter is simply “capable of” performing a given function but that the element, component, and/or other subject matter is specifically selected, created, implemented, utilized, programmed, and/or designed for the purpose of performing the function. It is also within the scope of the present disclosure that elements, components, and/or other recited subject matter that is recited as being adapted to perform a particular function may additionally or alternatively be described as being configured to perform that function, and vice versa.

As used herein, the phrase, “for example,” the phrase, “as an example,” and/or simply the term “example,” when used with reference to one or more components, features, details, structures, embodiments, and/or methods according to the present disclosure, are intended to convey that the described component, feature, detail, structure, embodiment, and/or method is an illustrative, non-exclusive example of components, features, details, structures, embodiments, and/or methods according to the present disclosure. Thus, the described component, feature, detail, structure, embodiment, and/or method is not intended to be limiting, required, or exclusive/exhaustive; and other components, features, details, structures, embodiments, and/or methods, including structurally and/or functionally similar and/or equivalent components, features, details, structures, embodiments, and/or methods, are also within the scope of the present disclosure.

Industrial Applicability

The methods disclosed herein are applicable to the oil and gas industries.

It is believed that the disclosure set forth above encompasses multiple distinct inventions with independent utility. While each of these inventions has been disclosed in its preferred form, the specific embodiments thereof as disclosed and illustrated herein are not to be considered in a limiting sense as numerous variations are possible. The subject matter of the inventions includes
5 all novel and non-obvious combinations and subcombinations of the various elements, features, functions and/or properties disclosed herein. Similarly, where the claims recite “a” or “a first” element or the equivalent thereof, such claims should be understood to include incorporation of one or more such elements, neither requiring nor excluding two or more such elements.

It is believed that the following claims particularly point out certain combinations and
10 subcombinations that are directed to one of the disclosed inventions and are novel and non-obvious. Inventions embodied in other combinations and subcombinations of features, functions, elements and/or properties may be claimed through amendment of the present claims or presentation of new claims in this or a related application. Such amended or new claims, whether they are directed to a different invention or directed to the same invention, whether
15 different, broader, narrower, or equal in scope to the original claims, are also regarded as included within the subject matter of the inventions of the present disclosure.

CLAIMS

1. A method for recovering viscous hydrocarbons from a subterranean formation, the method comprising:

a plurality of injection cycles, wherein each injection cycle in the plurality of injection cycles includes:

- (i) injecting, via an at least substantially horizontal region of an injection well and for a heated solvent vapor injection time period, a heated solvent vapor stream into a heated chamber that extends within the subterranean formation, wherein the heated solvent vapor stream includes at least 50 weight percent nonaqueous species;
- (ii) fluidly contacting the viscous hydrocarbons with the heated solvent vapor stream to generate mobilized viscous hydrocarbons within the heated chamber; and
- (iii) subsequent to the heated solvent vapor injection time period and for a steam injection time period, injecting, via the at least substantially horizontal region of the injection well, a steam stream into the heated chamber; and

during at least one injection cycle of the plurality of injection cycles, producing the mobilized viscous hydrocarbons from the subterranean formation via an at least substantially horizontal region of a production well that extends within the heated chamber and below the at least substantially horizontal region of the injection well.

2. The method of claim 1, wherein the subterranean formation includes subterranean strata, which extend within the heated chamber, wherein the method further includes condensing the heated solvent vapor stream on the subterranean strata to generate condensed solvent, and

further wherein the injecting the steam stream includes vaporizing the condensed solvent to generate vaporized solvent.

3. The method of any one of claims 1-2, wherein the subterranean formation
5 includes an interface region, which extends between the heated chamber and a remainder of the subterranean formation, and further wherein the injecting the steam stream includes at least one of:

(i) facilitating flow of the heated solvent vapor stream into fluid contact with the interface region; and

10 (ii) facilitating flow of a/the vaporized solvent into fluid contact with the interface region.

4. The method of any one of claims 1-3, wherein the injecting the steam stream includes flushing condensed solvent from the heated chamber.

15 5. The method of claim 4, wherein the flushing includes facilitating flow of the condensed solvent from the subterranean formation via the production well.

6. The method of any one of claims 4-5, wherein the flushing includes facilitating
20 condensation of the heated solvent vapor stream within an/the interface region that extends between the heated chamber and a remainder of the subterranean formation.

7. The method of any one of claims 1-6, wherein the method defines an injection time ratio of the heated solvent vapor injection time period to the steam injection time period.

8. The method of claim 7, wherein, during each injection cycle of the plurality of injection cycles, the injection time ratio is one of:

- (i) at least 1;
- (ii) at least 2;
- (iii) at least 3;
- (iv) at least 4;
- (v) at least 5;
- (vi) at least 6;
- (vii) at least 8;
- (viii) at least 10;
- (ix) at least 15;
- (x) at least 20;
- (xi) at least 25;
- (xii) at least 30;
- (xiii) at least 40; and
- (xiv) at least 50.

9. The method of any one of claims 7-8, wherein the injection time ratio is at least 1 and one of:

- (i) at most 100;
- (ii) at most 80;
- 5 (iii) at most 60;
- (iv) at most 50;
- (v) at most 40;
- (vi) at most 30;
- (vii) at most 25;
- 10 (viii) at most 20;
- (ix) at most 15; and
- (x) at most 10.

10. The method of any one of claims 7-8, wherein the injection time ratio is selected to prevent fluid contact between the steam stream and an/the interface region that extends between the heated chamber and a remainder of the subterranean formation.

11. The method of any one of claims 7-10, wherein, responsive to an increase in a volume of the heated chamber, the method further includes increasing the injection time ratio in a given injection cycle of the plurality of injection cycles relative to a prior injection cycle of the plurality of injection cycles.

12. The method of any one of claims 7-11, wherein the method further includes modifying the injection time ratio for a/the given injection cycle of the plurality of injection cycles relative to a/the prior injection cycle of the plurality of injection cycles based, at least in part, on at least one of:

- 5 (i) a change in a production rate of mobilized viscous hydrocarbons;
- (ii) the production rate of mobilized viscous hydrocarbons;
- (iii) a change in a concentration of solvent in the mobilized viscous hydrocarbons
produced from the subterranean formation;
- (iv) the concentration of solvent in the mobilized viscous hydrocarbons produced from
10 the subterranean formation;
- (v) a change in a production temperature of the mobilized viscous hydrocarbons;
- (vi) the production temperature of the mobilized viscous hydrocarbons; and
- (vii) a temperature within the heated chamber.

15

13. The method of any one of claims 1-12, wherein the method further includes transitioning from the injecting the heated solvent vapor stream to the injecting the steam stream based, at least in part, on at least one of:

(i) a/the change in a production rate of mobilized viscous hydrocarbons;

5 (ii) the production rate of mobilized viscous hydrocarbons;

(iii) a/the change in a concentration of solvent in the mobilized viscous hydrocarbons produced from the subterranean formation;

(iv) the concentration of solvent in the mobilized viscous hydrocarbons produced from the subterranean formation;

10 (v) a/the change in a/the production temperature of the mobilized viscous hydrocarbons;

(vi) the production temperature of the mobilized viscous hydrocarbons; and

(vii) a/the temperature within the heated chamber.

15

14. The method of any one of claims 1-13, wherein the heated solvent vapor injection time period is one of:

- (i) at least 0.1 days;
- (ii) at least 0.25 days;
- 5 (iii) at least 0.5 days;
- (iv) at least 1 day;
- (v) at least 2 days;
- (vi) at least 3 days;
- (vii) at least 4 days;
- 10 (viii) at least 5 days;
- (ix) at least 6 days;
- (x) at least 8 days;
- (xi) at least 10 days;
- (xii) at least 15 days;
- 15 (xiii) at least 20 days;
- (xiv) at least 25 days; and
- (xv) at least 30 days.

15. The method of any one of claims 1-14, wherein the heated solvent vapor injection time period is at least 1 and one of:

- (i) at most 45 days;
- (ii) at most 40 days;
- 5 (iii) at most 35 days;
- (iv) at most 30 days;
- (v) at most 25 days;
- (vi) at most 20 days;
- (vii) at most 15 days;
- 10 (viii) at most 10 days; and
- (ix) at most 5 days.

16. The method of any one of claims 1-15, wherein the steam injection time period is one of:

- (i) at least 0.1 days;
- (ii) at least 0.25 days;
- 5 (iii) at least 0.5 days;
- (iv) at least 0.75 days;
- (v) at least 1 day;
- (vi) at least 1.5 days;
- (vii) at least 2 days;
- 10 (viii) at least 4 days;
- (ix) at least 6 days;
- (x) at least 8 days; and
- (xi) at least 10 days.

15

17. The method of any one of claims 1-16, wherein the steam injection time period is at least 1 and one of:

- (i) at most 15 days;
- (ii) at most 10 days;
- 5 (iii) at most 8 days;
- (iv) at most 6 days;
- (v) at most 5 days;
- (vi) at most 4 days;
- (vii) at most 3 days;
- 10 (viii) at most 2 days; and
- (ix) at most 1 day.

18. The method of any one of claims 1-17, wherein the injecting the heated solvent vapor stream includes injecting a mass of heated solvent vapor, and further wherein the injecting
15 the steam stream includes injecting a mass of steam.

19. The method of claim 18, wherein, during each injection cycle of the plurality of injection cycles, an injection mass ratio of the mass of heated solvent vapor to the mass of steam is one of:

- (i) at least 1.0;
- 5 (ii) at least 1.25;
- (iii) at least 1.5;
- (iv) at least 2.0;
- (v) at least 3;
- (vi) at least 4;
- 10 (vii) at least 6;
- (viii) at least 8;
- (ix) at least 10;
- (x) at least 12.5;
- (xi) at least 15;
- 15 (xii) at least 20;
- (xiii) at least 25; and
- (xiv) at least 30.

20. The method of any one of claims 1-19, wherein the method further includes
20 maintaining a target operating pressure within the heated chamber.

21. The method of claim 20, wherein the maintaining includes performing the injecting the heated solvent vapor stream and the injecting the steam stream at the target operating pressure.

5 22. The method of any one of claims 20-21, wherein the maintaining includes selectively varying at least one of a temperature of the heated solvent vapor stream and a temperature of the steam stream to maintain the target operating pressure.

23. The method of any one of claims 1-22, wherein the fluidly contacting includes
10 condensing the heated solvent vapor stream to form a chamber liquid that includes condensed solvent and the mobilized viscous hydrocarbons, wherein the producing includes producing at least a portion of the chamber liquid as a produced chamber liquid, and further wherein:

(i) prior to the injecting the steam stream, the method includes accumulating the chamber liquid within the heated chamber to form a chamber liquid pool within the heated
15 chamber and immersing the at least substantially horizontal region of the injection well within the chamber liquid pool; and

(ii) initiating the injecting the steam stream subsequent to the at least substantially horizontal region of the injection well being immersed within the chamber liquid pool.

20 24. The method of claim 23, wherein the accumulating includes accumulating such that the at least substantially horizontal region of the injection well is completely immersed within the chamber liquid pool.

25. The method of any one of claims 23-24, wherein the accumulating includes accumulating such that the at least substantially horizontal region of the injection well is a threshold distance below an upper surface of the chamber liquid pool.

- 5 26. The method of claim 25, wherein the threshold distance is at least one of:
- (i) at least 0.5 meters;
 - (ii) at least 1 meter;
 - (iii) at least 2 meters;
 - (iv) at least 3 meters;
 - 10 (v) at least 4 meters;
 - (vi) at most 8 meters;
 - (vii) at most 6 meters; and
 - (viii) at most 4 meters.

15 27. The method of any one of claims 23-26, wherein the accumulating includes regulating a production rate of the produced chamber liquid to increase a volume of the chamber liquid within the heated chamber.

28. The method of claim 27, wherein the regulating includes at least one of:

(i) increasing the production rate of the produced chamber liquid responsive to an/the upper surface of the chamber liquid pool being above the at least substantially horizontal region of the injection well;

5 (ii) increasing the production rate of the produced chamber liquid responsive to the upper surface of the chamber liquid pool being greater than a/the threshold distance above the at least substantially horizontal region of the injection well; and

(iii) decreasing the production rate of the produced chamber liquid responsive to the upper surface of the chamber liquid pool being below the at least substantially horizontal region
10 of the injection well.

29. The method of any one of claims 23-28, wherein the injecting the steam stream includes utilizing the steam stream to vaporize at least a fraction of the condensed solvent from the chamber liquid pool.

15

30. The method of any one of claims 23-29, wherein the method further includes monitoring a composition variable associated with a solvent content of the produced chamber liquid.

20

31. The method of claim 30, wherein the method further includes at least one of:

(i) selectively regulating an injection rate of the heated solvent vapor stream based, at least in part, on the composition variable; and

(ii) selectively regulating an injection rate of the steam stream based, at least in part,
5 on the composition variable.

32. The method of any one of claims 30-31, wherein the monitoring the composition variable includes at least one of:

(i) monitoring a density of the produced chamber liquid;

10 (ii) monitoring a viscosity of the produced chamber liquid; and

(iii) monitoring a chemical composition of the produced chamber liquid.

33. The method of any one of claims 23-32, wherein the method further includes monitoring a liquid level variable associated with a location of an/the upper surface of the
15 chamber liquid pool within the heated chamber, and further wherein the accumulating is based, at least in part, on the liquid level variable.

34. The method of claim 33, wherein the monitoring the liquid level variable includes at least one of:

(i) monitoring at least one pressure within the heated chamber;

5 (ii) monitoring a differential pressure between two different depths within the heated chamber;

(iii) monitoring at least one temperature within the heated chamber and comparing the at least one temperature to an estimated bubble point temperature of the chamber liquid;

(iv) monitoring a temperature differential within the heated chamber;

10 (v) monitoring a change in a production temperature of the mobilized viscous hydrocarbons;

(vi) monitoring the production temperature of the mobilized viscous hydrocarbons;

and

(vii) monitoring a water-to-hydrocarbon ratio within the produced chamber liquid.

15 35. The method of any one of claims 23-34, wherein, during the injecting the steam stream, the method includes maintaining the at least substantially horizontal region of the injection well immersed within the chamber liquid pool.

20 36. The method of any one of claims 23-35, wherein, subsequent to the injecting the steam stream, the method further includes reducing a volume of chamber liquid within the heated chamber such that the at least substantially horizontal region of the injection well extends above an/the upper surface of the chamber liquid pool.

37. The method of claim 36, wherein, within each injection cycle of the plurality of injection cycles, the method includes performing the reducing the volume of chamber liquid within the heated chamber prior to the injecting the heated solvent vapor stream.

5 38. The method of any one of claims 23-37, wherein the heated solvent vapor injection time period is at least one of:

- (i) a predetermined heated solvent vapor injection time period; and
- (ii) a fixed heated solvent vapor injection time period.

10 39. The method of any one of claims 23-38, wherein the method includes ceasing the injecting the steam stream responsive to a/the composition variable associated with a/the solvent content of the produced chamber liquid indicating less than a threshold solvent content in the produced chamber liquid.

15 40. The method of any one of claims 23-39, wherein the method includes ceasing the producing at least one of:

- (i) prior to the injecting the steam stream; and
- (ii) during the injecting the steam stream.

20

41. The method of any one of claims 23-40, wherein the heated solvent vapor injection time period is one of:

- (i) at least 1 day;
- (ii) at least 3 days;
- 5 (iii) at least 5 days;
- (iv) at least 10 days; and
- (v) at least 15 days.

42. The method of any one of claims 23-41, wherein the steam injection time period is one of:

- (i) at least 1 day;
- (ii) at least 3 days;
- (iii) at least 5 days;
- (iv) at least 10 days; and
- 15 (v) at least 15 days.

43. The method of any one of claims 1-42, wherein, subsequent to the heated solvent vapor injection time period, the method further includes ceasing the injecting the heated solvent vapor stream.

44. The method of any one of claims 1-43, wherein, prior to the steam injection time period, the method further includes ceasing the injecting the heated solvent vapor stream.

45. The method of any one of claims 1-44, wherein, subsequent to the steam injection time period, the method further includes ceasing the injecting the steam stream and resuming the injecting the heated solvent vapor stream.

5 46. The method of any one of claims 1-45, wherein the method further includes ceasing the injecting the steam stream during a given injection cycle of the plurality of injection cycles prior to performing the injecting the heated solvent vapor stream during a subsequent injection cycle of the plurality of injection cycles.

10 47. The method of any one of claims 1-46, wherein the injecting the heated solvent vapor stream includes injecting such that the heated solvent vapor stream includes at least a threshold fraction of nonaqueous species.

15 48. The method of claim 47, wherein the threshold fraction of nonaqueous species is one of:

- (i) at least 51 weight percent (wt%);
- (ii) at least 60 wt%;
- (iii) at least 70 wt%;
- (iv) at least 80 wt%;
- 20 (v) at least 90 wt%;
- (vi) at least 95 wt%; and
- (vii) at least 99 wt%.

49. The method of any one of claims 1-48, wherein the heated solvent vapor stream consists essentially of solvent.

50. The method of any one of claims 1-49, wherein the heated solvent vapor stream
5 includes at least one of:

- (i) a hydrocarbon;
- (ii) an alkane;
- (iii) an alkene;
- (iv) an alkyne;
- 10 (v) an aliphatic compound;
- (vi) a naphthenic compound;
- (vii) an aromatic compound;
- (viii) an olefinic compound;
- (ix) natural gas condensate;
- 15 (x) liquefied petroleum gas; and
- (xi) a crude oil refinery stream.

51. The method of any one of claims 1-50, wherein the heated solvent vapor stream includes at least one of water and steam.

20

52. The method of any one of claims 1-51, wherein the heated solvent vapor stream includes a near-azeotropic mixture of a hydrocarbon solvent and water.

53. The method of claim 52, wherein a solvent molar fraction of the hydrocarbon solvent in the near-azeotropic mixture is 70%-130% of an azeotropic solvent molar fraction of the near-azeotropic mixture at a target operating pressure within the heated chamber.

5 54. The method of any one of claims 1-53, wherein a bubble point temperature of the heated solvent vapor stream at a/the target operating pressure within the heated chamber is less than a bubble point temperature of the steam stream at the target operating pressure within the heated chamber.

10 55. The method of any one of claims 1-54, wherein the injecting the heated solvent vapor stream includes injecting as part of at least one of:

- (i) a heated vapor extraction process; and
- (ii) an azeotropic heated vapor extraction process.

15 56. The method of any one of claims 1-55, wherein the injecting the steam stream includes injecting such that the steam stream includes at least a threshold fraction of steam.

57. The method of claim 56, wherein the threshold fraction of steam is one of:

(i) at least 51 weight percent (wt%);

(ii) at least 60 wt%;

(iii) at least 70 wt%;

5 (iv) at least 80 wt%;

(v) at least 90 wt%;

(vi) at least 95 wt%; and

(vii) at least 99 wt%.

10 58. The method of any one of claims 1-57, wherein the steam stream consists essentially of steam.

59. The method of any one of claims 1-58, wherein the producing the mobilized viscous hydrocarbons includes at least one of:

15 (i) continuously producing the mobilized viscous hydrocarbons during the method;

and

(ii) intermittently producing the mobilized viscous hydrocarbons during the method.

60. The method of any one of claims 1-59, wherein the producing the mobilized viscous hydrocarbons includes one of:

(i) producing the mobilized viscous hydrocarbons during the injecting the heated solvent vapor stream;

5 (ii) producing the mobilized viscous hydrocarbons during the injecting the steam stream; and

(iii) producing the mobilized viscous hydrocarbons during both the injecting the heated solvent vapor stream and the injecting the steam stream.

10 61. The method of any one of claims 1-60, wherein the method further includes draining the mobilized viscous hydrocarbons, under the influence of gravity, at least one of:

(i) toward a lower region of the heated chamber that includes the at least substantially horizontal region of the production well; and

(ii) toward the at least substantially horizontal region of the production well.

15

62. The method of any one of claims 1-61, wherein the at least substantially horizontal region of the injection well and the at least substantially horizontal region of the production well define an average separation distance therebetween.

20

63. The method of claim 62, wherein the average separation distance is at least one of:

- (i) at least 1 meter;
- (ii) at least 2 meters;
- 5 (iii) at least 3 meters;
- (iv) at least 4 meters;
- (v) at least 5 meters;
- (vi) at most 10 meters;
- (vii) at most 8 meters;
- 10 (viii) at most 6 meters;
- (ix) at most 5 meters;
- (x) at most 4 meters;
- (xi) at most 3 meters; and
- (xii) at most 2 meters.

15

64. The method of any one of claims 1-63, wherein the method further includes at least one of:

- (i) forming the injection well; and
- (ii) forming the production well.

20

65. A method for recovering viscous hydrocarbons from a subterranean formation, the method comprising:

injecting, via an at least substantially horizontal region of an injection well, a heated solvent vapor stream into a heated chamber that extends within the subterranean formation;

5 fluidly contacting the viscous hydrocarbons with the heated solvent vapor stream and condensing the heated solvent vapor stream to generate mobilized viscous hydrocarbons within the heated chamber and to form a chamber liquid that includes condensed solvent and the mobilized viscous hydrocarbons;

10 accumulating the chamber liquid to form a chamber liquid pool within the heated chamber and to immerse the at least substantially horizontal region of the injection well within the chamber liquid pool;

subsequent to the accumulating, injecting, via the at least substantially horizontal region of the injection well, a steam stream into the heated chamber such that the steam stream directly contacts at least a region of the chamber liquid pool and vaporizes a fraction of the chamber
15 liquid from the chamber liquid pool;

during at least one of the injecting the heated solvent vapor stream, the fluidly contacting, and the injecting the steam stream, producing at least a portion of the chamber liquid, as a produced chamber liquid, from the subterranean formation via an at least substantially horizontal region of a production well that extends within the heated chamber and below the at least
20 substantially horizontal region of the injection well; and

sequentially repeating, for a plurality of injection cycles, the injecting the heated solvent vapor stream, the fluidly contacting, the injecting the steam stream, and the producing.

66. The method of claim 65, wherein the sequentially repeating, for a plurality of injection cycles, includes the accumulating.

67. The method of claim 65 in combination with any suitable step of any of the
5 methods of any of claims 1-64.



2/5

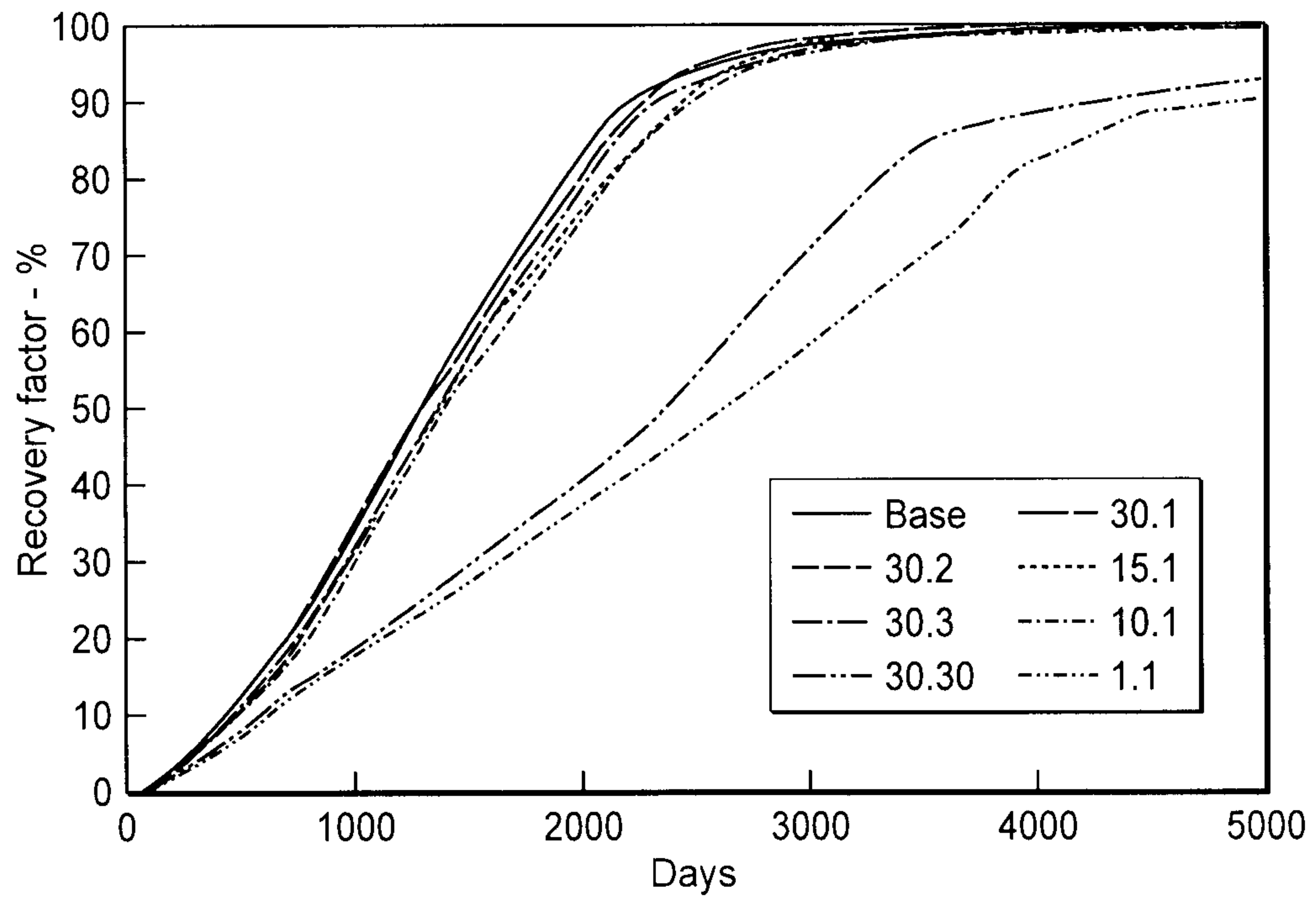


FIG. 2

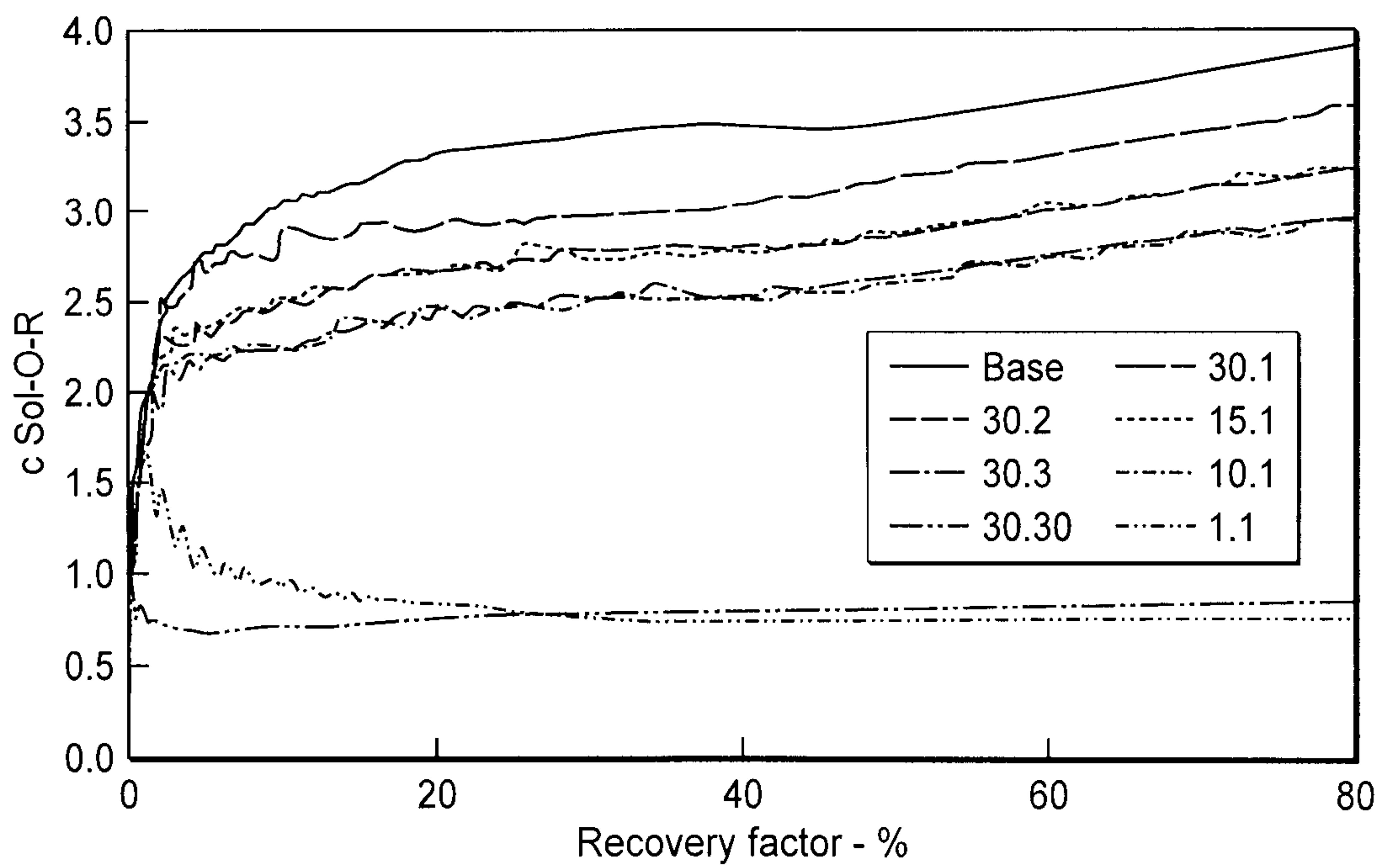


FIG. 3

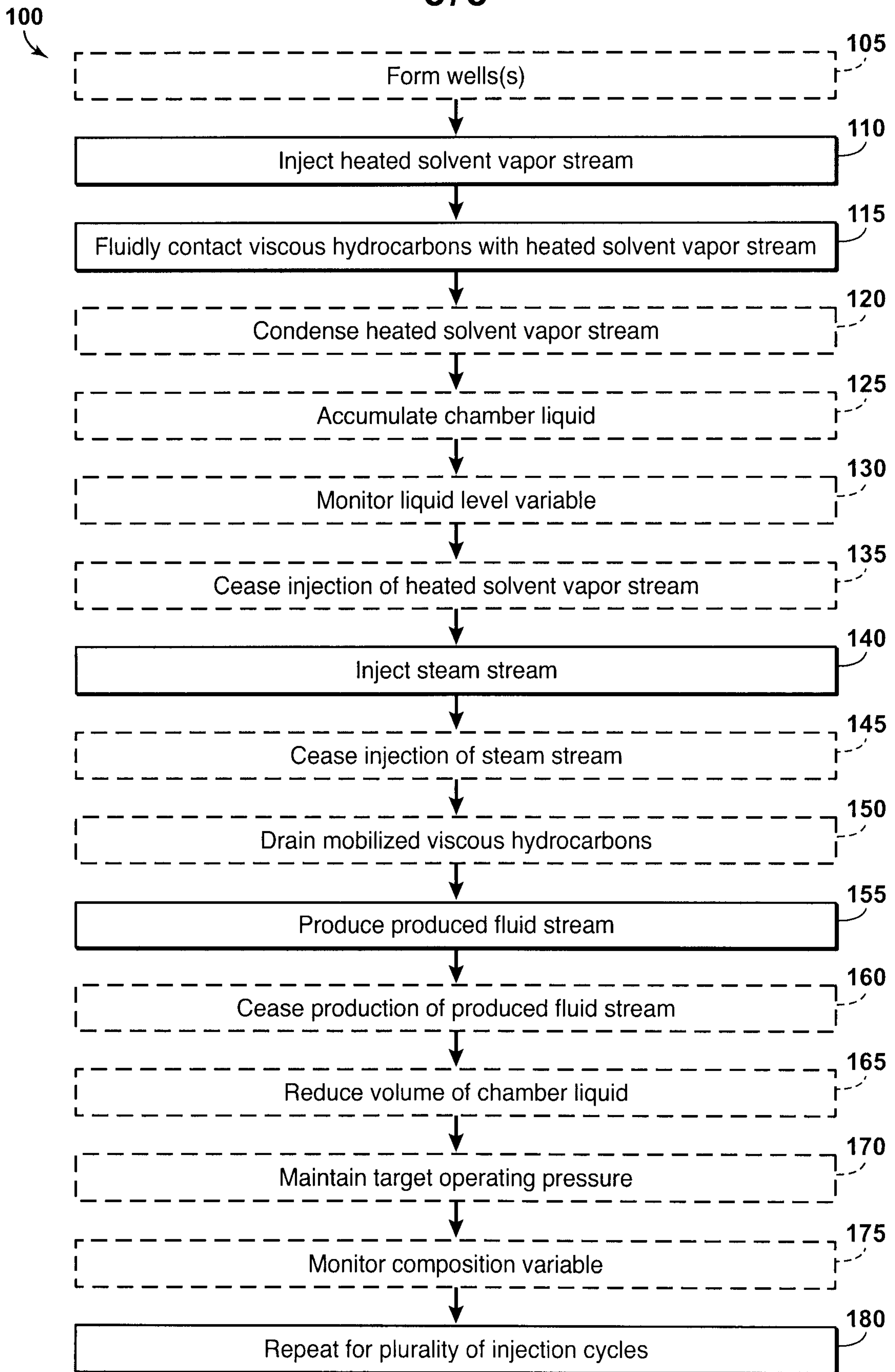


FIG. 4

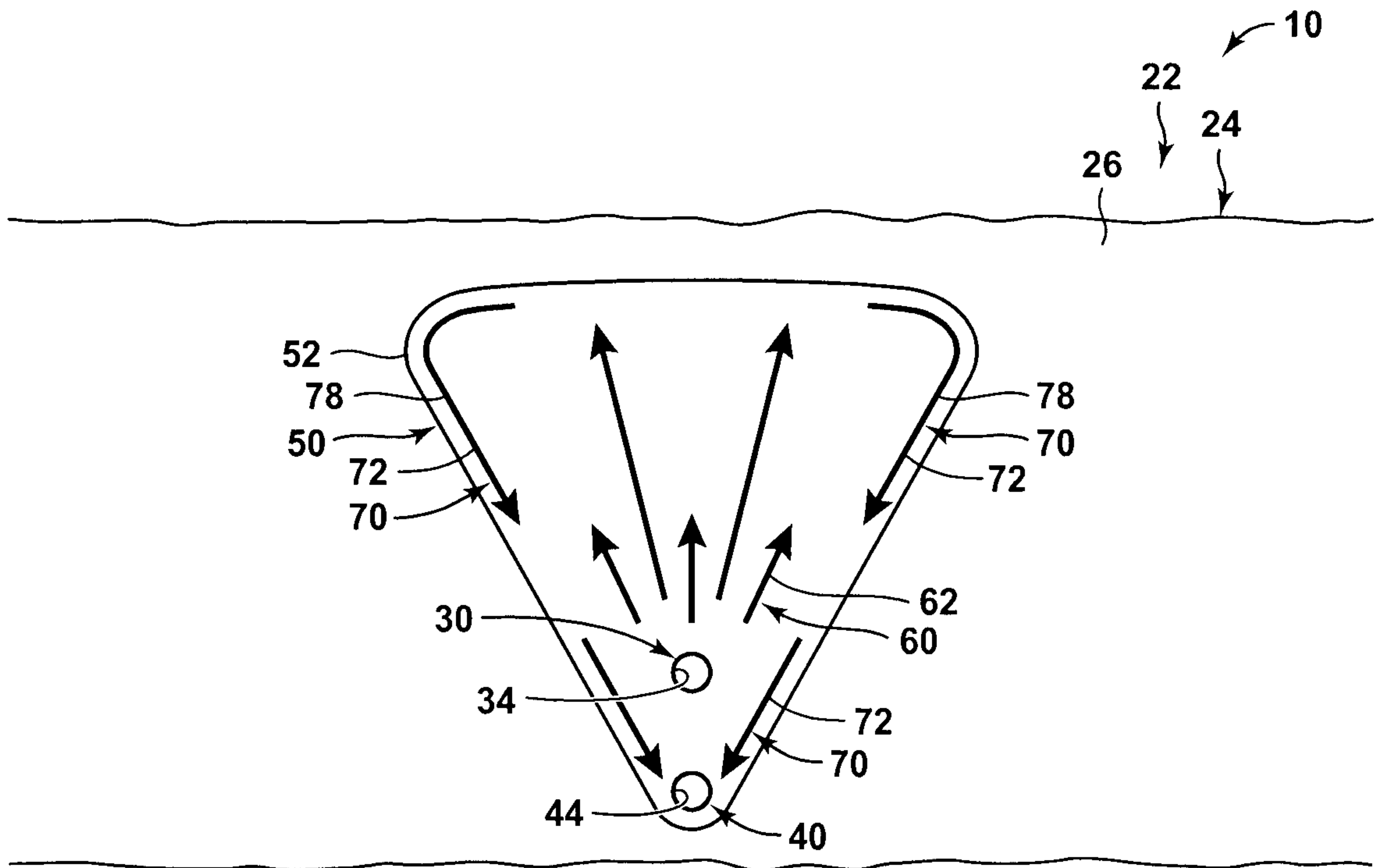


FIG. 5

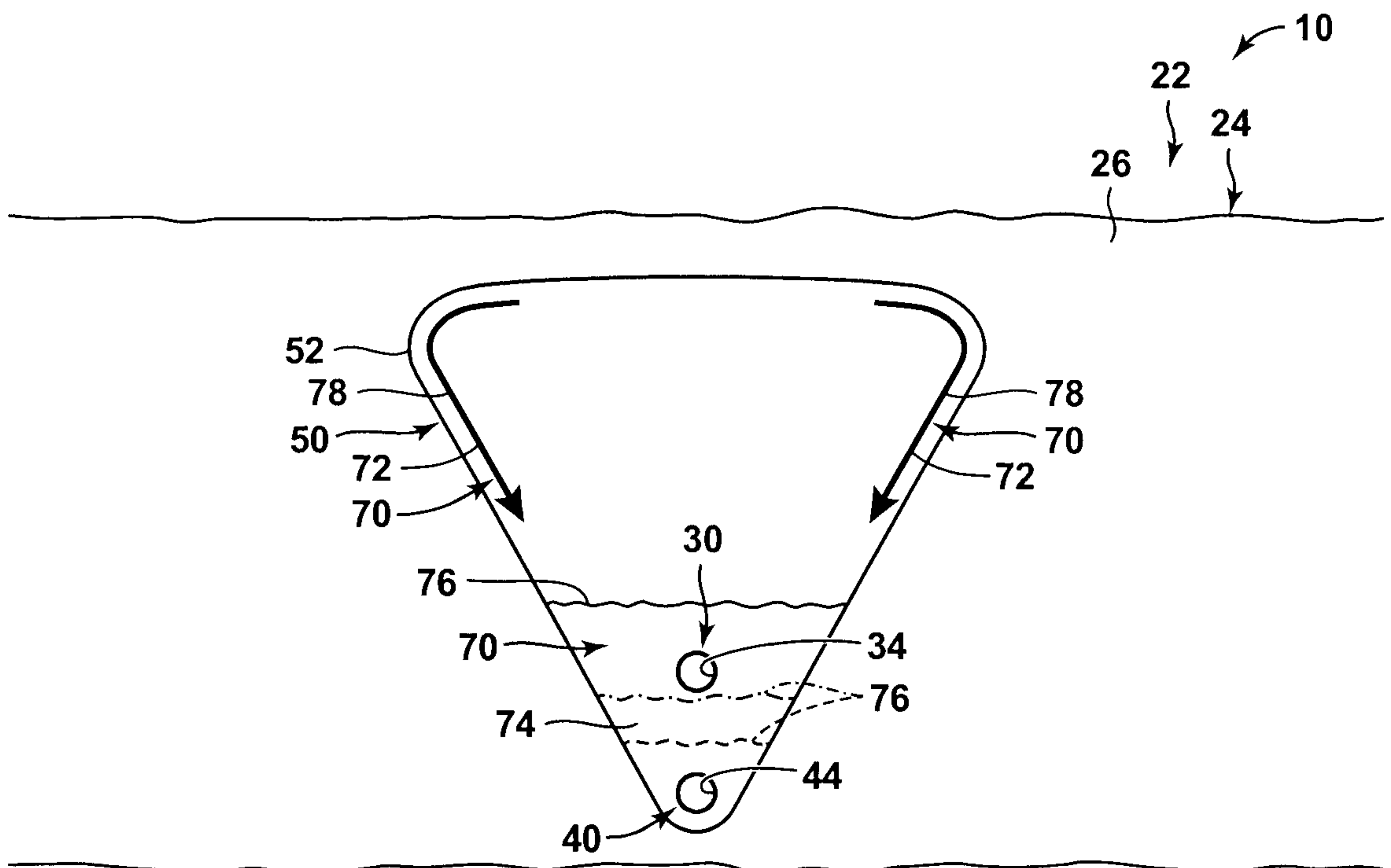


FIG. 6

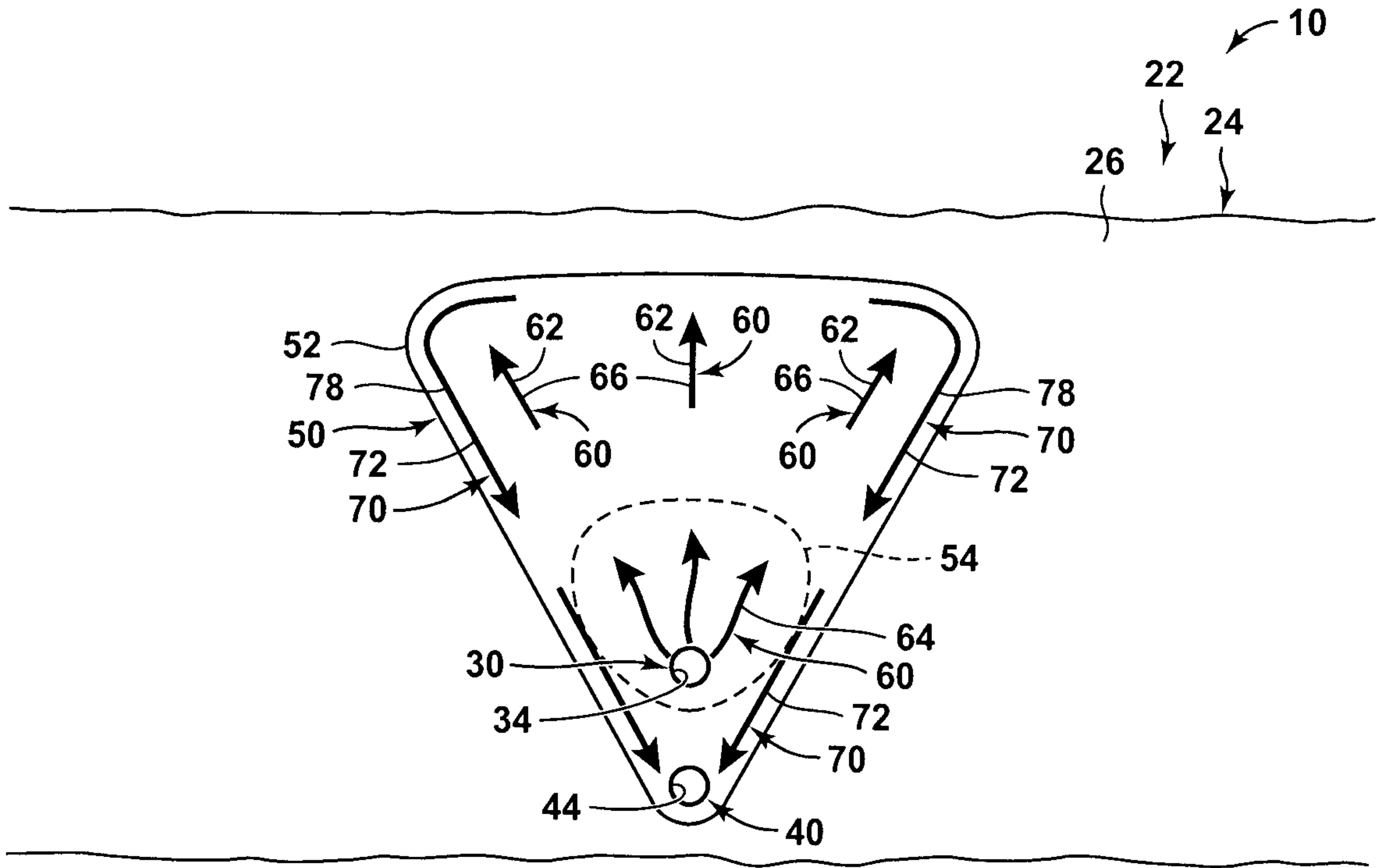


FIG. 7

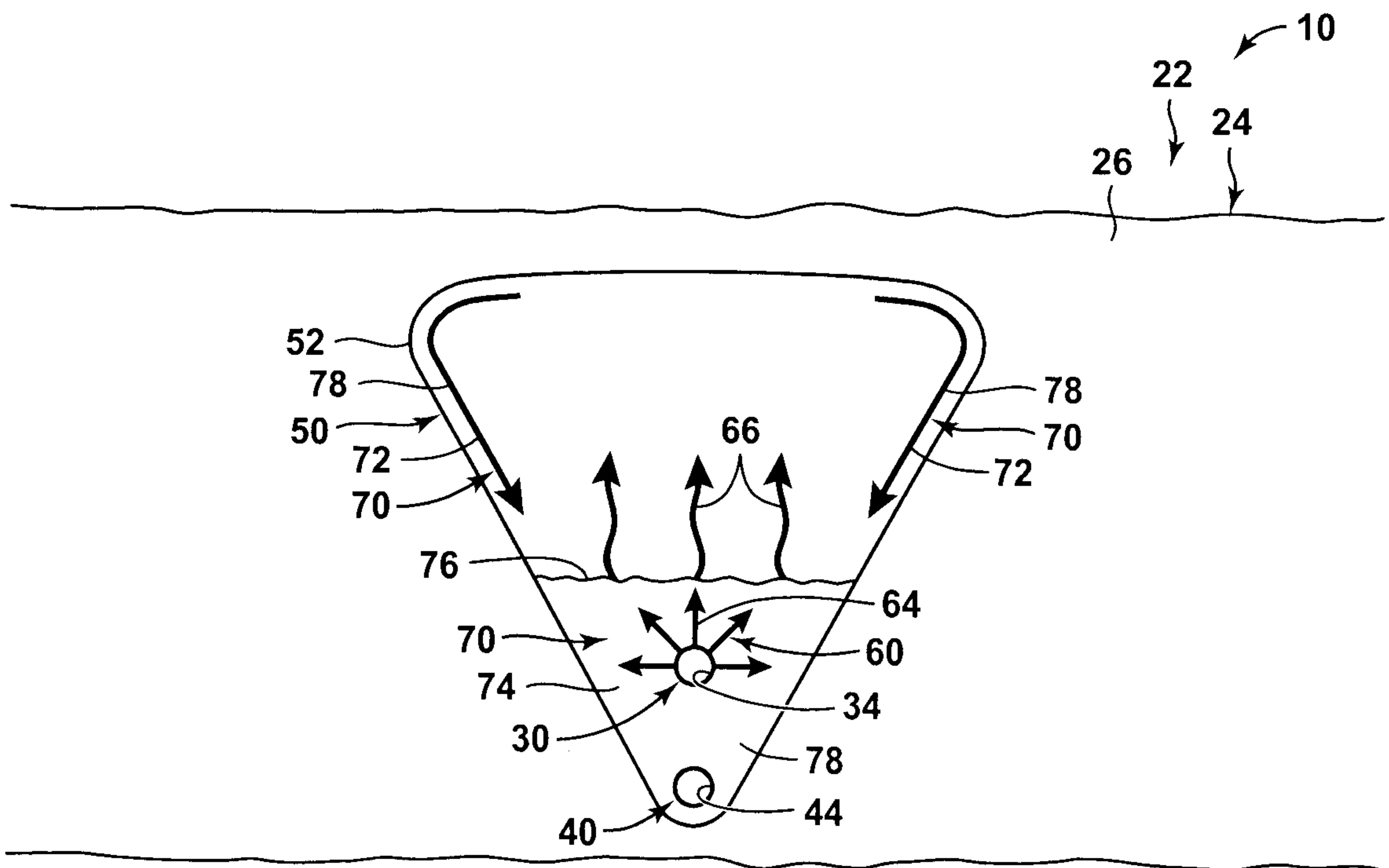


FIG. 8

