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(54) **METHOD OF AND SYSTEM FOR HYDROCARBON RECOVERY**

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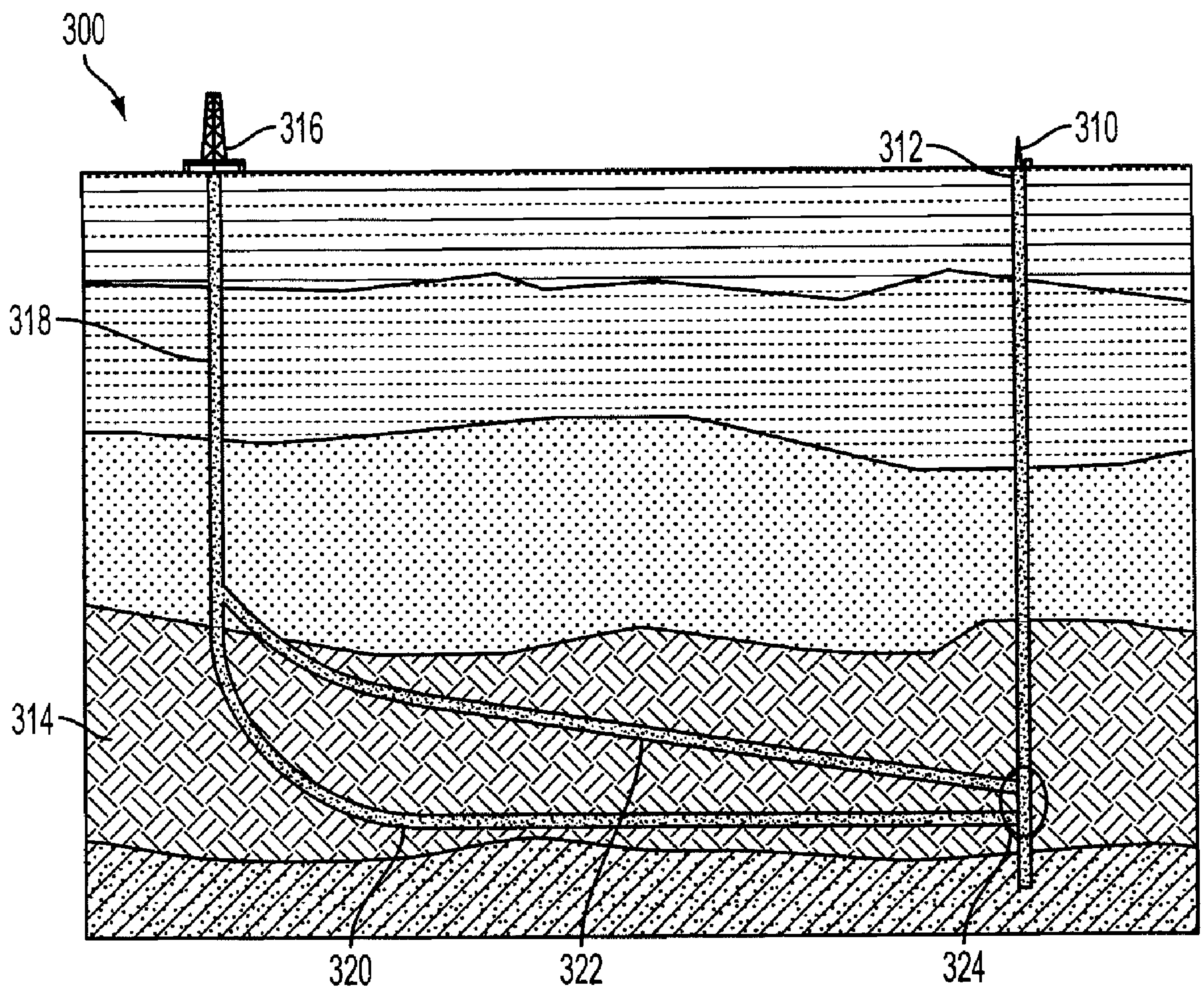
(52) **U.S. Cl.** **166/245**

(57) **ABSTRACT**

A method of recovering hydrocarbons from a subterranean reservoir. The method includes drilling a substantially-vertical primary production well, drilling a plurality of offset production wells generally around the substantially-vertical primary production well in a radial orientation, and drilling a plurality of offset injection wells generally around the substantially-vertical primary production well in a radial orientation. The method further includes injecting, via the plurality of offset injection wells, a liquid to mobilize the hydrocarbons from the subterranean reservoir and inducing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for secondary recovery and injecting, via the plurality of offset injection wells, a gas to mobilize the hydrocarbons from the subterranean reservoir and inducing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for tertiary recovery.



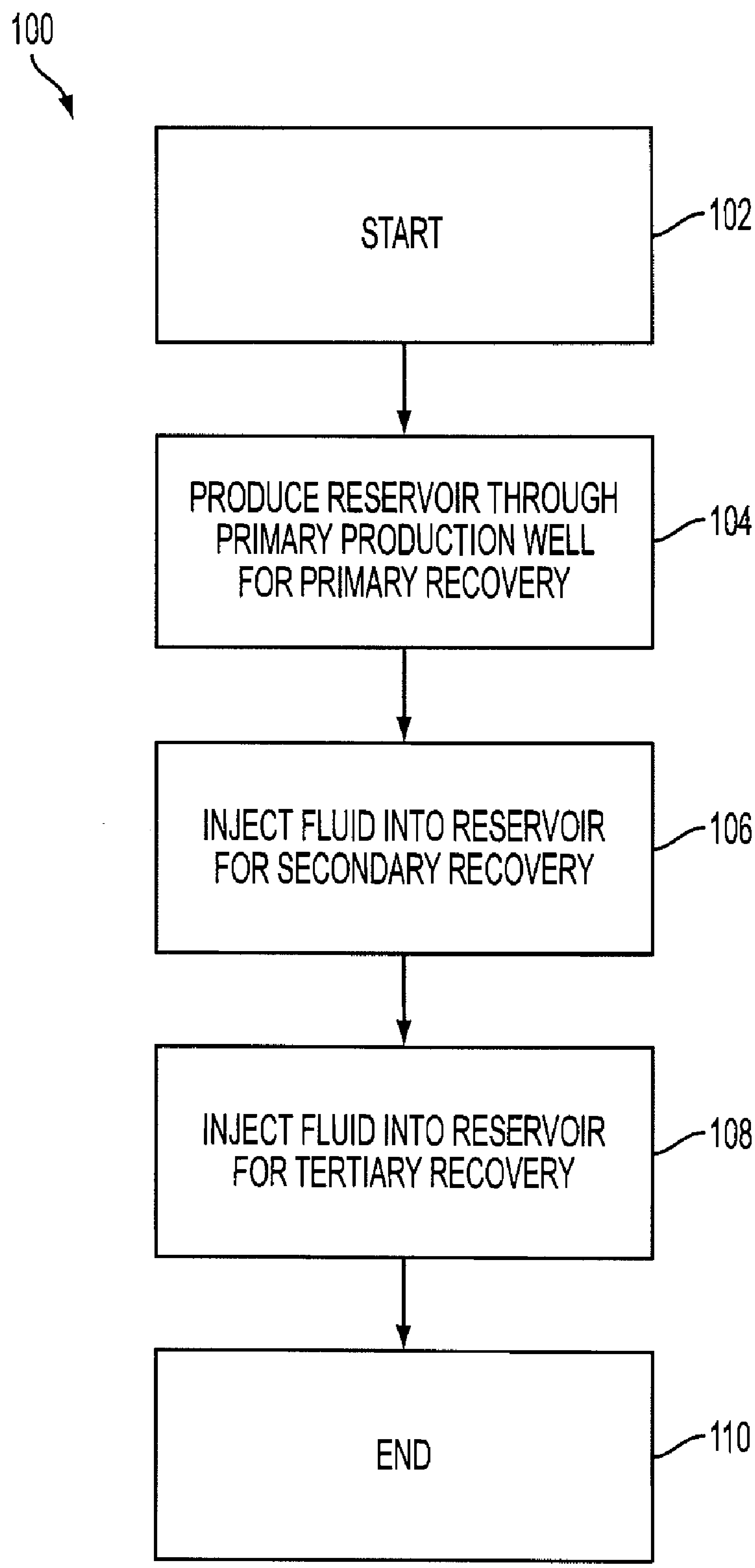

100
START
102
PRODUCE RESERVOIR THROUGH PRIMARY PRODUCTION WELL FOR PRIMARY RECOVERY
104
INJECT FLUID INTO RESERVOIR FOR SECONDARY RECOVERY
106
INJECT FLUID INTO RESERVOIR FOR TERTIARY RECOVERY
108
END
110

FIG. 1

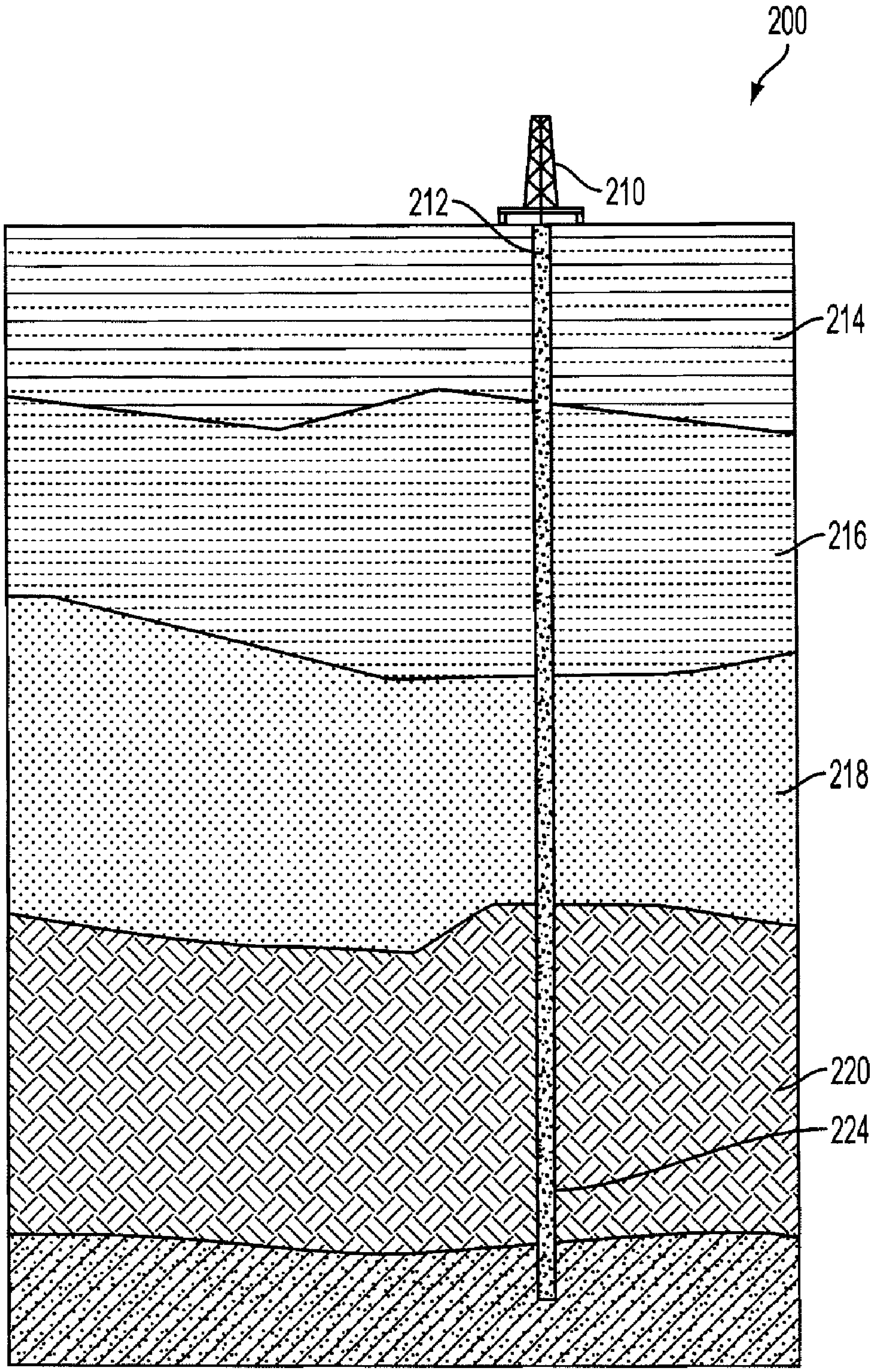


FIG. 2

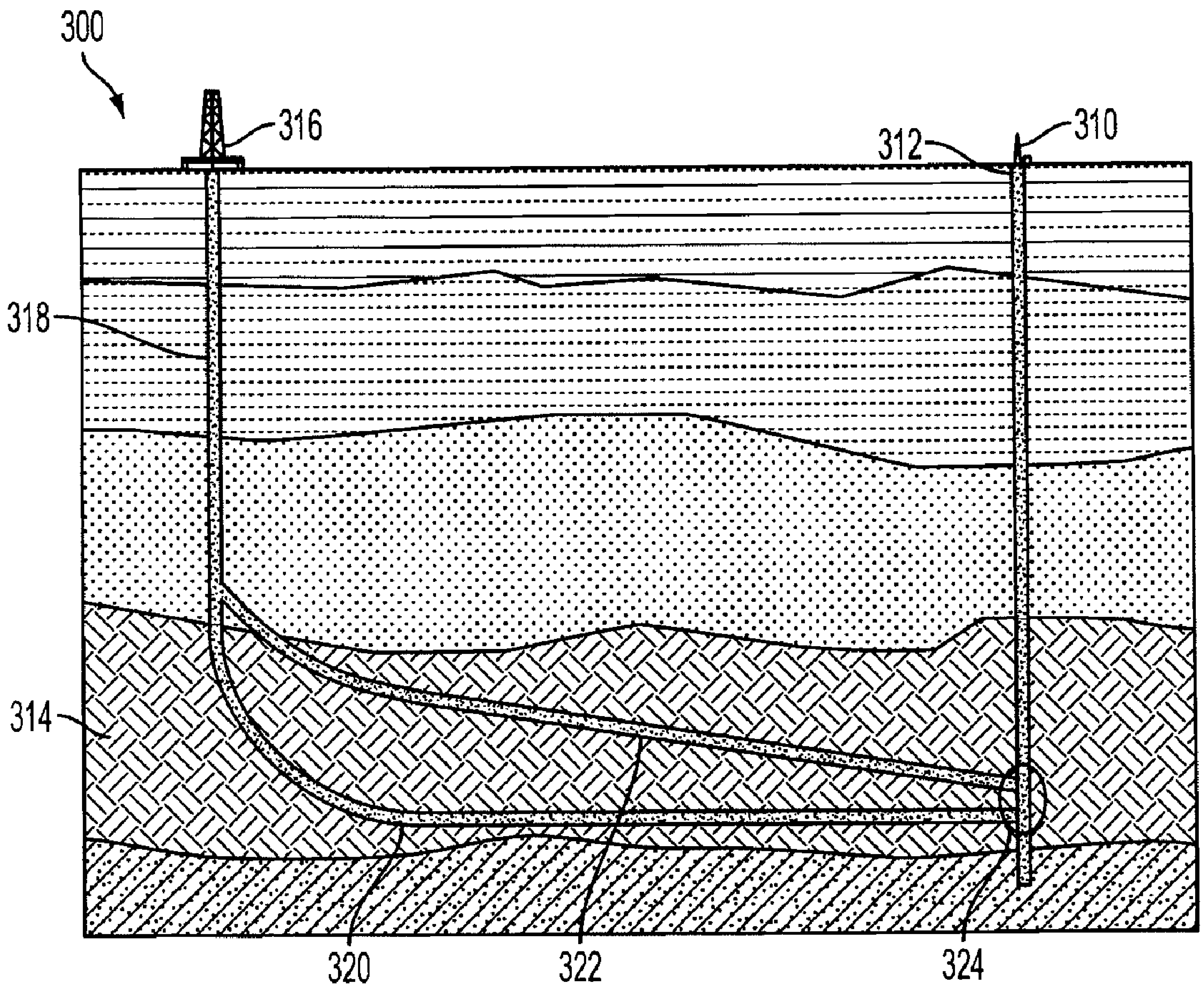


FIG. 3

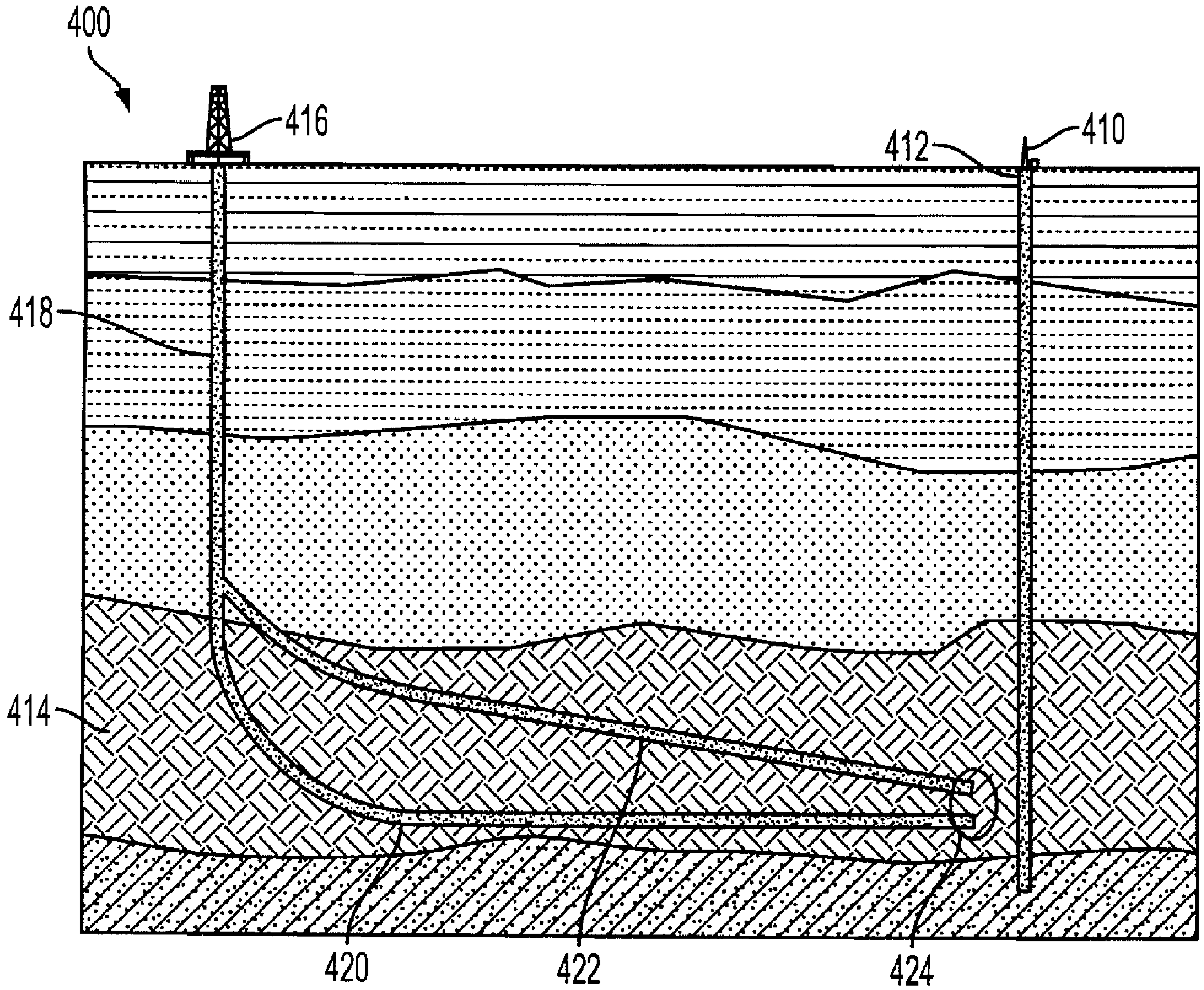


FIG. 4

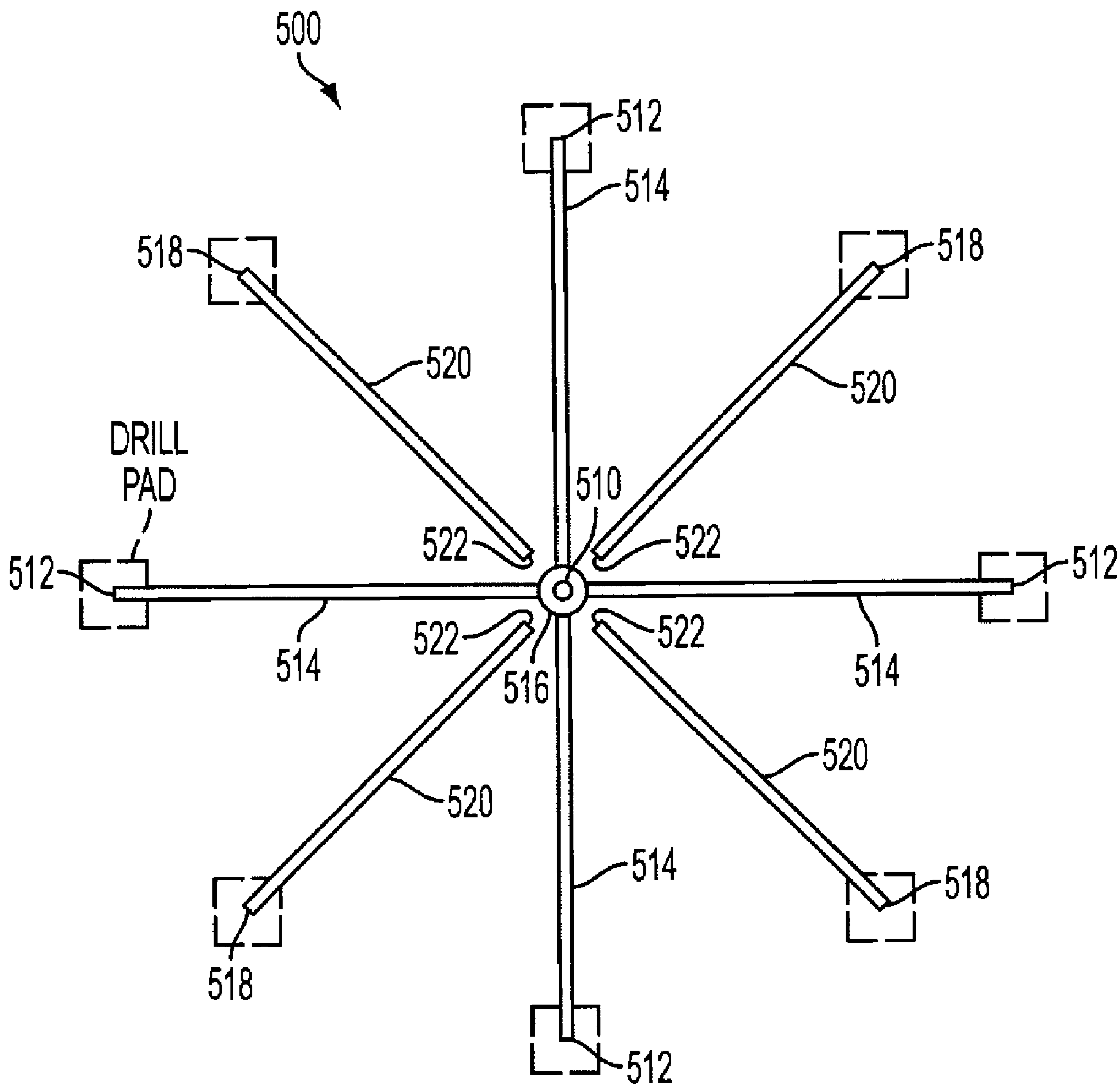


FIG. 5A

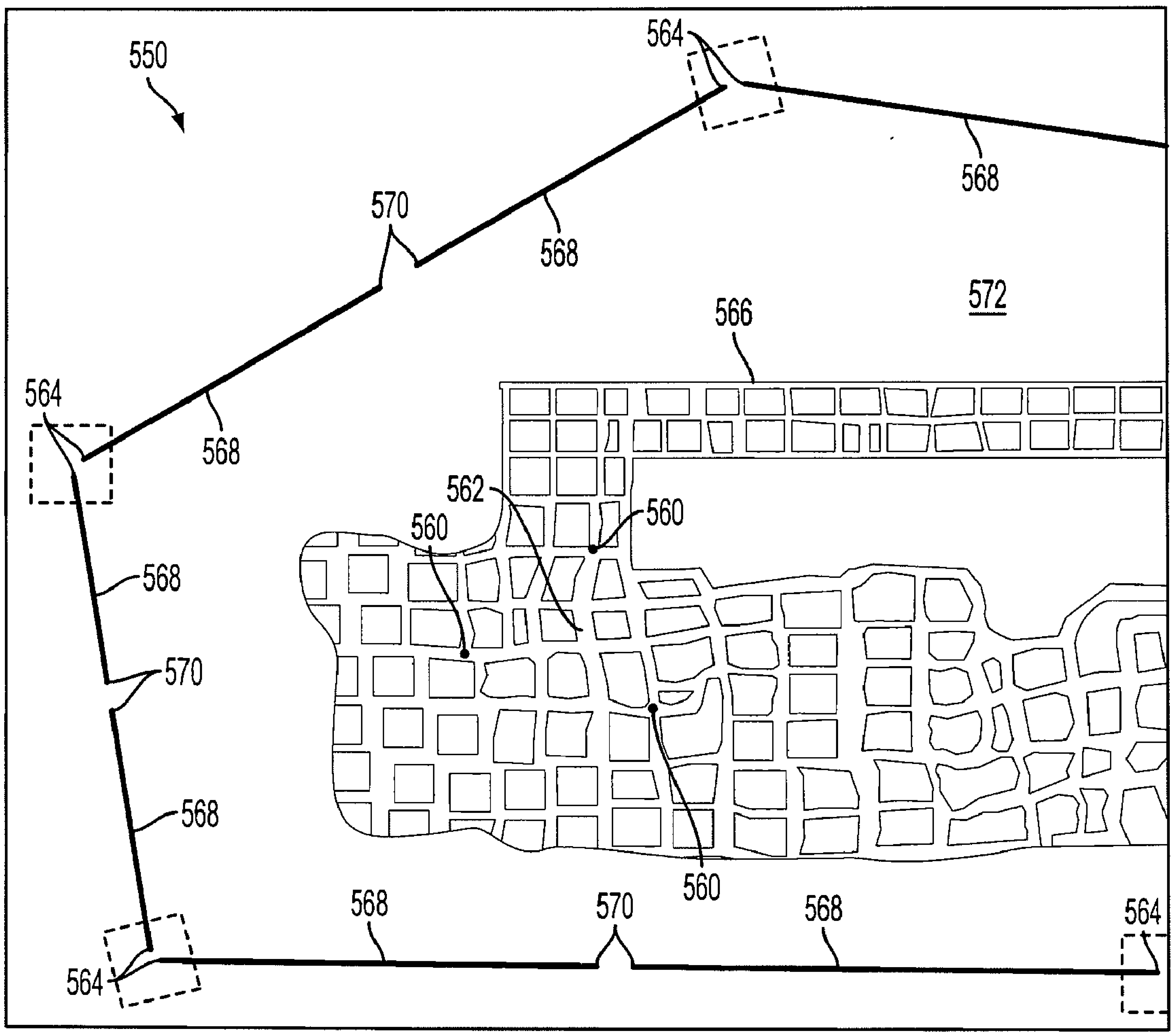

550
564
568
570
568
572
566
564
568
562
560
560
568
570
568
560
568
570
568
564
564

FIG. 5B

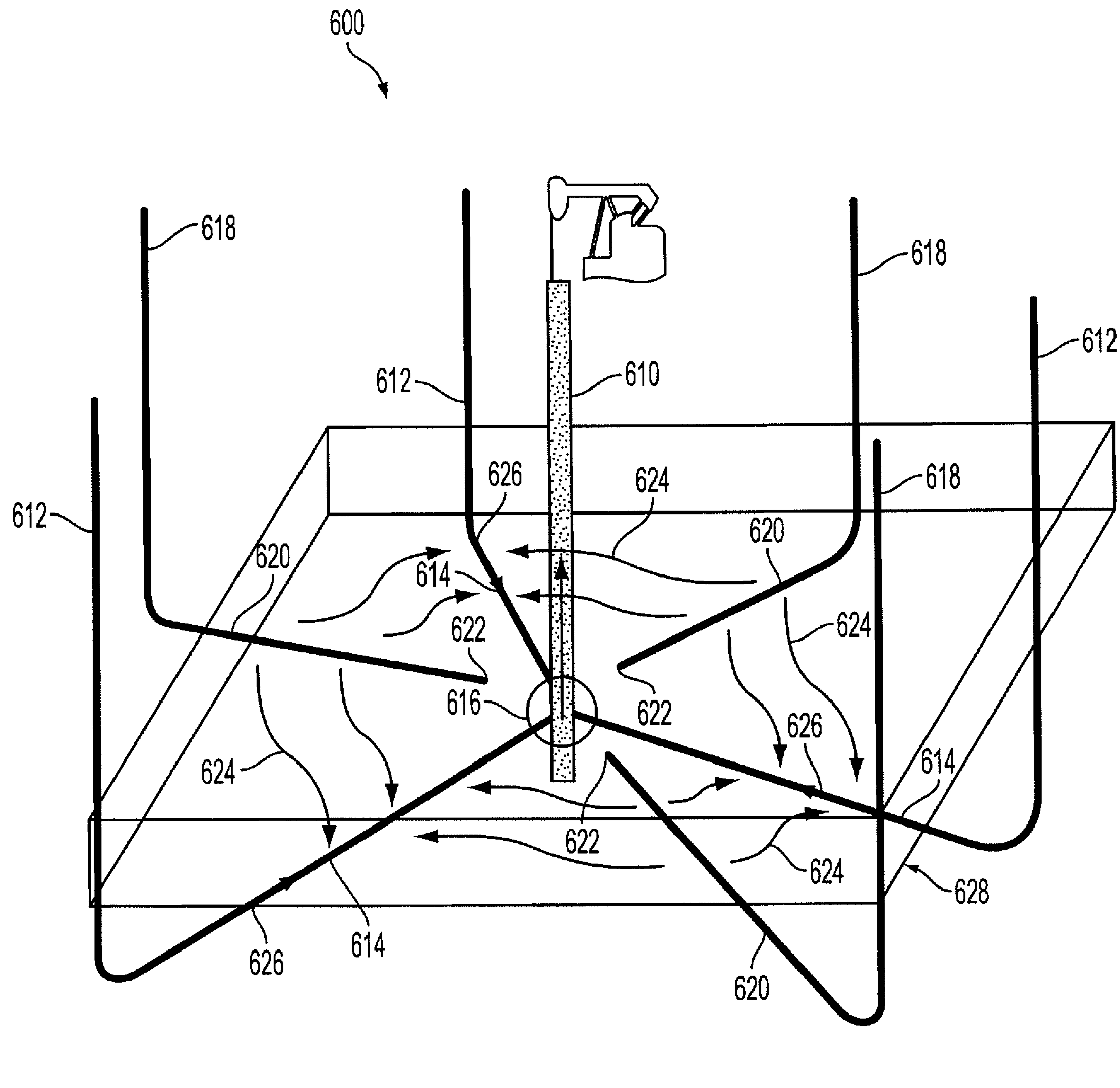

600
618
618
612
610
612
618
612
626
624
620
620
614
622
624
622
616
626
614
624
622
624
628
626
614
620

FIG. 6

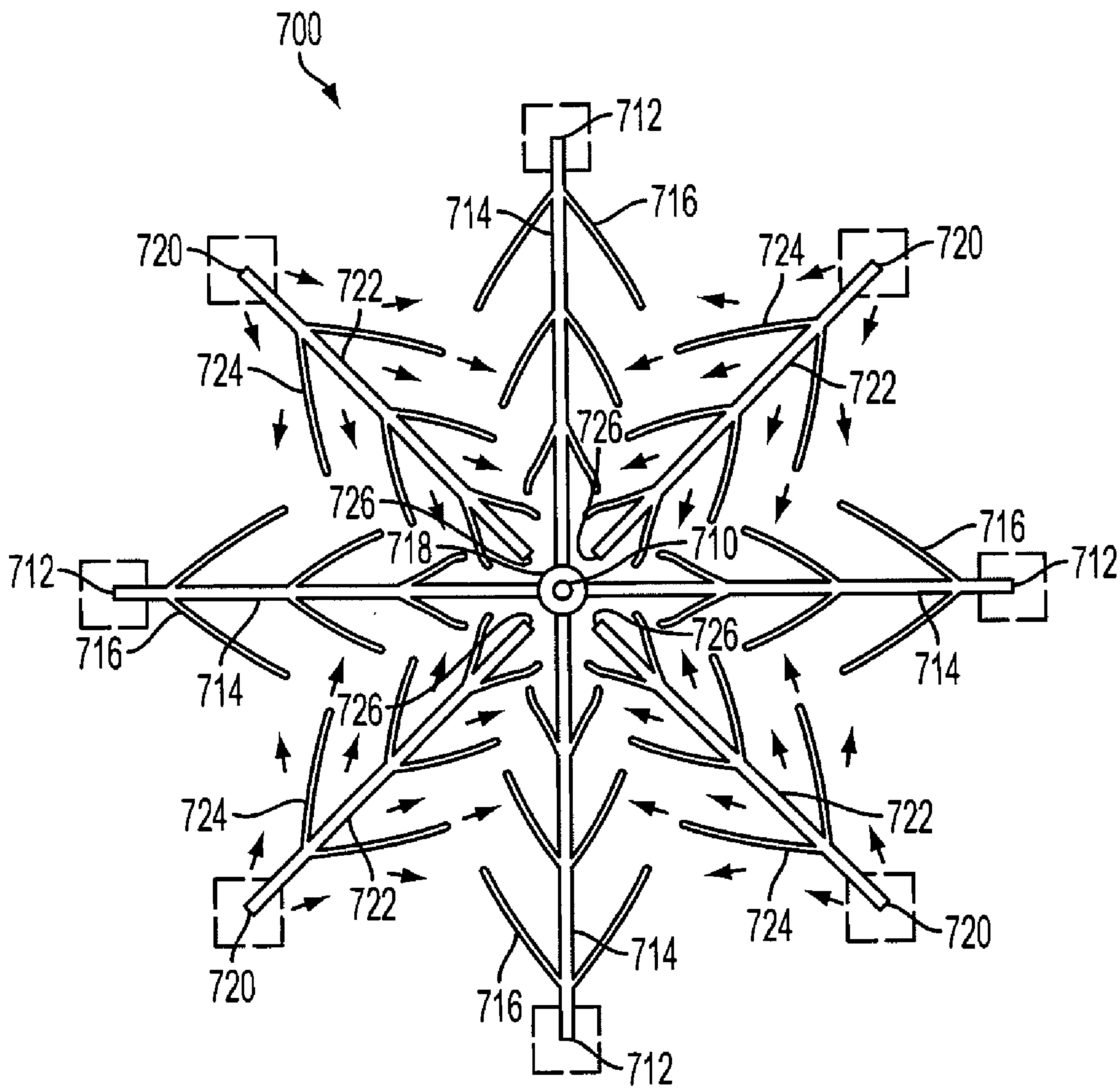


FIG. 7

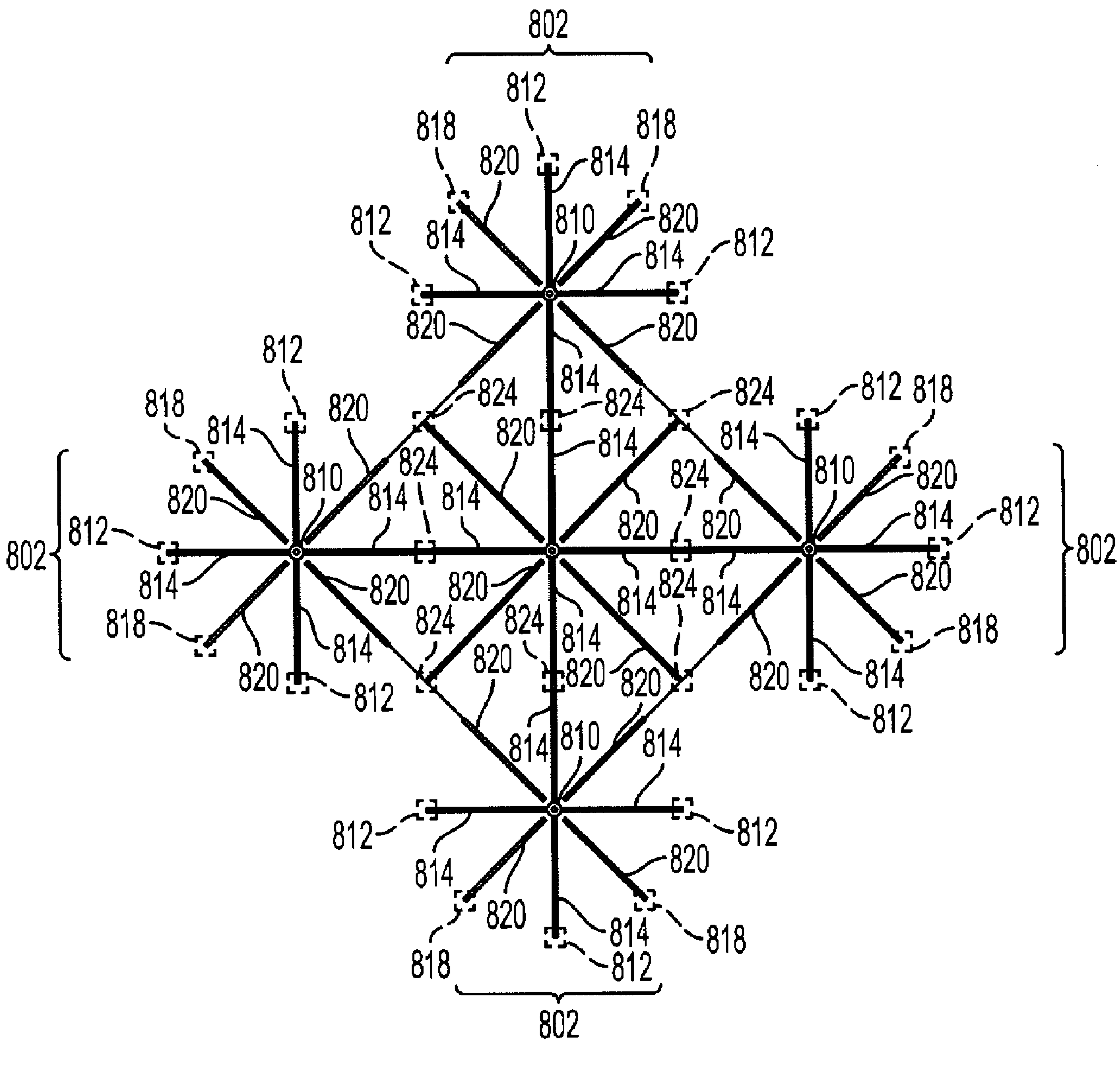


FIG. 8

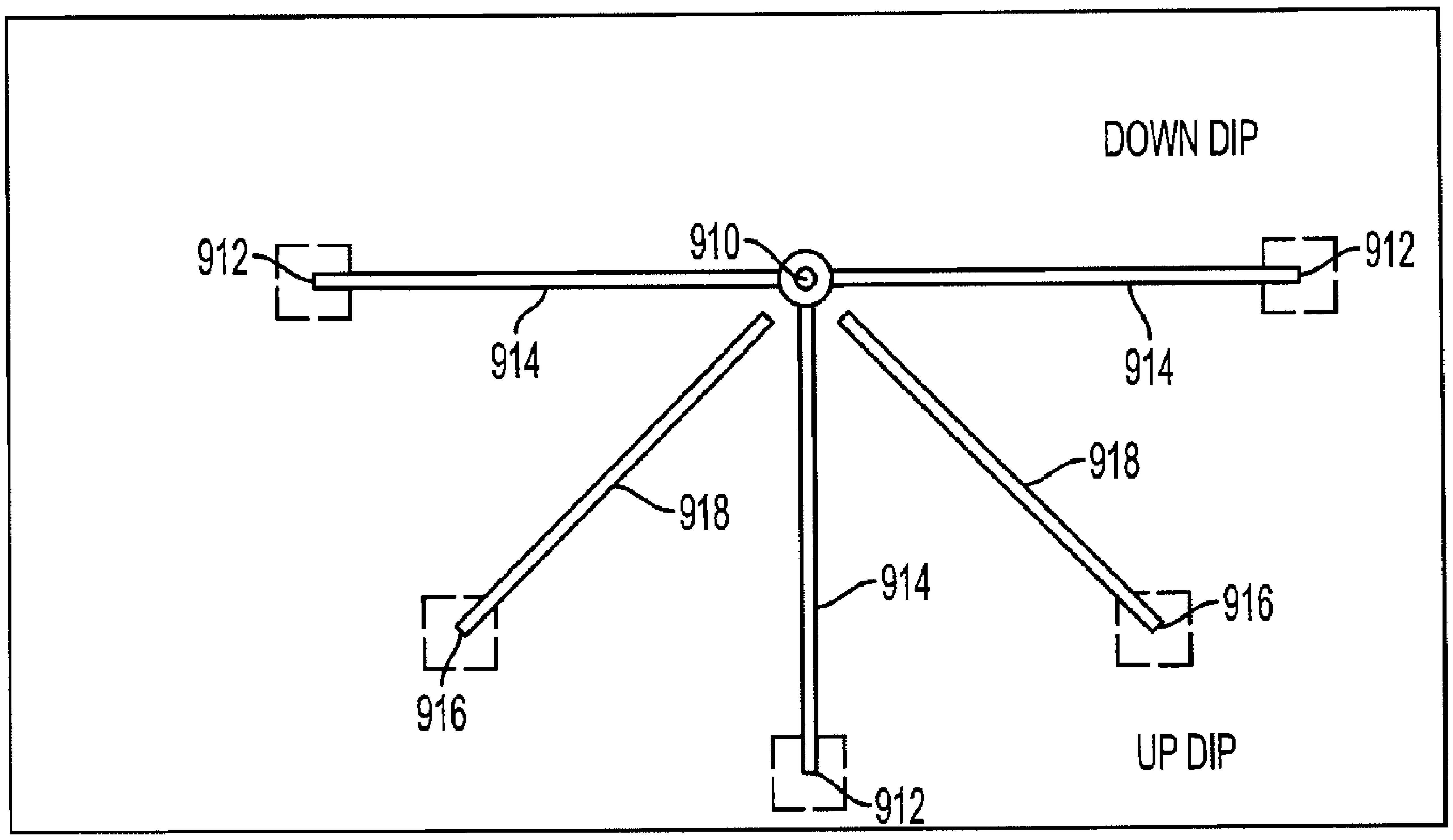


FIG. 9

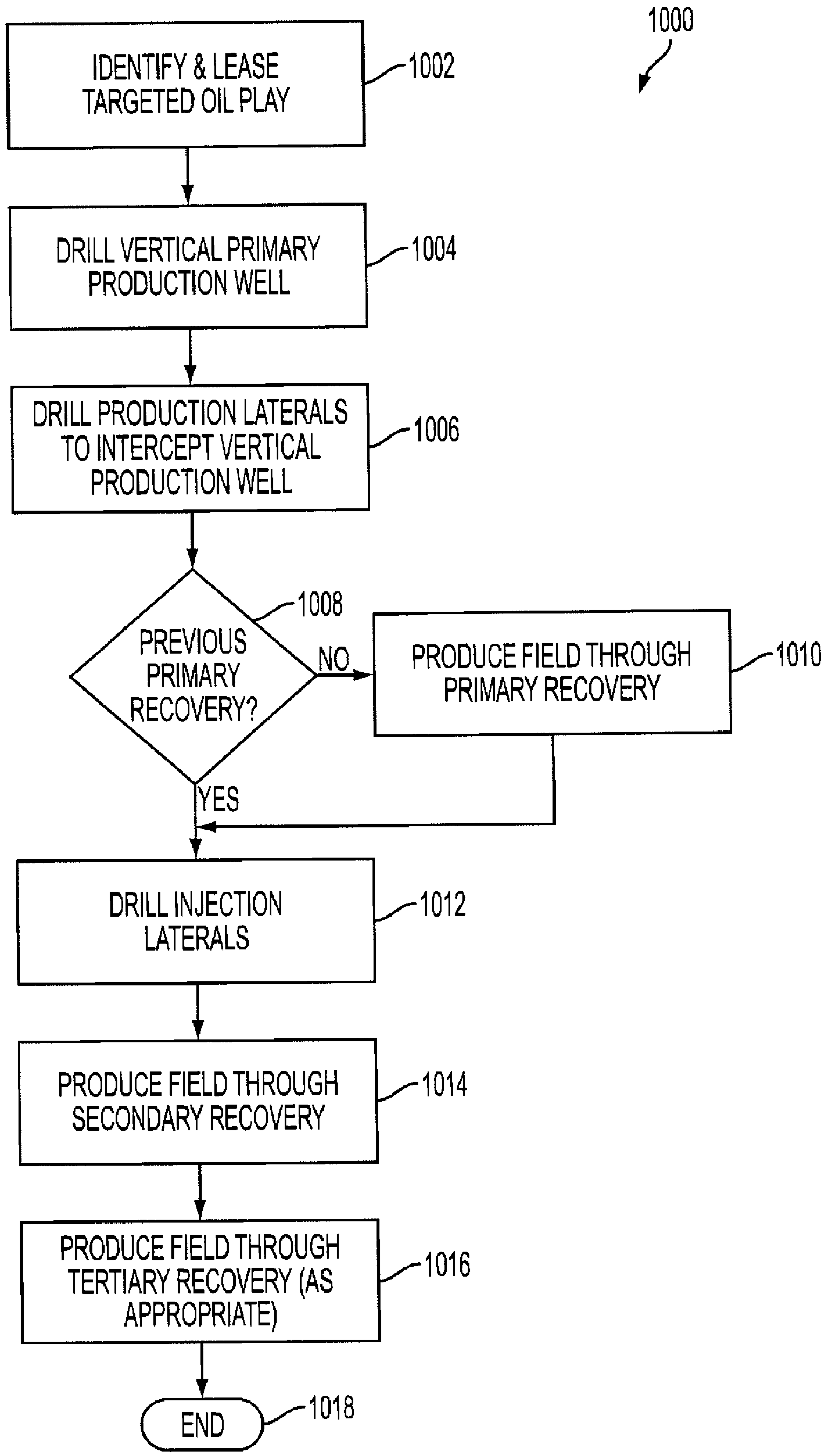

1000
IDENTIFY & LEASE TARGETED OIL PLAY
1002
DRILL VERTICAL PRIMARY PRODUCTION WELL
1004
DRILL PRODUCTION LATERALS TO INTERCEPT VERTICAL PRODUCTION WELL
1006
PREVIOUS PRIMARY RECOVERY?
1008
NO
PRODUCE FIELD THROUGH PRIMARY RECOVERY
1010
YES
DRILL INJECTION LATERALS
1012
PRODUCE FIELD THROUGH SECONDARY RECOVERY
1014
PRODUCE FIELD THROUGH TERTIARY RECOVERY (AS APPROPRIATE)
1016
END
1018

FIG. 10

METHOD OF AND SYSTEM FOR HYDROCARBON RECOVERY

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This patent application claims priority from and incorporates by reference the entire disclosure of U.S. Provisional Patent Application No. 61/080,314, filed on Jul. 14, 2008.

BACKGROUND OF THE INVENTION

[0002] 1. Technical Field

[0003] This application relates generally to a method of and system for hydrocarbon recovery, and, more particularly, but not by way of limitation, to utilizing directional drilling techniques to drill production and injection laterals in a radial pattern around a central production well to enhance hydrocarbon recovery from low-pressure, partially-depleted and other reservoirs.

[0004] 2. History of Related Art

[0005] Hydrocarbons recovered from a subterranean reservoir include oil, gases, gas condensates, shale gas, shale oil and bitumen. To recover such hydrocarbons which may be in the form of, for example, oil from a subterranean formation, a well is typically drilled down to the subterranean reservoir in order to collect oil at a well head. The recovery of hydrocarbons that are very heavy or dense, such as for example, the recovery of bitumen from oil sands, is difficult as these materials are often thick and viscous at reservoir temperatures. As a result, it is even more difficult to extract such hydrocarbons from the subterranean reservoir. Suitable methods for the recovery of hydrocarbons are obviously desirable to reduce the Country's dependence on foreign oil and increase the world's supply of energy.

[0006] Current conventional oil recovery using primary and secondary production techniques depend on natural reservoir pressure and externally-applied energy to the subterranean reservoir, respectively, to produce oil. These techniques, in many instances often extract less than one-third of the oil from a given reservoir. Tertiary techniques inject gas such as, for example, carbon dioxide, natural gas, nitrogen or steam into the subterranean reservoir where the gas dissolves in the oil to lower its viscosity or steam heats the oil, thereby improving the flow of oil to a production well. It has been reported that tertiary techniques may help recover an additional 5-10% of the original oil in-place.

[0007] Due to the limited recovery effectiveness of current technology, there remains a need to provide a more efficient, faster and lower-cost method to recover oil from all reservoirs such as, for example, partially-depleted or low-energy reservoirs. An estimated 300 billion barrels of domestic crude oil resource remains in identified reservoirs which are unable to be extracted using conventional oil recovery technology.

SUMMARY OF THE INVENTION

[0008] A method of recovering hydrocarbons from a subterranean reservoir. The method includes drilling a substantially-vertical primary production well, drilling a plurality of offset production wells generally around the substantially-vertical primary production well in a radial orientation, and drilling a plurality of offset injection wells generally around the substantially-vertical primary production well in a radial orientation. The method further includes injecting, via the plurality of offset injection wells, a liquid to mobilize the hydrocarbons from the subterranean reservoir and inducing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for secondary recovery and injecting, via the plurality of offset injection wells, a gas to mobilize the hydrocarbons from the subterranean reservoir and inducing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for tertiary recovery.

[0009] A method of recovering hydrocarbons from a subterranean reservoir. The method includes drilling a substantially-vertical primary production well, drilling a plurality of offset production wells around the substantially-vertical primary production well in a radial orientation, and drilling a plurality of offset injection wells around the substantially-vertical primary production well in a radial orientation, wherein each one of the plurality of offset injection wells is disposed between a pair of the plurality of offset production wells. The method further includes injecting, via the plurality of offset injection wells, a liquid to mobilize the hydrocarbons from the subterranean reservoir causing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for secondary recovery and injecting, via the plurality of offset injection wells, a gas to mobilize the hydrocarbons from the subterranean reservoir causing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for tertiary recovery.

[0010] A method of recovering hydrocarbons from a subterranean reservoir. The method includes drilling a substantially-vertical primary production well, drilling a plurality of offset production wells and a plurality of offset injection wells around the substantially-vertical primary production well creating an alternating pattern of offset production wells and offset injection wells, and injecting, via the plurality of offset injection wells, a liquid to mobilize the hydrocarbons from the subterranean reservoir causing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for secondary recovery. The method further includes injecting, via the plurality of offset injection wells, a gas to mobilize the hydrocarbons from the subterranean reservoir causing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for tertiary recovery.

[0011] A method of recovering hydrocarbons from a subterranean reservoir. The method includes drilling a substantially-vertical primary production well, drilling a plurality of offset production wells on one side of the substantially-vertical primary production, and drilling a plurality of offset injection wells on an opposite side of the substantially-vertical primary production. The method further includes injecting, via the plurality of offset injection wells, a liquid to mobilize the hydrocarbons from the subterranean reservoir causing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for secondary recovery and injecting, via the plurality of offset injection wells, a gas to mobilize the hydrocarbons from the subterranean reservoir causing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for tertiary recovery.

[0012] A method of recovering hydrocarbons from a subterranean reservoir. The method includes drilling a substantially-vertical primary production well, drilling a plurality of offset production wells and a plurality of offset injection wells around the substantially-vertical primary production well in a random pattern, and injecting, via the plurality of offset injection wells, a liquid to mobilize the hydrocarbons from the subterranean reservoir causing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for secondary recovery. The method further includes injecting, via the plurality of offset injection wells, a gas to mobilize the hydrocarbons from the subterranean reservoir causing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for tertiary recovery.

[0013] A well pattern to recover hydrocarbons from a subterranean reservoir includes a substantially-vertical primary production well extending into the subterranean reservoir, a plurality of offset production wells extending into the subterranean reservoir around the substantially-vertical primary production well in a radial orientation and a plurality of offset injection wells extending into the subterranean reservoir around the substantially-vertical primary production well in a radial orientation. The plurality of offset injection wells are operable to inject a liquid to mobilize the hydrocarbons from the subterranean reservoir so that the mobilized hydrocarbons migrate towards the plurality of offset production wells for secondary recovery. The plurality of offset injection wells operable to inject a gas to mobilize the hydrocarbons from the subterranean reservoir so that the mobilized hydrocarbons migrate towards the plurality of offset production wells for tertiary recovery.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] A more complete understanding of the system of the present invention may be obtained by reference to the following Detailed Description when taken in conjunction with the accompanying Drawings wherein:

[0015] FIG. **1** is a flow diagram illustrating a method of producing hydrocarbons in accordance with an embodiment of the present invention;

[0016] FIG. **2** is a profile view of a hydrocarbon recovery system in accordance with an embodiment of the present invention;

[0017] FIG. **3** is a profile view of a hydrocarbon recovery system in accordance with an embodiment of the present invention;

[0018] FIG. **4** is a profile view of a hydrocarbon recovery system in accordance with an embodiment of the present invention;

[0019] FIG. **5**A is a plan view of a hydrocarbon recovery system in accordance with an embodiment of the present invention;

[0020] FIG. **5**B is a plan view of a hydrocarbon recovery system in accordance with an embodiment of the present invention;

[0021] FIG. **6** is a perspective view of a hydrocarbon recovery system in accordance with an embodiment of the present invention;

[0022] FIG. **7** is a plan view of a hydrocarbon recovery system in accordance with an embodiment of the present invention;

[0023] FIG. **8** is a plan view of a hydrocarbon recovery system in accordance with an embodiment of the present invention;

[0024] FIG. **9** is a plan view of a hydrocarbon recovery system in accordance with an embodiment of the present invention; and

[0025] FIG. **10** is a flow diagram illustrating a detailed method of producing hydrocarbons in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS OF THE INVENTION

[0026] Various embodiments of the present invention will now be described more fully with reference to the accompanying drawings. The invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, the embodiments are provided so that this disclosure will be thorough and complete and will fully convey the scope of the invention to those skilled in the art.

[0027] According to exemplary embodiments, the method and system disclosed herein can be used for enhanced recovery of various hydrocarbons, including enhanced coalbed methane recovery through injection of inert gas, and coal mine methane recovery. In a typical embodiment, for enhanced coal mine methane recovery, lateral injection wells are disposed around an abandoned mine opening or shaft or other void area but do not intersect the void. Nitrogen gas or carbon dioxide is then injected into the lateral injection wells to enhance the production of methane from the mine voids.

[0028] Additionally, the exemplary method and system can be used for enhanced recovery of oil from various types of reservoirs including, for example, low-pressure reservoirs, low-energy reservoirs, partially-depleted reservoirs, and structurally dipping reservoirs. It is further contemplated that wellbores discussed in connection with the present invention can be created using any known drilling techniques including, for example, mechanical drilling, microwave irradiation, high-pressure water jetting, hydraulic and explosive fracturing, laser drilling, and the like. Wellbores for the exemplary method and system may also include all or part of existing wellbores.

[0029] According to exemplary embodiments, a length and orientation of substantially-lateral portions of the offset production and injection wells may be varied for each application. Lengths may be uniform or non-uniform depending on existing reservoir properties. The length of the substantially-lateral portions in reservoirs exhibiting anisotropic reservoir properties may be, for example, non-uniform in order to enhance the flow of hydrocarbons from such reservoirs. It is further contemplated that the substantially-lateral portions may decline or incline over their length in order to take greater advantage of gravity drainage and for improved sweep efficiency. It is also contemplated that, depending on the formation integrity, the offset production and injection wells of the exemplary method and system described herein may be, for example, left open hole or cased and perforated.

[0030] Drilling of sidetracks extending away from the offset production and injection wells may be accomplished with current, state of the art directional drilling methods. Measurement-while-drilling systems may be used to further enhance accurate placement of such sidetracks. It is contemplated that sidetracks may be strategically drilled from selected lateral portions of the offset production and injection wells to increase contact with the reservoir and/or span reservoir discontinuities or restrictions to enhance hydrocarbon production by increasing the fluid communication between wells within the reservoir.

[0031] Referring now to FIG. **1**, a flow diagram illustrating a process **100** for producing hydrocarbons from a subterranean reservoir in accordance with an embodiment of the present invention is shown. The exemplary process **100** utilizes a substantially-vertical primary production well, a plurality of offset production wells, and a plurality of offset injection wells. The process **100** starts at step **102**. At step **104**, primary recovery occurs. In order to produce hydrocarbons from a subterranean reservoir, a substantially-vertical primary production well is drilled into the subterranean reservoir. In a typical embodiment, the primary production well is cased and cemented in order to maintain the integrity of the primary production well. However, depending on the integrity of the subterranean reservoir, the substantially-vertical primary production well may be left open hole through a productive pay zone. Once the substantially-vertical primary production well is in place, the hydrocarbons may be recovered from the subterranean reservoir via, for example, natural pressure of the reservoir, by pumps placed in fluid communication with the subterranean reservoir, or by pumping gases into the reservoir to increase reservoir pressure. After a period of time, the recovery of the hydrocarbons from the subterranean reservoir becomes difficult. In order to increase recovery levels, secondary recovery techniques are implemented.

[0032] At step **106**, secondary recovery is initiated by injecting liquids into the subterranean reservoir. In a typical embodiment, the injection liquid may be, for example, a liquid, with or without additives, of greater density than the hydrocarbons. The injection liquid is pumped into the subterranean reservoir through one or more injection wells, which are in fluid communication with the subterranean reservoir. The greater density of the injection liquid displaces the hydrocarbons causing the hydrocarbons to migrate towards the substantially-vertical primary production well. After a further time period, it often becomes difficult to produce additional hydrocarbons from the subterranean reservoir. In order to recover a maximum amount of hydrocarbons contained in the subterranean reservoir, tertiary recovery techniques may be implemented.

[0033] At step **108**, tertiary recovery is initiated by injecting a gas into the subterranean reservoir. Gas is injected into the subterranean reservoir through the at least one injection well. In a typical embodiment, the injected gas is absorbed by the hydrocarbons. According to an exemplary embodiment, the injected gas may be, for example, carbon dioxide, hydrogen, natural gas, steam, or the like. The absorption of the gas by the hydrocarbons lowers the viscosity of the hydrocarbons or heats the hydrocarbons allowing the hydrocarbons to flow through the subterranean reservoir more easily, thereby enhancing recovery of hydrocarbons. The process **100** ends at step **110**.

[0034] Referring now to FIG. **2**, a profile view of an exemplary hydrocarbon recovery system **200** in accordance with an embodiment of the present invention is shown. In a typical embodiment, the hydrocarbons may be in the form of, for example, oil, gas, condensate, coalbed methane, shale gas, shale oil, and the like. The hydrocarbon recovery system **200** includes a drilling rig **210**. In a typical embodiment, the drilling rig **210** is operable to create a substantially-vertical primary production well **212** by drilling into the ground to recover the hydrocarbons. According to an exemplary embodiment, various types of drilling methods may be used to create the substantially-vertical primary production well **212** including, for example, mechanical drilling, microwave irradiation, high-pressure water jetting, hydraulic and explosive fracturing, laser drilling, and the like. In a typical embodiment, the substantially-vertical primary production well **212** is drilled to a depth sufficient to penetrate through a target formation **220**.

[0035] In a typical embodiment, the substantially-vertical primary production well **212** is cemented and cased with a casing **224**. In an alternative embodiment, depending on reservoir conditions, a portion of all of the substantially-vertical primary production well **212** may be left open hole. In a typical embodiment, the target formation **220** may be, for example, a region beneath several strata **214**, **216**, and **218**. The number of strata that must be drilled through to reach the target formation **220** may vary from location to location. In a typical embodiment, during primary recovery utilizing the substantially-vertical primary production well **212**, hydrocarbons may be produced from, for example, natural pressure existing in the subterranean reservoir, induced pressure from injected fluids, or via a pump (not explicitly shown) to pump the hydrocarbons from the subterranean reservoir.

[0036] Referring now to FIG. **3**, a profile view of an exemplary hydrocarbon recovery system **300** in accordance with an embodiment of the present invention is shown. The hydrocarbon recovery system **300** includes a drilling rig **310**. The drilling rig **310** is operable to create a substantially-vertical primary production well **312**. In a typical embodiment, the substantially-vertical primary production well **312** is drilled to a depth sufficient to reach a target formation **314**. In a typical embodiment, the target formation **314** may be located using, for example, various techniques and methods known in the field of hydrocarbon exploration. The hydrocarbon recovery system **300** further includes an offset production drilling rig **316** operable to create an offset production well **318**. In a typical embodiment, the offset production well **318** includes a substantially-lateral portion **320** which is oriented substantially horizontal and intersects the substantially-vertical primary production well **312** at an intersection region **324**. In an alternative embodiment, the offset production well **318** includes a declining portion **322** or inclining portion (not explicitly shown) oriented at a decline or incline and intersects or is in close proximity to the substantially-vertical primary production well **312** at the intersection region **324**. In a typical embodiment, drilling the declining portion **322** at a decline or incline with perforations throughout may result in improved sweep efficiency. This may be particularly true in thicker reservoirs.

[0037] Still referring to FIG. **3**, the configuration and orientation of the substantially-lateral portions **320** and **322** depend on the subterranean reservoir properties of the target formation **314**. Relevant subterranean reservoir properties include, for example, whether or not the subterranean reservoir is a dipping formation and whether or not the subterranean reservoir exhibits anisotropic reservoir properties (e.g. directional permeability, and the like). For illustrative purposes, only one substantially-lateral portion **320** and one declining portion **322** are illustrated; however, any number of substantially-lateral portions **320** and declining portions **322** or inclining portions (not explicitly shown) may be utilized depending on the subterranean reservoir properties such as, for example, oil saturation, permeability, permeability anisotropy, reservoir pressure, irreducible oil saturation, and the like. In a typical embodiment, the offset production well **318** may be, for example, cased and cemented or left open hole.

[0038] Referring now to FIG. **4**, a profile view of an exemplary hydrocarbon recovery system **400** in accordance with an embodiment of the present invention is shown. The hydrocarbon recovery system **400** includes a drilling rig **410** and a substantially-vertical primary production well **412**. In a typical embodiment, the substantially-vertical primary production well **412** is drilled to a depth sufficient to reach a target formation **414**. In a typical embodiment, the target formation **414** may be, for example, beneath several different strata and may vary from location to location. The hydrocarbon recovery system **400** further includes an offset injection drilling rig **416** and an offset injection well **418**. In a typical embodiment, the offset injection well **418** includes a substantially-lateral portion **420**, which is oriented relatively horizontal and which does not intersect the substantially-vertical primary production well **412**. The substantially-lateral portion **420** terminates at an end region **424**. Similar to the discussion above with respect to FIG. **3**, according to an alternate embodiment, the offset injection well **418** includes a substantially-lateral portion **422** oriented at a decline or incline to enhance hydrocarbon recovery. In a typical embodiment, the offset production well **418** may be cased and cemented or left open hole.

[0039] Referring now to FIG. **5**A, a plan view of an exemplary hydrocarbon recovery system **500** in accordance with an embodiment of the present invention is shown. In a typical embodiment, the hydrocarbon recovery system **500** includes a substantially-vertical primary production well **510** and a plurality of offset production wells **512** disposed about the substantially-vertical primary production well **510** in, for example, a radial pattern. Each of the plurality of offset production wells **512** includes a substantially-lateral portion **514** which intersects the substantially-vertical primary production well **510** at an intersection region **516**. The hydrocarbon recovery system **500** further includes a plurality of offset injection wells **518** disposed about the substantially-vertical primary production well **510** in, for example, a radial pattern. Each of the plurality of offset injection wells **518** includes a substantially-lateral portion **520**, which does not intersect the substantially-vertical primary production well **510** so as to not short circuit fluid flow. Each one of the plurality of substantially-lateral portions **520** terminates at an end region **522**.

[0040] According to an exemplary embodiment, each one of the plurality of offset injection wells **518** is disposed between a pair of the offset production wells **512** to create an alternating pattern of offset injection wells **518** and offset production wells **512**. According to an alternative embodiment, the plurality of offset production wells **512** may be disposed on, for example, one side of the substantially-vertical primary production well **510** while the plurality of offset injection wells **518** may be disposed on the opposite side of the substantially-vertical primary production well **510**. According to yet another alternative embodiment, the plurality of offset production wells **512** and the plurality of offset injection wells **518** may be randomly disposed about, for example, the substantially-vertical primary production well **510**. In a typical embodiment, the plurality of offset production wells **512** and the plurality of offset injection wells **518** may be, for example, cased and cemented or left open hole.

[0041] Still referring to FIG. **5**A, in a typical embodiment, the plurality of offset injection wells **518** are operable to introduce an injection fluid into the subterranean reservoir. In a typical embodiment, the injection fluid may be, for example, water, steam, carbon dioxide, nitrogen, and the like, with or without additives. Typically, during secondary recovery, a liquid of greater density than the hydrocarbons is injected into the plurality of offset injection wells **518** to displace the hydrocarbons, causing the hydrocarbons to migrate towards the plurality of offset production wells **512**. In a typical embodiment, the plurality of offset production wells **512** are in fluid communication with the substantially-vertical primary production well **510** via the intersection region **516**. During tertiary recovery, a gas is typically injected into the plurality of offset injection wells **518**. In a typical embodiment, the gas may be, for example, carbon dioxide, natural gas, nitrogen, steam, or the like. As the gas enters the subterranean reservoir, the gas is absorbed by the hydrocarbons, thereby lowering the viscosity of or heating the hydrocarbons contained in the subterranean reservoir. Lowering the viscosity of hydrocarbons or heating the hydrocarbons allows the hydrocarbons to more easily migrate towards the plurality of offset production wells **512**. In a typical embodiment, the plurality of offset productions wells **512** are in fluid communication with the substantially-vertical primary production well **510** via the intersection region **516**.

[0042] Referring now to FIG. **5**B, a plan view of an exemplary hydrocarbon recovery system **550** in accordance with an embodiment of the present invention is shown. The hydrocarbon recovery system **550** includes at least one substantially-vertical primary production well **560** extending into abandoned coal mining voids **562**. In the embodiment shown in FIG. **5**B, the hydrocarbon recovery system **550** includes three substantially-vertical primary production wells **560**. A plurality of offset injection wells **564** are disposed around a perimeter **566** of the abandoned coal mining voids **562** in a radial orientation and extend into a subterranean reservoir **572**. Each of the plurality of offset injection wells **564** includes at least one substantially-lateral portion **568**, which terminates at an end **570**. In other embodiments, the at least one substantially-lateral portion **568** may instead be either inclined or declined, depending on the subterranean reservoir **572** properties. In order to prevent short-circuiting the flow of an injected gas, each end **570** does not extend past the perimeter **566** of the abandoned coal mine voids **562**. Each of the at least one substantially-lateral portion **568** is operable to inject a gas, for example, carbon dioxide, nitrogen, hydrogen, and combinations thereof, into the subterranean reservoir **568** to mobilize remaining hydrocarbons to migrate towards the abandoned coal mining voids **562**.

[0043] Referring now to FIG. **6**, a perspective view of an exemplary hydrocarbon recovery system **600** in accordance with an embodiment of the present invention is shown. The hydrocarbon recovery system **600** is similar to the hydrocarbon recovery system **500** of FIG. **5**A (illustrated from a different view) and includes a substantially-vertical primary production well **610**, a plurality of offset production wells **612**, and a plurality of offset injection wells **618**. Each of the plurality of offset production wells **612** includes a substantially-lateral portion **614** which intersects the substantially-vertical primary production well **610** at an intersection region **616**. Each of the plurality of the offset injection wells **618** includes a substantially-lateral portion **620** which terminates at an end region **622**. In a typical embodiment, the plurality of offset injection wells do not intersect the substantially-vertical primary production well **610**. Although not explicitly shown, it is contemplated that the substantially-lateral portion **614** and **620**, depending on reservoir properties, may be oriented flat, on a decline, incline, or porpoising configuration to further enhance hydrocarbon recovery. For illustrative purposes, only three offset production and injection wells **612**, **618** are illustrated; however, any number of offset production and injections wells **612**, **618** may be utilized in alternate embodiments.

[0044] In order to maximize the recovery of hydrocarbons from the subterranean reservoir, the hydrocarbon recovery system **600** may be used in the following manner. During secondary recovery, a liquid (not explicitly shown) may be pumped into the plurality of offset injection wells **618**. In a typical embodiment, the liquid may be, for example, water, with or without additives, and the like. The liquid enters a subterranean reservoir **628** through perforations or slots (not explicitly shown) in the substantially-lateral portion **620** of each of the plurality of offset injection wells **618**. The general path of the liquid is illustrated by arrows **624** and **626**. As the liquid enters the subterranean reservoir **628**, remaining hydrocarbons are displaced by the liquid causing the hydrocarbons to migrate towards at least one of the plurality of substantially-lateral portions **614**. Once the hydrocarbons reach the at least one substantially-lateral portion **614**, the hydrocarbons are recovered by the substantially-vertical primary production well **610**. In a typical embodiment, the general path of the hydrocarbons is illustrated by arrows **624** and **626**. For example, arrows **624** illustrate the liquid dispersing from each of the substantially-lateral portions **620** while arrows **626** illustrate the hydrocarbons that have been driven into the substantially-lateral portions **614**.

[0045] During tertiary recovery, a gas, such as, for example, nitrogen, natural gas, carbon dioxide, steam, and the like, is pumped into the plurality of offset injection wells **618**. The arrows **626** further demonstrate how the gas permeates the subterranean reservoir. Pumping the gas into the subterranean reservoir **628** acts to lower the viscosity of the hydrocarbons or heats the hydrocarbons within the subterranean reservoir **628**, allowing the hydrocarbons to more easily migrate within the subterranean reservoir **628**. In a typical embodiment, the hydrocarbons migrate within the subterranean reservoir **628** towards lower-pressure areas around the substantially-lateral portions **614** and are produced through the substantially-vertical primary production well **610**.

[0046] Referring now to FIG. **7**, a plan view of an exemplary hydrocarbon recovery system **700** in accordance with an embodiment of the present invention is shown. The hydrocarbon recovery system **700** is similar to the hydrocarbon recovery systems **500** and **600** of FIG. **5**A and FIG. **6**, respectively. According to an exemplary embodiment, the hydrocarbon recovery system **700** further includes a plurality of substantially-lateral sidetracks **716** and **724**. The hydrocarbon recovery system **700** includes a substantially-vertical primary production well **710** and a plurality of offset production wells **712** disposed about the substantially-vertical primary production well **710** in a radial pattern. Each of the plurality of offset production wells **712** includes a substantially-lateral portion **714** which intersects the substantially-vertical primary production well **710** at an intersection region **718**. Each substantially-lateral portion **714** further includes a plurality of substantially-lateral sidetracks **716**, which extend outwardly from each of the substantially-lateral portion **714**. The plurality of substantially-lateral sidetracks **716** may be drilled substantially horizontal or oriented on a decline or incline based on structure and reservoir conditions.

[0047] The hydrocarbon recovery system **700** further includes a plurality of offset injection wells **720** disposed about the substantially-vertical primary production well **710** in a radial pattern. Each of the plurality of offset injection wells **720** includes a substantially-lateral portion **722**. In a typical embodiment, the plurality of offset injection wells **720** do not intersect with the substantially-vertical primary production well **710** but instead terminates at an end region **726** to prevent short-circuiting of fluid flow paths. Each of the plurality of substantially-lateral portion **722** further includes a plurality of substantially-lateral sidetracks **724**, which extend outwardly from each of the substantially-lateral portion **722**. The plurality of substantially-lateral sidetracks **716** and **724** further enhance secondary and tertiary recovery stages by providing greater fluid communication to the subterranean reservoir. The plurality of substantially-lateral sidetracks **716** and **724** may be created using directional drilling techniques and, depending on the subterranean reservoir properties, may be cased and cemented, perforated, or left open hole.

[0048] Still referring to FIG. **7**, according to exemplary embodiments, the location of the end region **726** depends upon the subterranean reservoir properties. In some embodiments, it may be desirable for the end region **726** to be located close to the substantially-vertical primary production well **610**; however, in other embodiments, it may be desirable for the end region **726** to be located far away from the substantially-vertical primary production well **610**. For example, if the reservoir is relatively soft and/or fractured, it may be desirable for the end region **726** to be located far away from the substantially-vertical primary production well **710** to prevent fluid in the substantially-lateral portion **722** from breaking through to the substantially-vertical primary production well **710**. Such a breakthrough decreases the amount of fluid that interacts with the remaining hydrocarbons. Conversely, it may be necessary for the end region **726** to be located closer to the substantially-vertical primary production well **710** to maintain fluid communication between the substantially-lateral portion **722** and the substantially-vertical primary production well **710**.

[0049] Still referring to FIG. **7**, in one embodiment of the hydrocarbon recovery system **700**, each of the plurality of offset injection wells **720** is disposed between a pair of the plurality of offset production wells **712** to create an alternating pattern of offset production wells **712** and offset production wells **720**. In another embodiment, the plurality of offset production wells **712** are disposed on one side of the substantially-vertical primary production well **710** and the plurality of offset injection wells **720** may be disposed on an opposite side of the substantially-vertical primary production well **710**. In another embodiment, the plurality of offset production wells **712** and the plurality of offset injection wells **720** are randomly disposed about the substantially-vertical primary production well **710**.

[0050] Referring now to FIG. **8**, a plan view of a field-wide hydrocarbon recovery system **800** in accordance with an embodiment of the present invention is shown. In planning a field-wide development, a pattern like the one shown in FIG. **8** may be used. The field-wide hydrocarbon recovery system **800** includes a plurality of hydrocarbon recovery systems **802**, such as the ones shown and described above with reference to FIGS. **5-7**. In order to implement a field-wide development, the plurality of hydrocarbon recovery systems **802** may be, for example, in fluid communication with one another through adjacent offset production wells **824**. According to exemplary embodiments, placing the plurality of hydrocarbon recovery systems **802** in close proximity to one another allows fluid communication between the plurality of hydrocarbon recovery systems **802** and enhances the secondary and tertiary recovery of hydrocarbons from the subterranean reservoir.

[0051] Similar to the systems described with respect to FIGS. **5-7**, each of the plurality of substantially-vertical primary production wells **810** is surrounded by a plurality of offset production wells **812** and a plurality of offset injection wells **818**. Each of the plurality of offset production wells **812** includes a substantially-lateral portion **814** which intersects with one of the plurality of substantially-vertical primary production wells **810**. Each of the plurality of offset injection wells **818** includes a substantially-lateral portion **820**, which does not intersect with one of the plurality of vertical primary production wells **810**. Although not shown, according to alternate embodiments, each of the plurality of substantially-lateral portions **814** and **820** may also include a plurality of substantially-lateral sidetracks similar to the ones shown in FIG. **7**.

[0052] Referring now to FIG. **9**, an alternative embodiment of a hydrocarbon recovery system **900** in accordance with an embodiment of the present invention is shown. According to exemplary embodiments, when producing hydrocarbons from a dipping formation, it may be beneficial to utilize the hydrocarbon recovery system **900** as shown in FIG. **9**. In a typical embodiment, a down-dipping formation is a subterranean reservoir in which one side of the subterranean reservoir is deeper than an opposite side. Due to the shape of a down-dipping formation, gravity tends to cause hydrocarbons contained therein to pool to the deeper side of the subterranean reservoir.

[0053] In one embodiment, the hydrocarbon recovery system **900** includes a semi- circular shape and having a substantially-vertical primary production well **910** disposed towards a central region of the semi-circle. As with the systems described by FIGS. **5-8**, the hydrocarbon recovery system **900** includes a plurality of offset production wells **912** and a plurality of offset injection wells **916**. Each of the plurality of offset production wells includes a substantially-lateral portion **914**, which intersects the substantially-vertical primary production well **910**. Each of the plurality of offset injection wells **916** includes a substantially-lateral portion **918**. In a typical embodiment, the plurality of offset injection wells **916** do not intersect the substantially-vertical primary production well **910**. In a typical embodiment, the plurality of offset production wells **912** and the plurality of injection wells **916** are disposed on an up-dip side of the subterranean reservoir. The hydrocarbon recovery system **900** creates an enhanced gravity drainage condition. Injection of a fluid, with or without additives, during secondary recovery or injection of a gas during tertiary recovery increases the pressure within the formation causing the hydrocarbons to migrate to the deeper end of the formation where the substantially-vertical primary production well **910** is situated.

[0054] Referring now to FIG. **10**, there is shown a flow diagram illustrating a detailed process **1000** in accordance with an embodiment of the present invention for producing hydrocarbons. The process **1000** starts at step **1002**. At step **1002**, a subterranean reservoir is identified and hydrocarbon developments rights are secured. At step **1004**, a substantially- vertical primary production well is drilled into the subterranean reservoir. The substantially-vertical primary production well may be drilled using a variety of drilling techniques such as, for example, rotary drilling, water jet drilling, and the like. The substantially-vertical primary production well may be, for example, (i) cased, cemented and perforated, or (ii) lined with a slotted or pre-perforated liner without cementing, or (iii) left open hole. If necessary, artificial lift such as, for example, beam pump, submersible pump, progressive cavity pump, and the like may be installed in the substantially-vertical primary production well to assist with the production process. The process **1000** then proceeds to step **1006**.

[0055] At step **1006**, a plurality of offset production wells is drilled about the substantially-vertical primary production well in a radial pattern to form a circle about the substantially-vertical primary production well. In one embodiment, each of the plurality of offset production wells is drilled down to a desired depth, typically to a depth within the subterranean reservoir, and then a substantially-lateral portion for each of the plurality of production wellbores is created using conventional directional drilling techniques. The placement of lateral wellbores may be drilled more accurately using measurement-while-drilling surveying instruments. Drilling of each lateral wellbore continues until the substantially-lateral portion intersects with the substantially-vertical primary production well. The intersection of the offset production well with the substantially-vertical primary production well facilitates fluid flow from each production lateral to the substantially-vertical primary production well.

[0056] In another embodiment, each of the plurality of offset production wells is drilled down to a desired depth, after which directional drilling is used to create, for example, a flat portion, an inclined portion or a declined portion for each of the plurality of offset production wells. Each flat portion, inclined portion or declined portion is extended until it intersects the substantially-vertical primary production well. In yet another embodiment, the substantially-lateral portion, the inclined portion or the declined portion may include a plurality of substantially-lateral sidetracks which extend outwardly from the flat or inclined portions, respectively. The number of offset production and injection wells depends on reservoir properties such as, for example, oil saturation, permeability, permeability anisotropy, reservoir pressure, irreducible oil saturation, and the like. The plurality of offset production wells may be, for example, (i) cased, cemented and perforated, or (ii) lined with a slotted or pre-perforated liner without cementing, or (iii) left open hole. The process **1000** proceeds from step **1006** to step **1008**.

[0057] At step **1008**, it is determined whether the subterranean reservoir has been through primary recovery. If it is determined at step **1008** that the subterranean reservoir has not been through primary recovery, the process **1000** proceeds to step **1010**. At step **1010**, primary recovery is initiated utilizing the substantially-vertical primary production well and the plurality of offset production wells. After primary recovery has been completed, the method **1000** proceeds to step **1012**. However, if it is determined at step **1008** that the subterranean reservoir has been through primary recovery, the process **1000** proceeds from step **1008** to step **1012**. At step **1012** a plurality of offset injection wells is created. In one embodiment, the plurality of offset injection wells is created by drilling new wells at desired locations around the substantially-vertical primary production well. In another embodiment, the plurality of offset injection wells may include wells that have been previously drilled. For example, the process **1000** may be applied to a prior production operation that has already begun. If the prior production operation includes a central well and one or more previously-existing outlying wells, the one or more previously-existing outlying wells may be adapted for use with the process **1000**. For example, the one or more previously-existing outlying wells may be incorporated into the process **1000** as one of the plurality of offset injection wells by plugging back the one or more previously-existing outlying well to the desired length, or extending the one or more previously-existing outlying wells further if needed. Similarly, a previously-existing outlying well may be incorporated for use as one of the plurality of offset production wells by using directional drilling to connect the previously-existing outlying well to the substantially-vertical primary production well.

[0058] Still referring to step **1012**, in a typical embodiment, the number of offset injection wells drilled is equal to the number of offset production wells drilled; however, this limitation is not required. In a typical embodiment the lateral injection wells are drilled such that they are located between two offset production wells, creating an alternating pattern of lateral injection and production wells in a radial pattern about the substantially-vertical primary production well. Each of the plurality of offset injection wells is drilled (or plugged back) to a length to maximize the effectiveness of injection/production during secondary or tertiary recovery. The plurality of offset injection wells may be, for example, (i) cased, cemented and perforated, or (ii) lined with a slotted or pre-perforated liner without cementing, or (iii) left open hole. The process **1000** proceeds from step **1012** to step **1014**.

[0059] At step **1014** secondary recovery is initiated. During secondary recovery, an injection liquid, with or without additives, is injected into the subterranean reservoir in order to displace the hydrocarbons to allow the substantially-vertical primary production well to recover the hydrocarbons. In one embodiment, pumps in fluid communication with the substantially- vertical primary production well and the plurality of offset production wells can be used to create zones of relatively low pressure around the substantially-vertical primary production well and the plurality of offset production wells in the subterranean reservoir. Creating relatively low pressure zones around the substantially-vertical primary production well and the plurality of offset production wells will, due to the pressure gradient, cause the hydrocarbons, which were displaced by the injection liquid, to migrate towards the relatively low-pressure zones and aid in the recovery of hydrocarbons. After secondary recovery is completed, the process **1000** proceeds to step **1016**.

[0060] At step **1016**, tertiary recovery is initiated. During tertiary recovery, gas such as, for example natural gas, carbon dioxide, steam, and the like is injected into the subterranean reservoir. In a typical embodiment, the injected gas is absorbed by the remaining hydrocarbons lowering their viscosity or heated and allowing the hydrocarbons to more easily move within the subterranean reservoir. In one embodiment, pumps in fluid communication with the substantially-vertical primary production well and the plurality of offset production wells can be used to create zones of relatively low pressure around the substantially-vertical primary production well and the plurality of offset production wells in the subterranean reservoir. Creating relatively low pressure zones around the substantially-vertical primary production well and the plurality of offset production wells will, due to the pressure gradient, cause the hydrocarbons, due to their lower viscosity, to migrate towards the relatively low pressure zones and aid in the recovery of the hydrocarbons. The process **1000** ends at step **1018**.

[0061] Although various embodiments of the hydrocarbon recovery system of the present invention have been illustrated in the accompanying Drawings and described in the forgoing Detailed Description, it will be understood that the invention is not limited to the embodiments disclosed, but is capable of numerous rearrangements, modifications, and substitutions without departing from the spirit of the invention as set forth herein.

What is claimed is:

1. A method of recovering hydrocarbons from a subterranean reservoir, the method comprising:
- drilling a substantially-vertical primary production well;
- drilling a plurality of offset production wells generally around the substantially-vertical primary production well in a radial orientation;
- drilling a plurality of offset injection wells generally around the substantially-vertical primary production well in a radial orientation;
- injecting, via the plurality of offset injection wells, a liquid to mobilize the hydrocarbons from the subterranean reservoir and inducing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for secondary recovery; and
- injecting, via the plurality of offset injection wells, a gas to mobilize the hydrocarbons from the subterranean reservoir and inducing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for tertiary recovery.

2. The method according to claim **1**, further comprising disposing each one of the plurality of offset injection wells between a pair of the plurality of offset production wells.

3. The method of claim **2**, wherein the step of disposing is operable to create an alternating pattern of offset production wells and offset injection wells.

4. The method according to claim **1**, further comprising:
- disposing at least one substantially-lateral portion from at least one of the plurality of offset production wells; and
- connecting, via the at least one substantially-lateral portion, the at least one of the plurality of offset production wells with the substantially-vertical primary production well at an intersection region.

5. The method according to claim **4**, further comprising disposing a plurality of substantially-lateral sidetracks from the at least one substantially-lateral portion, the plurality of substantially-lateral sidetracks extend outwardly from the at least one substantially-lateral portion.

6. The method according to claim **5**, wherein the plurality of substantially-lateral sidetracks are operable to enhance secondary recovery of hydrocarbons.

7. The method according to claim **4**, wherein the step of connecting is operable to provide, via the intersection region, fluid communication between the substantially-vertical primary production well and at least one of the plurality of offset production wells.

8. The method according to claim **1**, wherein the liquid has a density higher than the hydrocarbons.

9. The method according to claim **1**, wherein the gas is absorbed by the hydrocarbons.

10. The method according to claim **9**, wherein the absorbed gas lowers the viscosity of the hydrocarbons.

11. The method according to claim **1**, wherein the gas is selected from the group consisting of carbon dioxide, nitrogen, hydrogen, and combinations thereof.

12. The method according to claim **1**, further comprising disposing at least one substantially-lateral portion from at least one of the plurality of offset injection wells.

13. The method according to claim **12**, wherein the at least one substantially-lateral portion does not intersect the substantially-vertical primary production well.

14. The method according to claim **13**, further comprising disposing a plurality of substantially-lateral sidetracks from the at least one substantially-lateral portion, the plurality of substantially-lateral sidetracks extend outwardly from the at least one substantially-lateral portion.

15. The method according to claim **14**, wherein the plurality of substantially-lateral sidetracks are operable to enhance tertiary recovery of hydrocarbons.

16. The method of claims **1**, wherein at least one substantially-lateral portion of the plurality of offset production wells decline through the subterranean reservoir.

17. The method of claims **1**, wherein at least one substantially-lateral portion of the plurality of offset production wells extend substantially through a down-dip side of the subterranean reservoir.

18. A method of recovering hydrocarbons from a subterranean reservoir, the method comprising:
- drilling a substantially-vertical primary production well;
- drilling a plurality of offset production wells around the substantially-vertical primary production well in a radial orientation;
- drilling a plurality of offset injection wells around the substantially-vertical primary production well in a radial orientation, wherein each one of the plurality of offset injection wells is disposed between a pair of the plurality of offset production wells;
- injecting, via the plurality of offset injection wells, a liquid to mobilize the hydrocarbons from the subterranean reservoir causing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for secondary recovery; and
- injecting, via the plurality of offset injection wells, a gas to mobilize the hydrocarbons from the subterranean reser-

voir causing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for tertiary recovery.

19. The method according to claim **18**, wherein the liquid includes additives.

20. The method according to claim **18**, wherein the liquid does not include additives.

21. A method of recovering hydrocarbons from a subterranean reservoir, the method comprising:

drilling a substantially-vertical primary production well;

drilling a plurality of offset production wells and a plurality of offset injection wells around the substantially-vertical primary production well creating an alternating pattern of offset production wells and offset injection wells;

injecting, via the plurality of offset injection wells, a liquid to mobilize the hydrocarbons from the subterranean reservoir causing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for secondary recovery; and

injecting, via the plurality of offset injection wells, a gas to mobilize the hydrocarbons from the subterranean reservoir causing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for tertiary recovery.

22. A method of recovering hydrocarbons from a subterranean reservoir, the method comprising:

drilling a substantially-vertical primary production well;

drilling a plurality of offset production wells on one side of the substantially-vertical primary production;

drilling a plurality of offset injection wells on an opposite side of the substantially-vertical primary production;

injecting, via the plurality of offset injection wells, a liquid to mobilize the hydrocarbons from the subterranean reservoir causing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for secondary recovery; and

injecting, via the plurality of offset injection wells, a gas to mobilize the hydrocarbons from the subterranean reservoir causing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for tertiary recovery.

23. A method of recovering hydrocarbons from a subterranean reservoir, the method comprising:

drilling a substantially-vertical primary production well;

drilling a plurality of offset production wells and a plurality of offset injection wells around the substantially-vertical primary production well in a random pattern;

injecting, via the plurality of offset injection wells, a liquid to mobilize the hydrocarbons from the subterranean reservoir causing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for secondary recovery; and

injecting, via the plurality of offset injection wells, a gas to mobilize the hydrocarbons from the subterranean reservoir causing the mobilized hydrocarbons to migrate towards the plurality of offset production wells for tertiary recovery.

24. A well pattern to recover hydrocarbons from a subterranean reservoir comprising:

a substantially-vertical primary production well extending into the subterranean reservoir;

a plurality of offset production wells extending into the subterranean reservoir around the substantially-vertical primary production well in a radial orientation;

a plurality of offset injection wells extending into the subterranean reservoir around the substantially-vertical primary production well in a radial orientation;

the plurality of offset injection wells operable to inject a liquid to mobilize the hydrocarbons from the subterranean reservoir so that the mobilized hydrocarbons migrate towards the plurality of offset production wells for secondary recovery; and

the plurality of offset injection wells operable to inject a gas to mobilize the hydrocarbons from the subterranean reservoir so that the mobilized hydrocarbons migrate towards the plurality of offset production wells for tertiary recovery.

25. A well pattern to recover hydrocarbons from a subterranean reservoir comprising:

a substantially-vertical primary production well extending into abandoned coal mining voids;

a plurality of offset injection wells extending into the subterranean reservoir around the perimeter of the abandoned coal mining voids in a radial orientation; and

the plurality offset injection wells operable to inject a gas to mobilize the hydrocarbons from the subterranean reservoirs so that the mobilized hydrocarbons migrate towards the abandoned coal mining voids for hydrocarbon recovery.

26. The well pattern of claim **25**, wherein the gas is selected from the group consisting of carbon dioxide, nitrogen, hydrogen, and combinations thereof.

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