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

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(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.

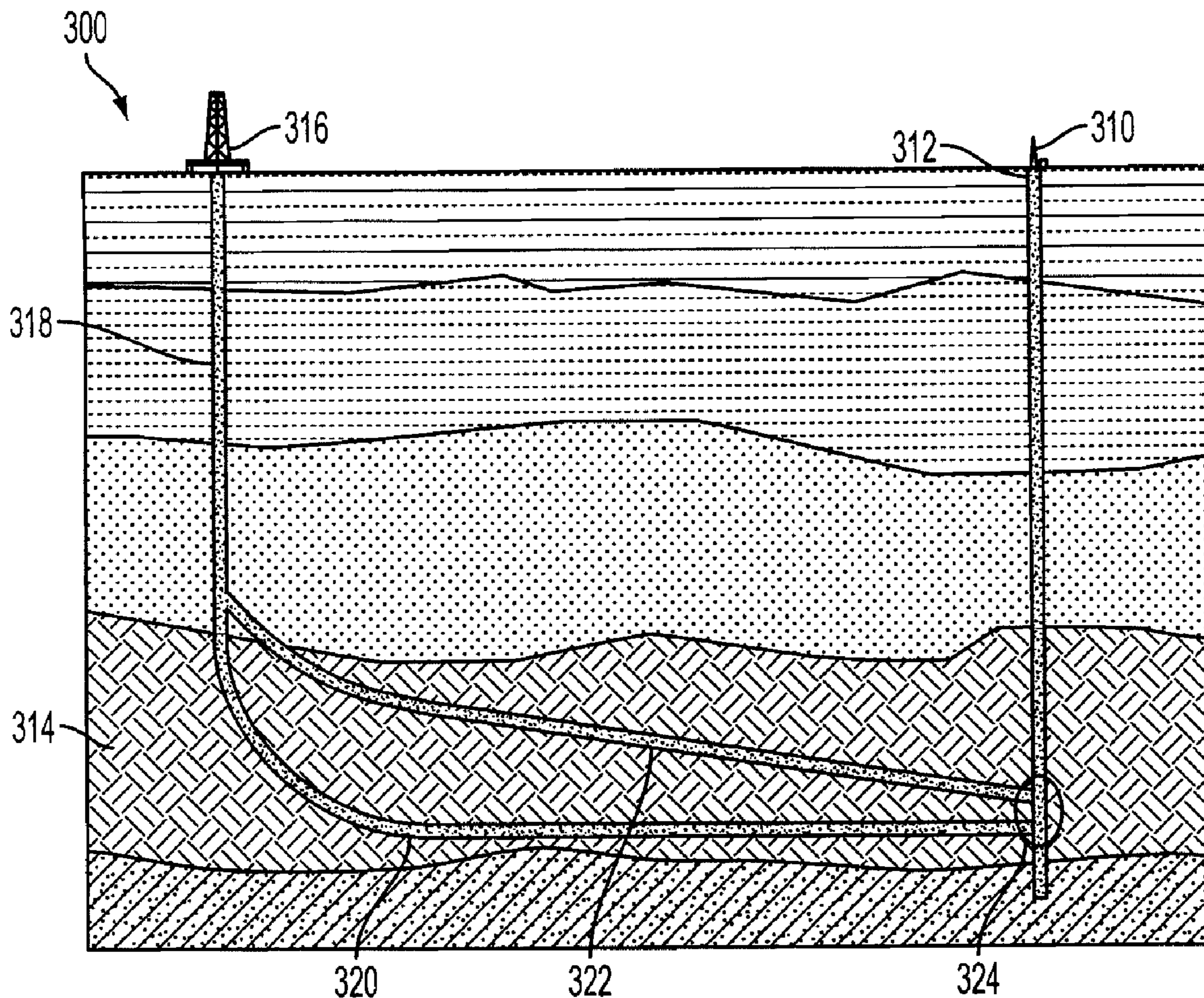
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(60) Provisional application No. 61/080,314, filed on Jul. 14, 2008.



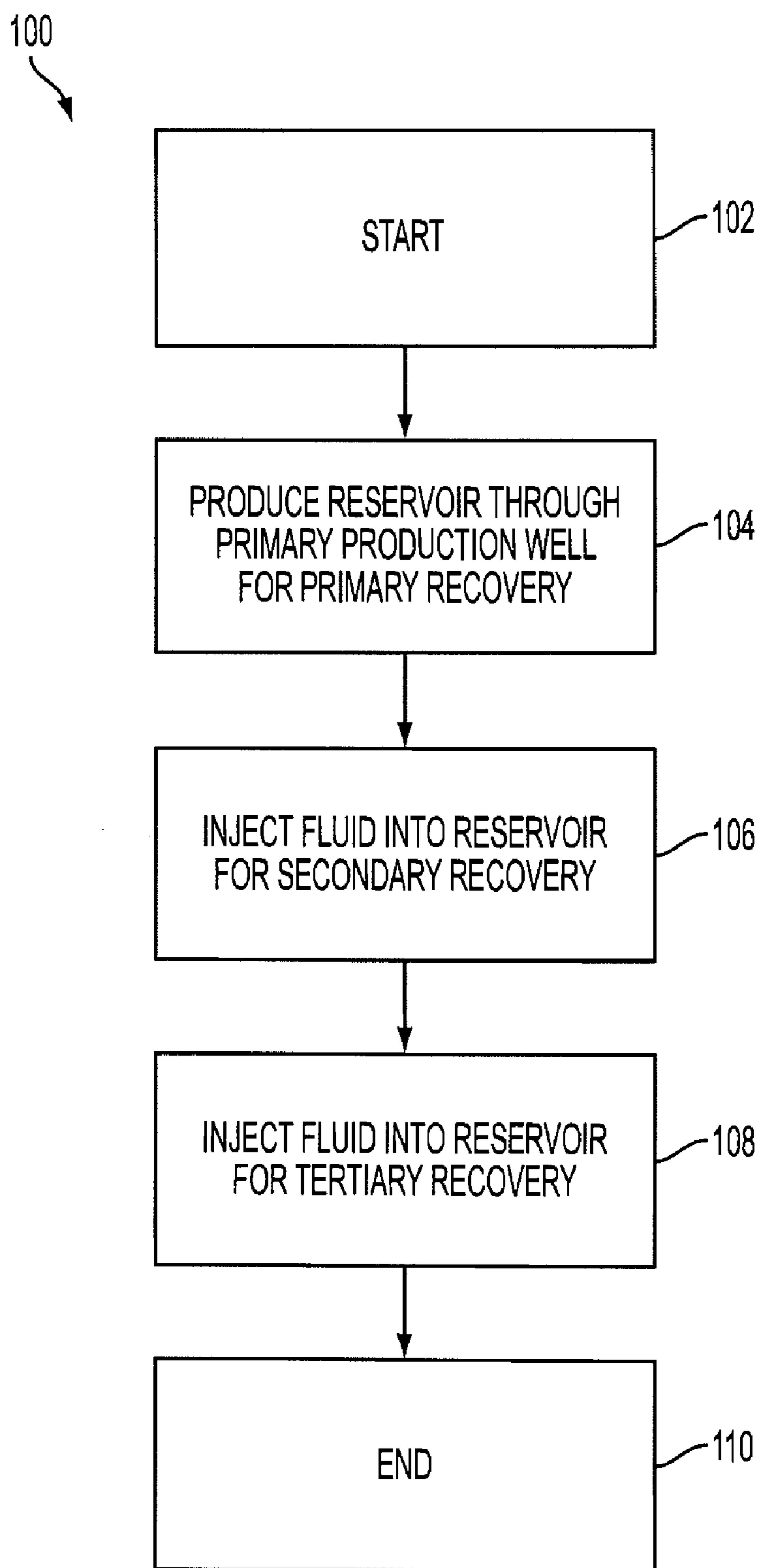


FIG. 1

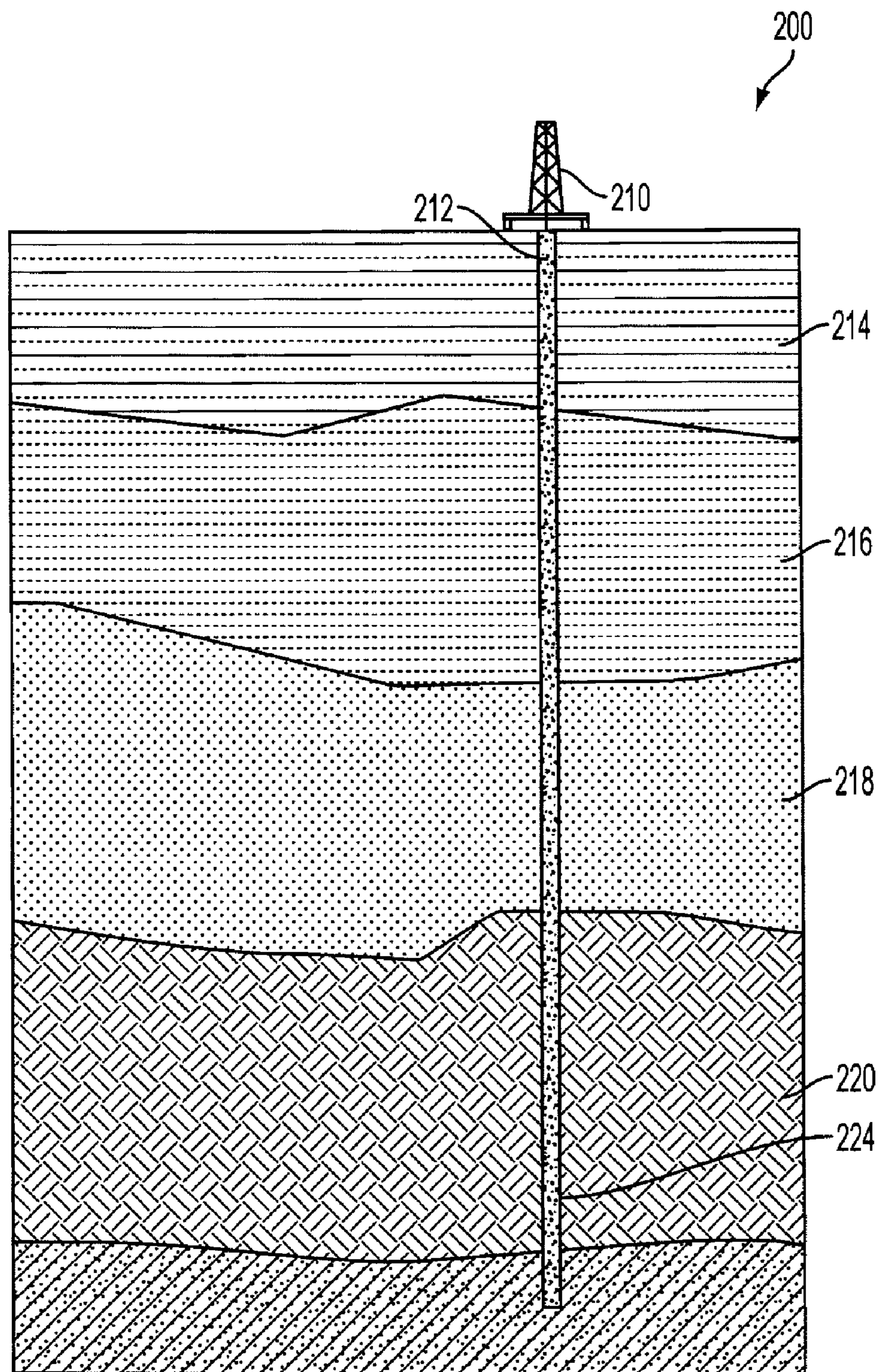


FIG. 2

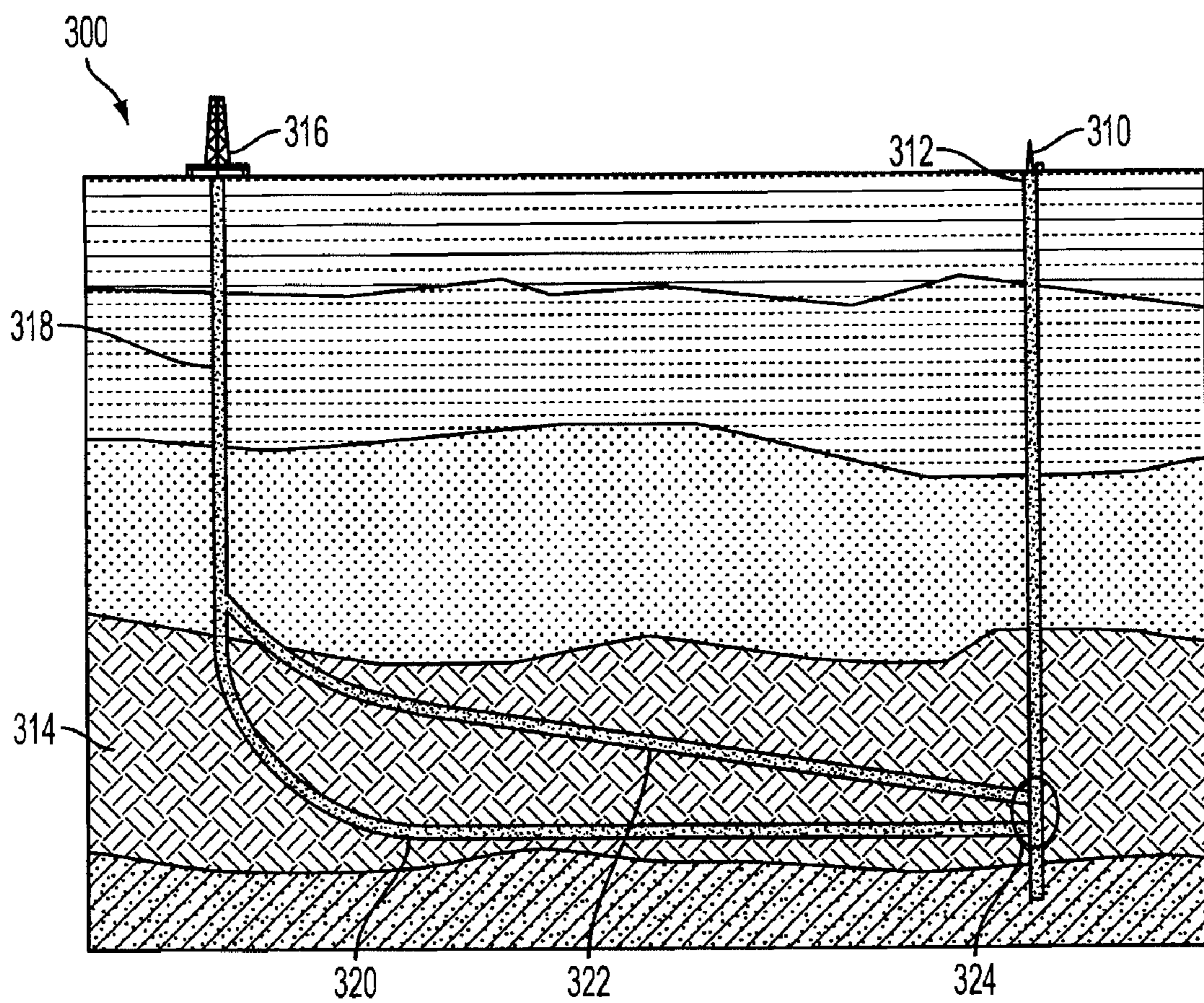


FIG. 3

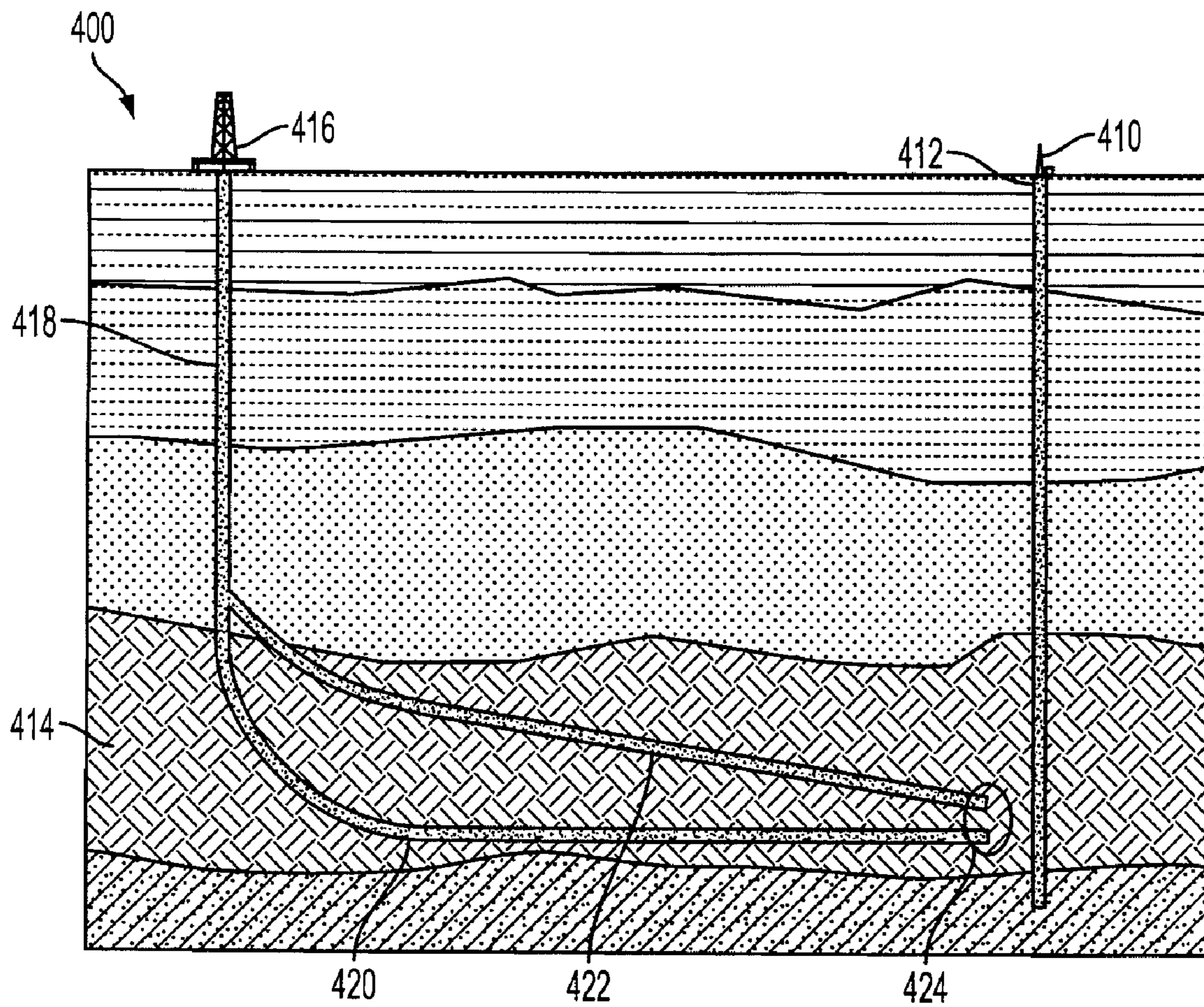


FIG. 4

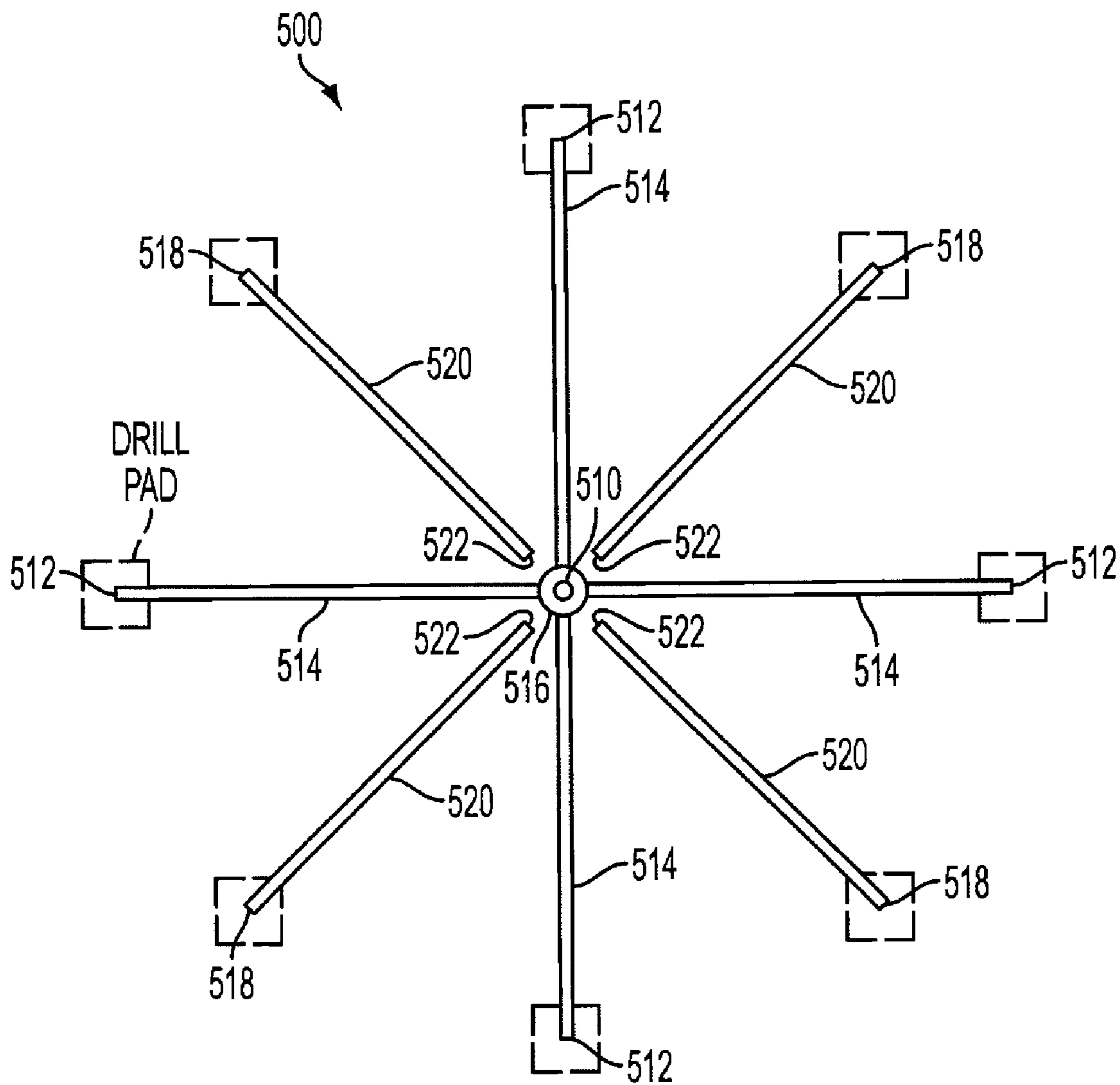


FIG. 5A

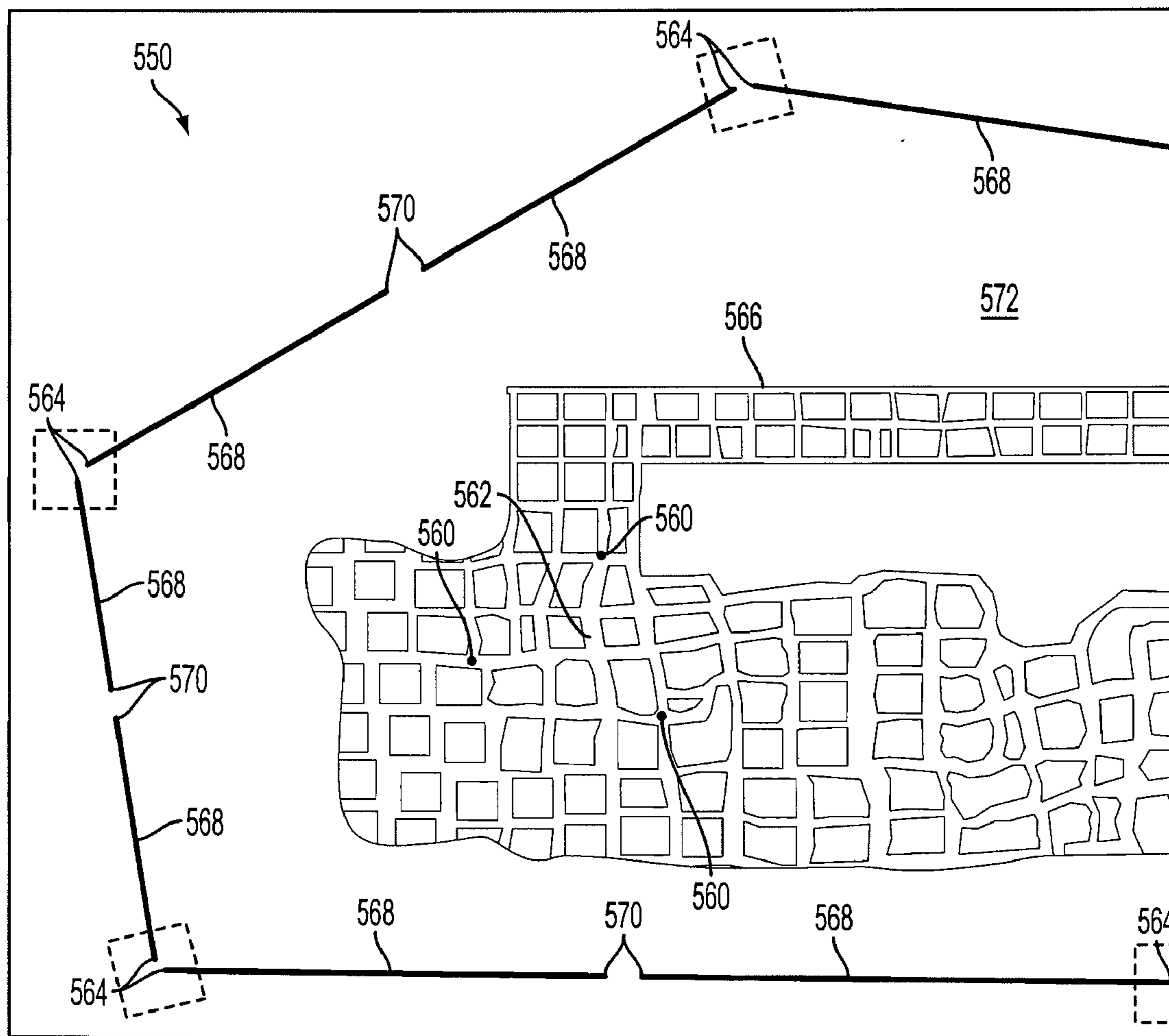


FIG. 5B

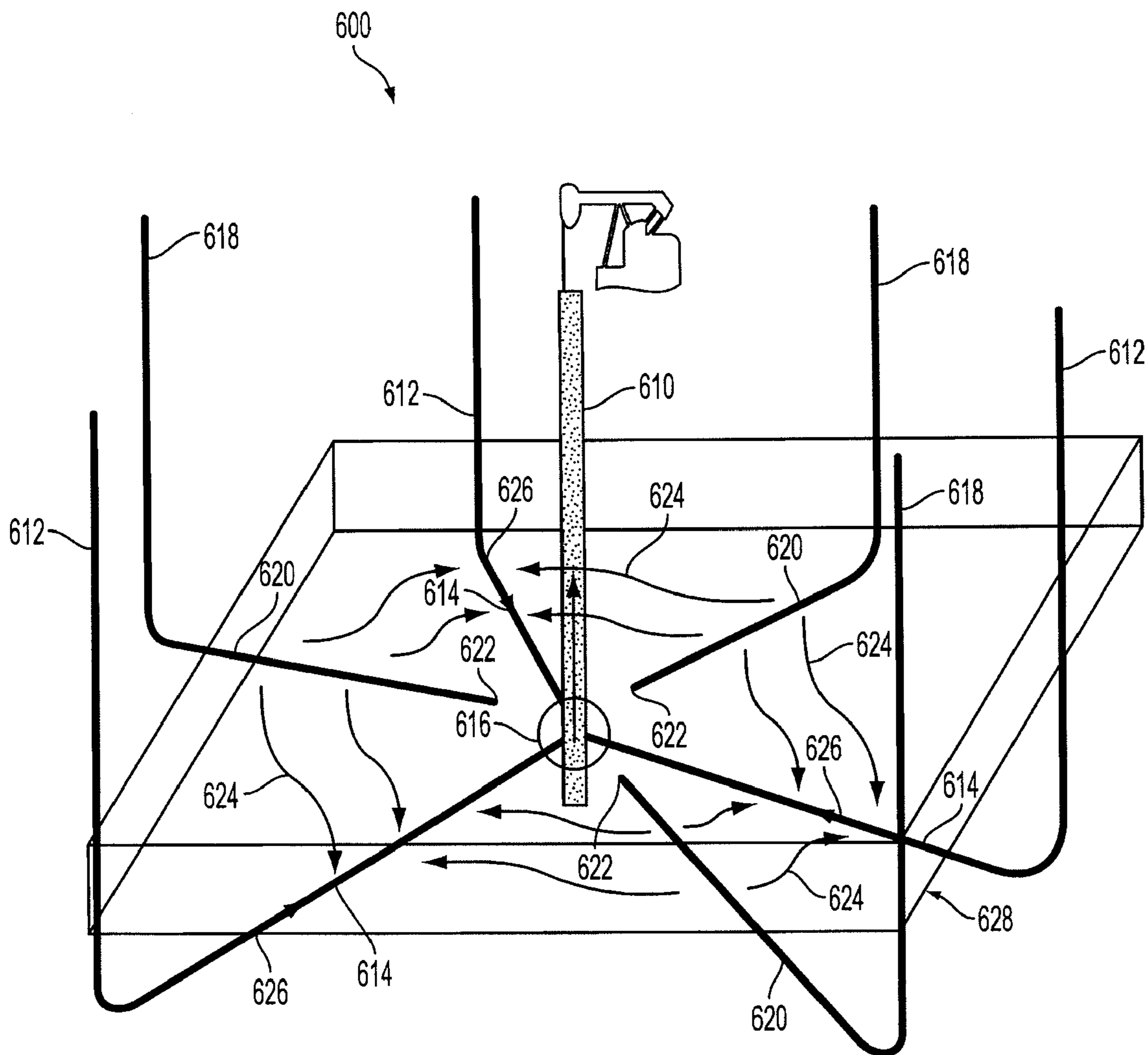


FIG. 6

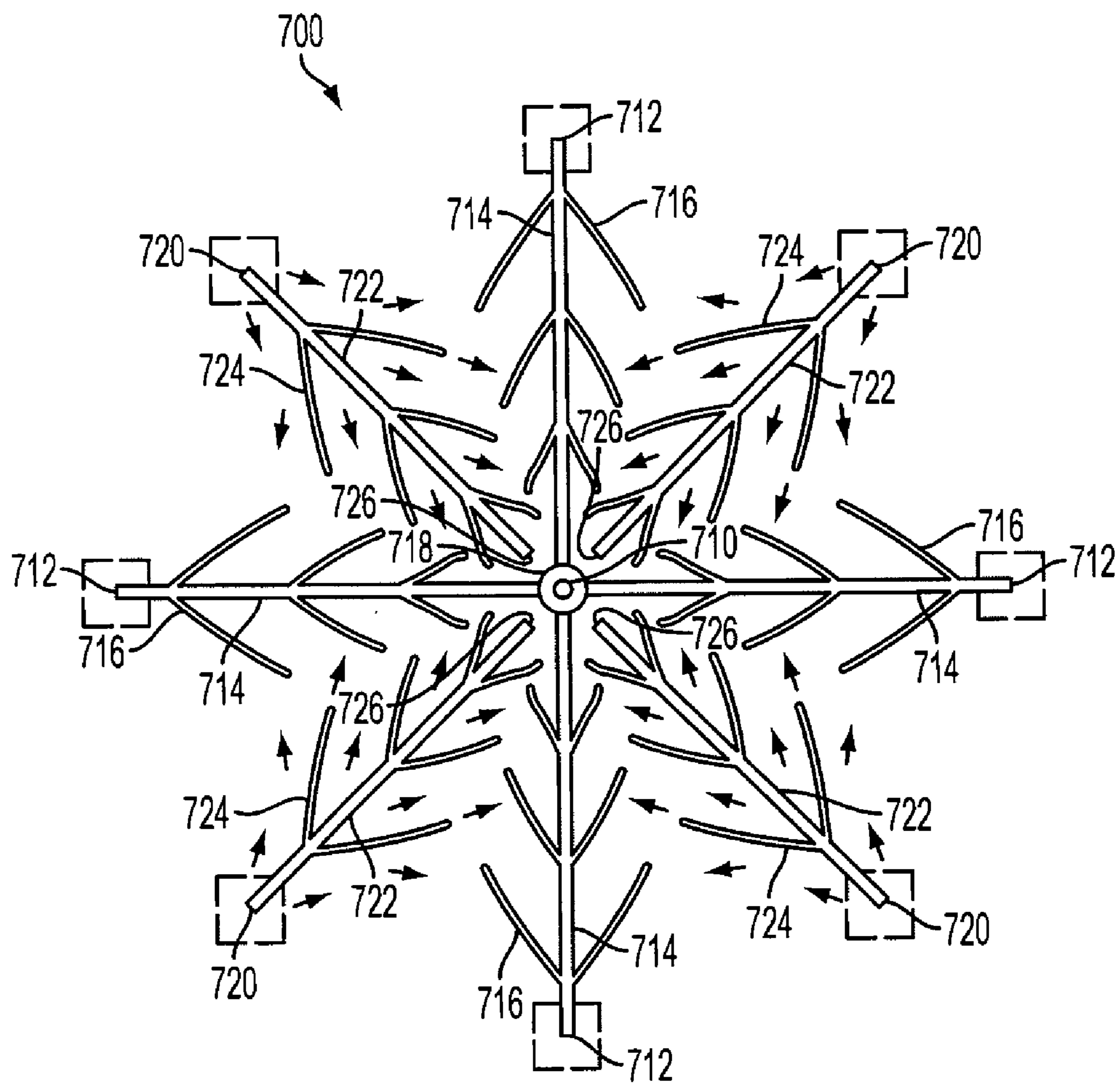


FIG. 7

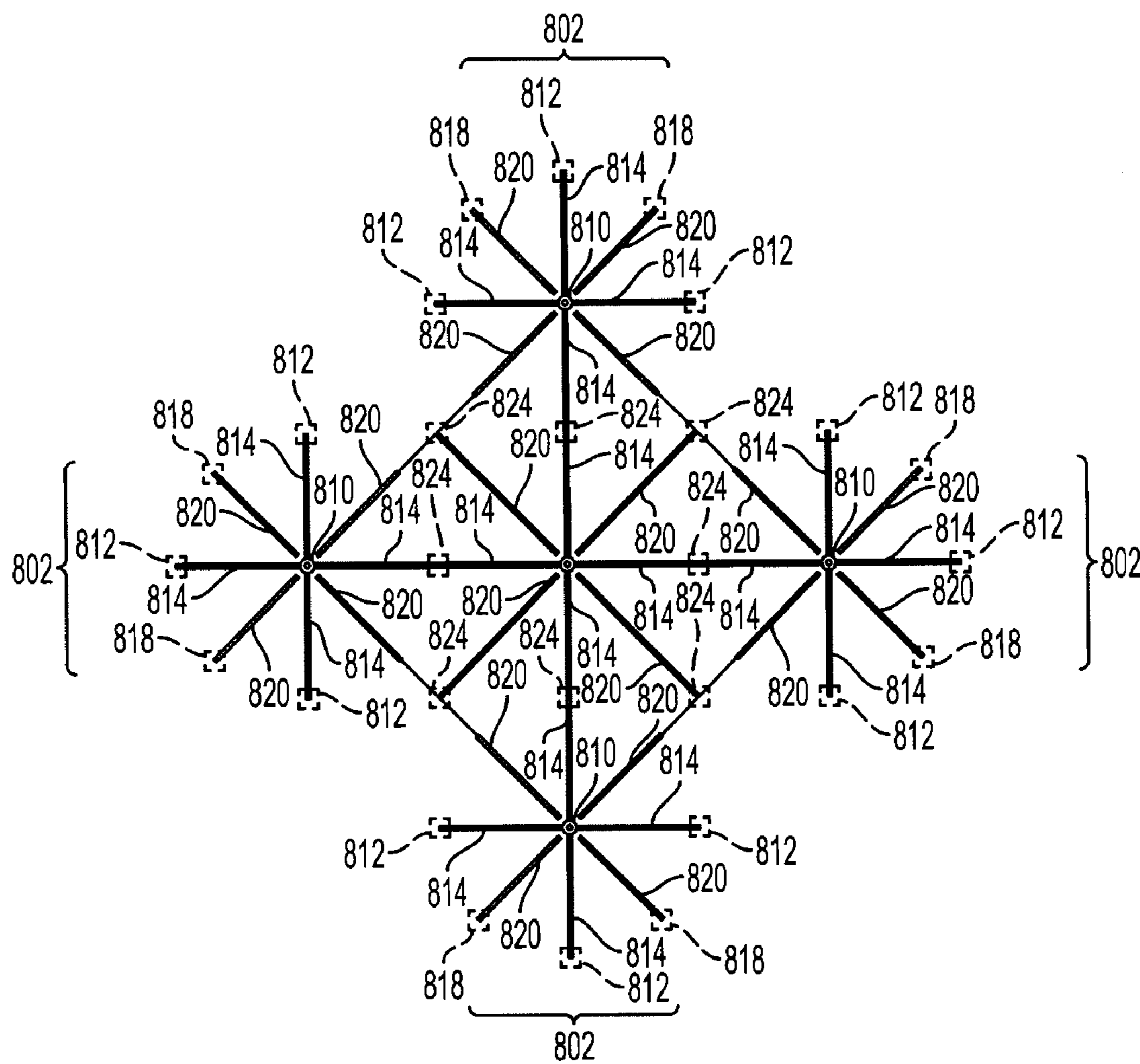


FIG. 8

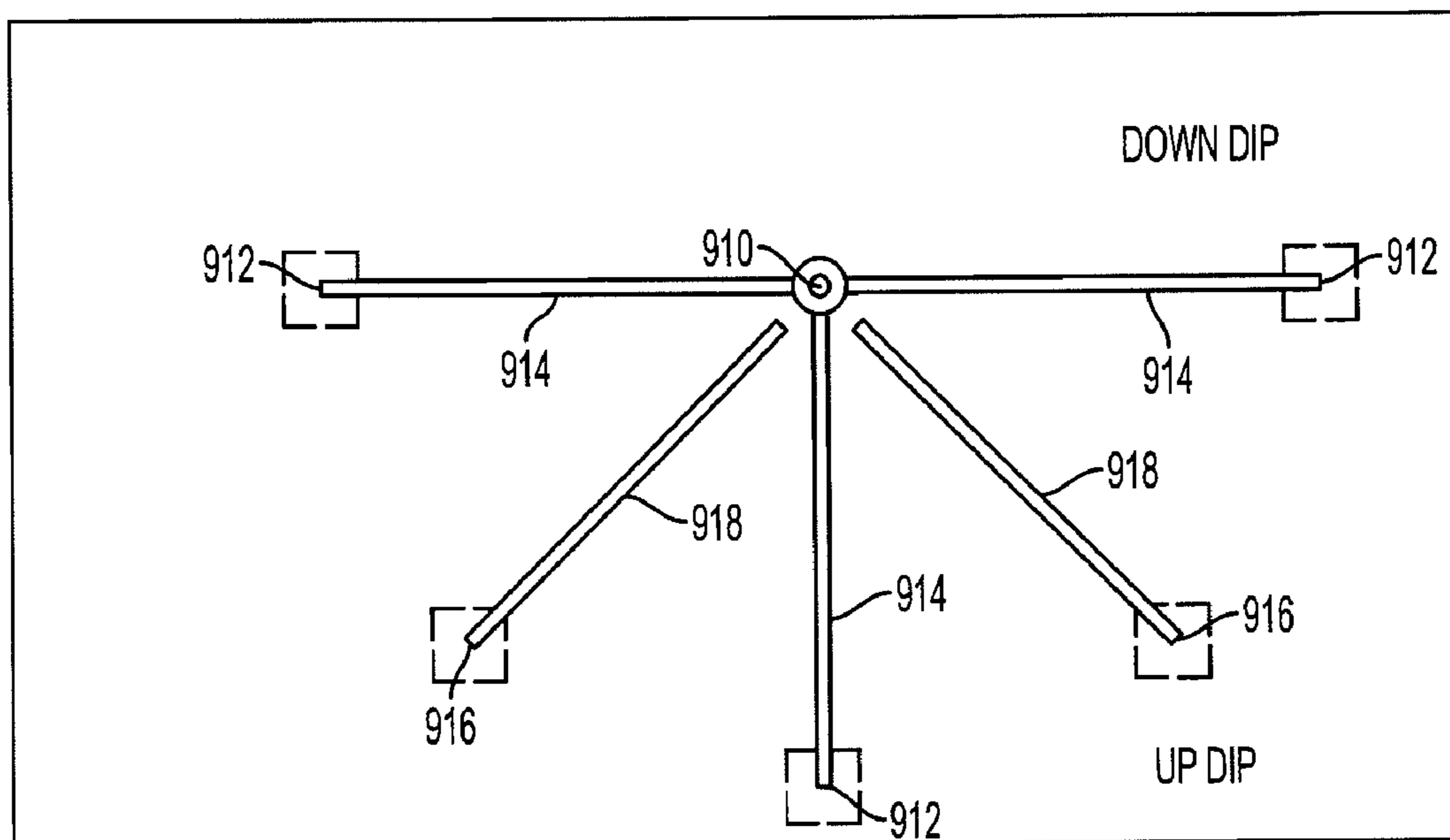


FIG. 9

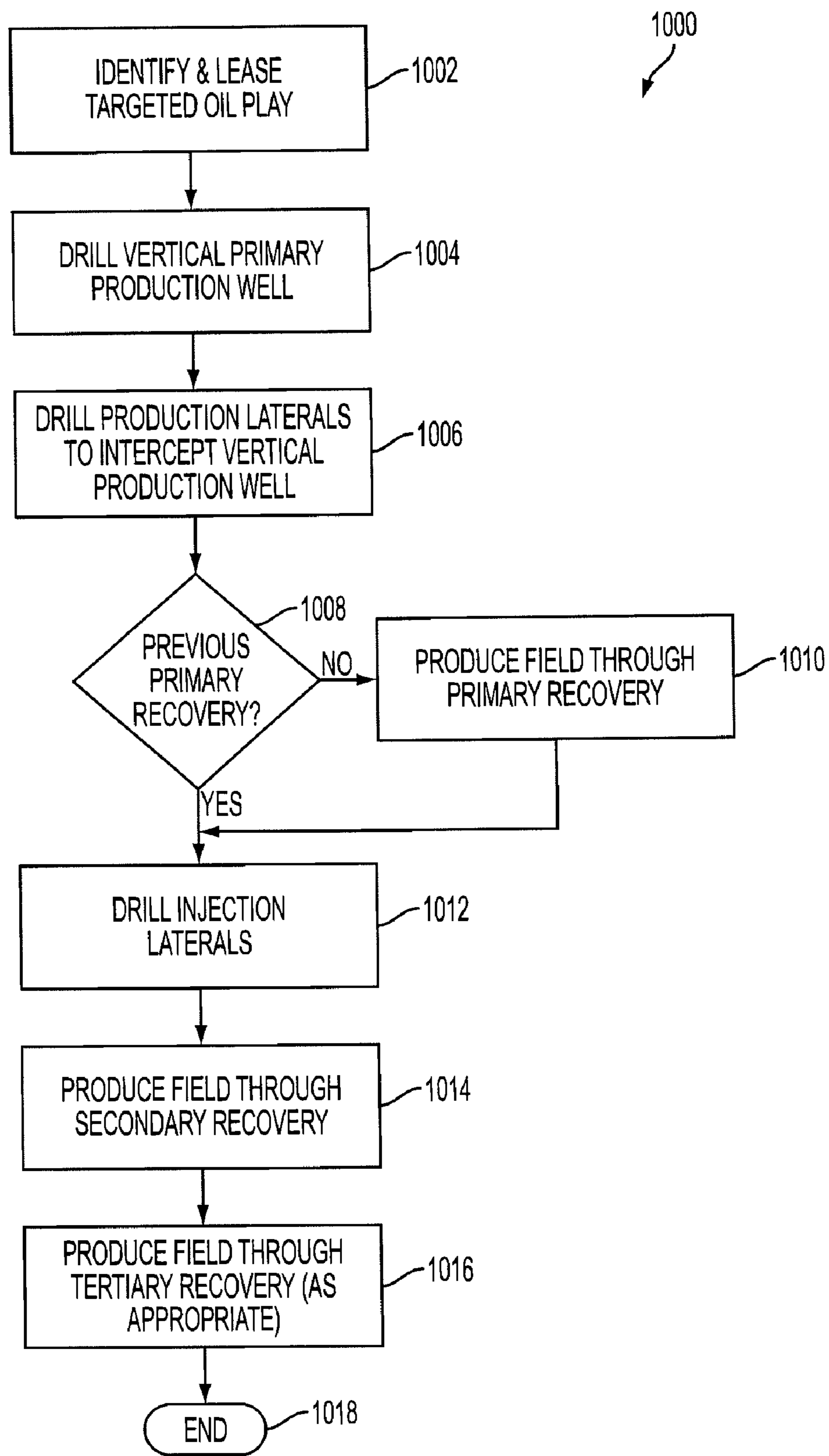


FIG. 10

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 are 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. 5A is a plan view of a hydrocarbon recovery system in accordance with an embodiment of the present invention;

[0020] FIG. 5B 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. 5A, 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. 5A, 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 production wells 512 are in fluid communication with the substantially-vertical primary production well 510 via the intersection region 516.

[0042] Referring now to FIG. 5B, 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 substan-

tially-vertical primary production well 560 extending into abandoned coal mining voids 562. In the embodiment shown in FIG. 5B, 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. 5A (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. 5A 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 substan-

tially-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 of 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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