(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
28 February 2013 (28.02.2013)

WIPO | PCT

(10) International Publication Number
WO 2013/028752 A2

(51) International Patent Classification:
E21B 43/24 (2006.01)

(21) International Application Number:
PCT/US2012/051849

(22) International Filing Date:
22 August 2012 (22.08.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
13/215,663 23 August 2011 (23.08.2011) US

(71) Applicant *(for all designated States except US)*: **HARRIS CORPORATION** [US/US]; 1025 W. NASA Blvd., MS A-11I, Melbourne, Florida 32919 (US).

(72) Inventors: **PARSCHE, Francis Eugene**; 1107 Glenham Drive NE, Palm Bay, Florida 32905 (US). **TRAUTMAN, Mark**; 1001 Worthington Spring Drive, Melbourne, Florida 32940 (US).

(74) Agents: **YATSKO, Michael S.** et al.; Harris Corporation, 1025 W. NASA Blvd., MS A-11I, Melbourne, Florida 32919 (US).

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

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

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

(54) **Title**: METHOD FOR HYDROCARBON RESOURCE RECOVERY BY REPAIRING A FAILED HYDROCARBON RECOVERY ARRANGEMENT

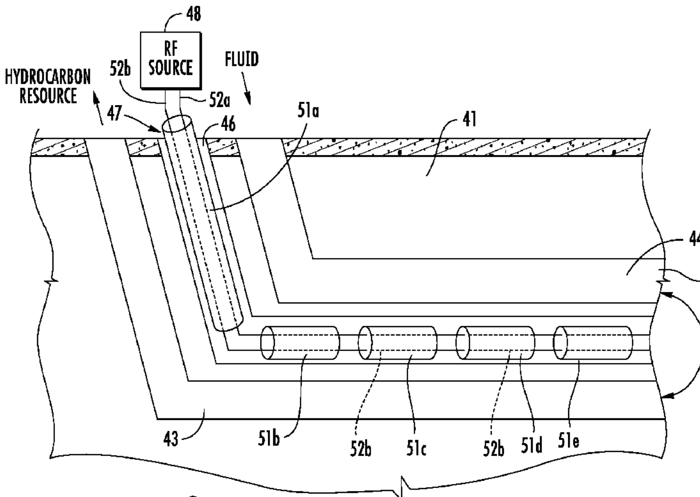


FIG. 2

(57) **Abstract**: A method of hydrocarbon resource recovery from a subterranean formation may include forming a plurality of spaced apart injector/producer well pairs in the subterranean formation, each injector/producer well pair including a laterally extending producer well, and a laterally extending injector well spaced thereabove. The method may include determining a failed injector/producer well pair from among the plurality thereof. The method may further include repairing the failed injector/producer well pair by at least forming a repair well adjacent the failed injector/producer well pair, and applying radio frequency (RF) heating from the repair well to the subterranean formation adjacent the failed injector/producer well pair. The method may further include recovering hydrocarbon resources from the plurality of injector/producer well pairs including the repaired injector/producer well.

WO 2013/028752 A2

METHOD FOR HYDROCARBON RESOURCE RECOVERY BY REPAIRING A FAILED HYDROCARBON RECOVERY ARRANGEMENT

The present invention relates to the field of hydrocarbon resource recovery, and, more particularly, to hydrocarbon resource recovery using RF heating.

Energy consumption worldwide is generally increasing, and conventional hydrocarbon resources are being consumed. In an attempt to meet demand, the exploitation of unconventional resources may be desired. For example, highly viscous hydrocarbon resources, such as heavy oils, may be trapped in tar sands where their viscous nature does not permit conventional oil well production. Estimates are that trillions of barrels of oil reserves may be found in such tar sand formations.

In some instances these tar sand deposits are currently extracted via open-pit mining. Another approach for *in situ* extraction for deeper deposits is known as Steam-Assisted Gravity Drainage (SAGD). The heavy oil is immobile at reservoir temperatures and therefore the oil is typically heated to reduce its viscosity and mobilize the oil flow. In SAGD, pairs of injector and producer wells are formed to be laterally extending in the ground. Each pair of injector/producer wells includes a lower producer well and an upper injector well. The injector/production wells are typically located in the payzone of the subterranean formation between an underburden layer and an overburden layer.

The upper injector well is used to typically inject steam, and the lower producer well collects the heated crude oil or bitumen that flows out of the formation, along with any water from the condensation of injected steam. The injected steam forms a steam chamber that expands vertically and horizontally in the formation. The heat from the steam reduces the viscosity of the heavy crude oil or bitumen which allows it to flow down into the lower producer well where it is collected and recovered. The steam and gases rise due to their lower density so that steam is not produced at the lower producer well and steam trap control is used to the same affect. Gases, such as methane, carbon dioxide, and hydrogen sulfide, for example, may tend to rise in the steam chamber and fill the void space left by the oil defining an insulating layer above the steam. Oil and water flow is by gravity driven drainage, into the lower producer well.

Operating the injection and production wells at approximately reservoir pressure may address the instability problems that adversely affect high-pressure steam processes. SAGD may produce a smooth, even production that can be as high as 70% to 80% of the original oil in place (OOIP) in suitable reservoirs. The SAGD process may be relatively sensitive to shale streaks and other vertical barriers since, as the rock is heated, differential thermal expansion causes fractures in it, allowing steam and fluids to flow through. Moreover, hydrocarbon reservoirs may be inhomogeneous may include “thief zones” which may allow steam to escape in the SAGD wells. Local regions of relatively poor formation permeability may also be disadvantageous for hydrocarbon extraction. SAGD may be twice as efficient as the older cyclic steam stimulation (CSS) process.

Many countries in the world have large deposits of oil sands, including the United States, Russia, and various countries in the Middle East. Oil sands may represent as much as two-thirds of the world's total petroleum resource, with at least 1.7 trillion barrels in the Canadian Athabasca Oil Sands, for example. At the present time, only Canada has a large-scale commercial oil sands industry, though a small amount of oil from oil sands is also produced in Venezuela. Because of increasing oil sands production, Canada has become the largest single supplier of oil and products to the United States. Oil sands now are the source of almost half of Canada's oil production, although due to the 2008 economic downturn work on new projects has been deferred, while Venezuelan production has been declining in recent years. Oil is not yet produced from oil sands on a significant level in other countries.

U.S. Published Patent Application No. 2010/0078163 to Banerjee et al. discloses a hydrocarbon recovery process whereby three wells are provided: an uppermost well used to inject water, a middle well used to introduce microwaves into the reservoir, and a lowermost well for production. A microwave generator generates microwaves which are directed into a zone above the middle well through a series of waveguides. The frequency of the microwaves is at a frequency substantially equivalent to the resonant frequency of the water so that the water is heated.

Along these lines, U.S. Published Application No. 2010/0294489 to Dreher, Jr. et al. discloses using microwaves to provide heating. An activator is injected below the surface and is heated by the microwaves, and the activator then heats the heavy oil in the production well. U.S. Published Application No. 2010/0294489 to Wheeler et al. discloses a similar approach. The radial penetration depth of microwaves may be insufficient for timely and economic recovery of hydrocarbon resources. For example, oil sand strata may be 10 or more meters thick, yet the depth of a 2450 MHz microwave for heating may penetrate about 9 inches.

U.S. Patent No. 7,441,597 to Kasevich discloses using a radio frequency generator to apply RF energy to a horizontal portion of an RF well positioned above a horizontal portion of a oil/gas producing well. The viscosity of the oil is reduced as a result of the RF energy, which causes the oil to drain due to gravity. The oil is recovered through the oil/gas producing well.

To improve the SAGD process, for example, SAGD wells may be monitored, and more particularly, an injection process may be monitored, as disclosed by U.S. Patent No. 7,640,133 to Monmont et al. A tool that includes a temperature sensor, a pressure sensor, and a flow rate meter is used for measuring temperature, pressure, and velocity at various measurement locations along an injector portion of a wellbore. The tool is conveyed along the wellbore by coiled tubing which is capable of being repeatedly coiled and uncoiled from a truckable spool.

Unfortunately, long production times, for example, due to a failed start-up, to extract oil using SAGD may lead to significant heat loss to the adjacent soil, excessive consumption of steam, and a high cost for recovery. Over fifty percent of failed start-ups, for example, are typically abandoned. Significant water resources are also typically used to recover oil using SAGD which impacts the environment. Limited water resources may also limit oil recovery. SAGD is also not an available process in permafrost regions, for example.

In view of the foregoing background, it is therefore an object of the present invention to recover a hydrocarbon resource from a failed injector/producer well pair.

This and other objects, features, and advantages in accordance with the present invention are provided by a method of hydrocarbon resource recovery from a subterranean formation that includes forming a plurality of spaced apart injector/producer well pairs in the subterranean formation, each injector/producer well pair including a laterally extending producer well, and a laterally extending injector well spaced thereabove. The method also includes determining a failed injector/producer well pair from among the plurality thereof. The method further includes repairing the failed injector/producer well pair by at least forming a repair well adjacent the failed injector/producer well pair, and applying radio frequency (RF) heating from the repair well to the subterranean formation adjacent the failed injector/producer well pair. The method further includes recovering hydrocarbon resources from the plurality of injector/producer well pairs including the repaired injector/producer well. Accordingly, a failed injector/producer well pair may be repaired so that the hydrocarbon resources may be recovered.

Determining a failed injector/producer well pair may be based upon at least one of a fluid flow and a temperature associated with the failed injector/producer well pair. Applying RF heating may include applying the RF heating to increase hydraulic communication between the failed injector/producer well pair along a length thereof, for example. Recovering hydrocarbon resources may include using Steam Assisted Gravity Drainage (SAGD).

Applying RF heating may include positioning at least one RF applicator within the repair well. Applying RF heating may also include supplying RF energy to the at least one RF applicator, for example.

The at least one RF applicator may include a plurality of tubular conductors arranged in end-to-end relation, and a pair of spaced apart feed conductors extending within the plurality of tubular conductors and coupled thereto. The at least one RF applicator may further include a dielectric layer on each of the plurality of tubular conductors, for example. The at least one RF applicator may be positioned to at least one predetermined location within the repair well to selectively apply RF heating to at least one corresponding portion of the subterranean formation, for example.

FIG. 1 is a flow chart of a method of repairing a failed injector/producer well pair in accordance with the present invention.

FIG. 2 is a schematic diagram of a hydrocarbon resource recovery arrangement for use with the method of FIG. 1.

FIG. 3 is a flow chart of a method of hydrocarbon resource recovery in accordance with the present invention.

FIG. 4 is a cross-sectional view of a portion of an RF applicator of according to an embodiment of the present invention.

FIG. 5 is a flow chart of a method of hydrocarbon resource recovery according to another embodiment of the present invention.

FIG. 6a is a schematic diagram of a hydrocarbon resource arrangement for use with the method of FIG. 5.

FIG. 6b is an enlarged cross-sectional view of a portion of the RF applicator in FIG. 6a.

FIG. 7 is a more detailed flow chart of the method of hydrocarbon resource recovery of FIG. 5.

FIG. 8 is a flow chart of a method of hydrocarbon resource recovery according to another embodiment of the present invention.

FIG. 9a is a schematic diagram of a hydrocarbon resource arrangement for use with the method of FIG. 8.

FIG. 9b is a enlarged cross-sectional view of a portion of the RF sensor in FIG. 9a.

FIG. 10 is a more detailed flow chart of the method of hydrocarbon resource recovery of FIG. 8.

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these 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. Like numbers refer to like elements throughout, and prime and multiple prime notation is used to indicate similar elements in alternative embodiments.

Referring initially to the flowchart **20** in FIG. 1, and FIG. 2, beginning at Block **22**, a method of repairing a failed injector/producer well pair **42** from among a plurality of spaced apart injector/producer well pairs in a subterranean formation **41** is now described. Each injector/producer well pair includes a laterally extending producer well **43** and a laterally extending injector well **44** spaced thereabove as illustrated. The method includes, at Block **24**, forming a repair well **46** adjacent the failed injector/producer well pair **42**. More particularly, the repair well **46** may be formed between each well of the failed injector/producer well pair **42**.

A well pair **42** may fail because of insufficient hydrocarbon resource, i.e. bitumen, mobility, for example. In particular, convective flow may convey steam heat, but it may be increasingly difficult to initiate this flow at the outset. RF heating may provide initial softening of the hydrocarbon resource to initiate convective flow. In particularly cold subterranean formations, when steam is used, the relatively high hydrocarbon resource viscosity may not allow any steam to penetrate the subterranean formation through the laterally extending injector well **44**, or the steam may escape at an undesired location. Other reasons for an injector/producer well pair **42** to fail will be appreciated by those skilled in the art.

At Block **26**, the method includes applying radio frequency (RF) heating from the repair well **46** to the subterranean formation **41** adjacent the failed injector/producer well pair **42**. As will be appreciated by those skilled in the art, the RF heating may soften or improver permeability of the hydrocarbon resource to allow the desired operation of the failed injector/producer well pair **42** so that hydrocarbon resources may be recovered from the laterally extending producer well **43**. In other words, the RF heating may be applied to increase, for example, improve or establish, hydraulic communication between the failed injector/producer well pair **42** along a length thereof to repair the failed injector/producer well pair. The method ends at Block **28**.

Referring now additionally to the flowchart **60** in FIG. 3, beginning at Block **62**, the method of hydrocarbon resource recovery includes forming spaced apart injector/producer well pairs in a subterranean formation **41** (Block **64**). The subterranean formation **41** may include an oil sand formation, for example. Each injector/producer well pair **42** includes a laterally extending producer well **43** and laterally extending injector well **44** spaced above the laterally extending injector well.

The method also includes, at Block **66**, determining a failed well pair **42** from among the spaced apart injector/producer well pairs. The determination of whether a well pair has failed may be based upon one or more of a fluid flow and a temperature associated with the failed injector/producer well pair **42**. For example, a fluid that may include a gas (e.g., steam), liquid, or combination of gas and liquid, that may be injected into the laterally extending injector well **44** may not flow properly into the subterranean formation **41** when steam, for example, escapes from a location other than a distal end **45** thereof. Additionally, for example, a temperature reading at the injector or producer wells **43**, **44** may indicate that steam may not flow properly in the injector, producer, or into the subterranean formation **41**.

Other indicia of a failure may include insufficient or no fluid flow, for example. One way, in particular, of determining whether the well pair **42** has failed is by measuring a back pressure of the injector well **44**. A failed well pair **42** may be determined using other techniques, as will be appreciated by those skilled in the art.

As noted above, a well pair may fail because of insufficient hydrocarbon resource, i.e. oil, mobility, for example. In particularly cold subterranean formations, when steam is used, the relatively high hydrocarbon viscosity may not allow any steam to flow, or the steam may escape at an undesired location. Conduction, for starting convection, is often unreliable, as steam may escape to a “thief zone” or the surface, for example. Other reasons for an injector/producer well pair to fail will be appreciated by those skilled in the art.

Once a well pair has been determined as being failed, the method further includes repairing the failed injector/producer well pair **42**. Repairing the failed injector/producer well pair **42** includes, at Block **68**, forming a repair well **46** adjacent the failed injector/producer well. The repair well **46** is also laterally extending in the subterranean formation **41** and is positioned between the failed injector/producer well pair **42**. Of course, as will be appreciated by those skilled in the art, the repair well **46** may be positioned in another configuration adjacent the failed injector/producer well pair **42**.

In some embodiments, repairing the failed injector/producer well **42** may include optionally sensing a quantity associated with the subterranean formation **41** from within the repair well **46** (Block **70**). The sensed quantity may be an impedance, for example. The sensed quantity may be particularly advantageous for determining a location of the failure, as will be appreciated by those skilled in the art. Further details of sensing will be explained below.

RF heating is applied from the repair well **46** to the subterranean formation **41** adjacent the failed injector/producer well pair **42**. More particularly, an RF applicator **47** is positioned within the repair well **46** (Block **72**).

Positioning of the RF applicator **47** may be based upon the sensing, for example. In some embodiments, the RF applicator **47** may be positioned to a predetermined location within the repair well to selectively apply RF heating to the corresponding portion of the subterranean formation. This may be particularly advantageous, for example, when the failure of the failed injector/producer well pair **42** has been isolated to the predetermined location, as will be appreciated by those skilled in the art.

RF energy is supplied from an RF source **48** above the subterranean formation **41** to the RF applicator **47** (Block **74**) to apply the RF heating. RF heating may be applied to increase hydraulic communication between the failed injector/producer well pair **42** along an entire length thereof. More particularly, RF heating may be applied so that fluid that may be injected into the injector well **44** may result in hydrocarbon resources being collected at the producer well **43**, for example, as in steam assisted gravity drainage (SAGD) recovery. As will be appreciated by those skilled in the art, the RF heating may soften or improve the permeability of the hydrocarbon resource to allow the desired fluid flow.

The RF applicator **47** illustratively includes tubular conductors **51a-51e** arranged in end-to-end relation. The laterally extending tubular conductors **51b-51e** may have a length sized to be at a natural resonance at a desired operating frequency of the RF source **48**. The length corresponding to the natural resonance may be about a half-wavelength of a desired operating frequency of the RF source **48**, and may be determined according to the equation $l = c/2f\sqrt{\varepsilon_r}$, where l is the length of each tubular conductor **51a**, c is the speed of light, f is the frequency of the RF source, and ε_r is the dielectric permittivity of the subterranean formation **41**. A typical operating frequency range is about 3-30 MHz, for example. The tubular conductors **51a-51e** may include a metallic material, for example.

The RF applicator **47** also includes a pair of spaced apart feed conductors **52a, 52b** that extend the length of the repair well **46** and within the tubular conductors **51a-51e**. The pair of spaced apart feed conductors **52a, 52b** is coupled to the tubular conductors **51a-51e** at each tubular conductor. More particularly, the first feed conductor **52a** is coupled to a proximal end of each tubular conductors **51a-51e**, and the second feed conductor **52b** is coupled to the distal end of each tubular conductor **51a-51e** (FIG. 2). The pair of spaced apart feed conductors **52a, 52b** may be in the form of a twinaxial cable, for example.

Referring now to FIG. 4, in another embodiment, a dielectric layer **53'** may be on each tubular conductor **51a'**. More particularly, the dielectric layer **53'** may surround an outer portion of each tubular conductor **51a**'. Insulating each tubular conductor **51a'** from the adjacent subterranean formation **41'** may advantageously result in increased electrical load resistance and a reduced size for the spaced apart feed conductors **52a'**, **52b'**. Alternatively, each tubular conductor **51a'** may be configured without electrical insulation, and larger gauge spaced apart feed conductors **52a'**, **52b'** may be used. More or less tubular conductors **51a'** may be used based upon the length of the repair well **46'**. Additionally, each of the pair of spaced apart feed conductors **52a', 52b'** also includes a respective dielectric layers **54a', 54b'**. In other words, each of the pair of spaced apart feed conductors **52a', 52b'** is also electrically insulated.

Further details of the RF applicator may be found in application Serial No. 12/950,339 filed November 19, 2010, which is assigned to the assignee of the present application, and the entire contents of which are herein incorporated by reference. Of course, other types and configurations of RF applicators may be used.

After the well pair **42** has been repaired, or if was determined at Block **66** that the well pair has not failed, the hydrocarbon resource is recovered from the injector/producer well pairs including the repaired injector/producer well pair **42** (Block **76**). As described above, the hydrocarbon resource may be recovered using SAGD, for example. Other techniques for hydrocarbon resource recovery may be used, such as using hot water instead of steam may be used as will be appreciated by those skilled in the art. The method ends at Block **78**.

Referring now to the flowchart **90** in FIG. 5 and FIG. 6a another advantageous embodiment is now described. Beginning at Block **92**, the method is for hydrocarbon resource recovery in a subterranean formation **241** including a plurality of spaced apart injector/producer well pairs in the subterranean formation, wherein each injector/producer well pair includes a laterally extending producer well **243** and a laterally extending injector well **244** spaced thereabove, and an intermediate well **246** is adjacent a given injector/producer well pair. The subterranean formation **241** may include an oil sand formation, for example.

The method includes operating a positioning actuator **255** to position a radio frequency (RF) applicator **247** coupled to the positioning actuator to a predetermined location within the intermediate well **246** (Block **94**). The predetermined location may be failure location in a failed injector/producer well pair, for example. In other words, the given injector/producer well pair **242** may be a failed injector/producer well pair.

The method also includes, at Block **96**, supplying RF energy from an RF source **248** to the RF applicator **247** at the predetermined location within the intermediate well **246** to selectively heat the corresponding portion of the subterranean formation **241** adjacent the given injector/producer well pair **242**. The RF energy may be supplied to increase hydraulic communication between the given injector/producer well pair **242**, for example. More particularly, RF energy may be applied so that fluid injected into the injector well **244** may result in hydrocarbon resources being collected at the producer well **243**, for example, as in SAGD. As will be appreciated by those skilled in the art, the RF energy may soften or improve the permeability of the hydrocarbon resource to allow the desired hydrocarbon recovery and/or fluid flow.

The method also includes recovering hydrocarbon resources from the plurality of injector/producer well pairs including the given injector/producer well pair **242** (Block **98**). As described above, the hydrocarbon resource may be recovered using SAGD, for example. Other techniques for hydrocarbon resource recover may be used, for example, solvent assisted techniques, miscible processes, gas drive techniques, and hot-water drive techniques, as will be appreciated by those skilled in the art. The method ends at Block **100**.

Referring now additionally to FIG. 6b, and the flowchart **110** in FIG. 7, beginning at Block **112**, the method of hydrocarbon resource recovery from a subterranean formation **241** includes forming a plurality of spaced apart injector/producer well pairs in the subterranean formation (Block **114**). The subterranean formation **241** may include an oil sand formation, for example. Each injector/producer well pair includes a laterally extending producer well **243** and a laterally extending injector well **244** spaced thereabove. The method also includes forming an intermediate well **246** adjacent, and more particularly, between, a given injector/producer well pair **242** (Block **116**).

At Block **118**, the method optionally includes positioning a dielectric tubular liner **256** within the intermediate well **246**. The dielectric tubular liner **256** may advantageously improve RF heating uniformity, as will be appreciated by those skilled in the art.

The method also includes operating a positioning actuator **255** to position the radio frequency (RF) applicator **247** coupled to the positioning actuator **255** to at least one predetermined location within the intermediate well **246**. In particular, the method includes, at Block **120**, operating the positioning actuator **255** to position the RF applicator **247** to predetermined locations over time. In other words, the RF applicator **247** is moveable within the intermediate well **246** along a length thereof by way of the positioning actuator **255**.

The positioning actuator **255** may include a rotatable reel **257** and an electrical coupling arrangement **258** carried by the rotatable reel that may be advantageously driven by an electrical motor as would be appreciated by those skilled in the art. The electrical coupling arrangement **258** is coupled to the RF source **248** and may be in the form of slip rings, for example. The positioning actuator **255** may include other arrangements configured to position the RF applicator **247** within the intermediate well **246**.

The RF applicator **247** illustratively includes a coaxial transmission line **232** having a proximal end **233** coupled at the positioning actuator **255**. The positioning actuator **255** may hold or store the coaxial transmission line **232**, which may be flexible. The coaxial transmission line **232** may have an outer shield tube of soft corrugated copper. For example, the transmission line **232** may be Heliax® Cable, available from by Commscope, Inc., of Hickory, North Carolina. In some embodiments, other types of transmission lines may be used, for example, a shielded transmission line. The RF applicator **247** also includes a dipole antenna **234** coupled to a distal end **235** of the coaxial transmission line **232**.

In some embodiments, an end, for example, the distal end **235** of the coaxial transmission line **232** may form the dipole antenna **234**. More particularly, the inner conductor **237** of the coaxial transmission line **232** may be coupled to a conductive tube **259** carried by the outer jacket or insulation **238**, while the outer conductor **239** may extend beyond the end of the inner conductor to define the dipole antenna **234**, for example (FIG. 6b). A dielectric layer **249** is illustratively between the inner and outer conductors **237, 239**. The RF applicator **247** may include other types of transmission lines, for example, a triaxial cable, and may also include other types of antennas and antenna coupling arrangements, as will be appreciated by those skilled in the art.

At Block **122**, the method includes supplying RF energy from the RF source **248** to the RF applicator **247** at the predetermined locations within the intermediate well **246** to selectively heat the corresponding portion of the subterranean formation **241** adjacent the given injector/producer well pair **242**. In other words, the method includes supplying RF energy from the RF source **248** to the RF applicator **247** when positioned at the predetermined locations over time. RF energy may be supplied to the RF applicator **247** to heat the subterranean formation **241** and increase hydraulic communication between the given injector/producer well pair, for example.

The RF source **248** may generate about 100 to 500 kilowatts of power for selective application as in this embodiment, instead of power in the range of several megawatts as in those embodiments providing RF heating along the entire length of the well **246**. This is because the RF energy is localized at the dipole antenna **234**.

As will be appreciated by those skilled in the art, the method steps may be particularly useful for repairing the given injector/producer well pair **242** when they have failed. Additionally, moving the RF applicator **247** to different positions along the intermediate well **246** may be particularly useful for jump-starting hydrocarbon resource recovery, and/or for increased localized RF heating.

The method further includes recovering hydrocarbon resources from the plurality of injector/producer well pairs including the given injector/producer well pair **242** (Block **124**). As described above, the hydrocarbon resource may be recovered using SAGD, for example. Other techniques for hydrocarbon resource recovery may be used, for example, solvent assisted techniques, miscible processes, gas drive techniques, and hot-water drive techniques, as will be appreciated by those skilled in the art. The method ends at Block **126**.

The related hydrocarbon resource recovery apparatus **230** is for a subterranean formation **241** that includes spaced apart injector/producer well pairs in the subterranean formation, wherein each injector/producer well pair including a laterally extending producer well **243** and a laterally extending injector well **244** spaced thereabove, and an intermediate well **246** adjacent a given injector/producer well pair. The hydrocarbon resource recovery apparatus **230** includes a radio frequency (RF) applicator **247** and a positioning actuator **255** coupled to the RF applicator and configured to position the RF applicator to at least one predetermined location within the intermediate well **246**. The hydrocarbon resource apparatus **230** also includes an RF source **248** coupled to the positioning actuator **255** and configured to supply RF energy to the RF applicator **247**. The RF applicator **247** is configured to supply the RF energy to at least one predetermined location within the intermediate well **246** to selectively heat at least one corresponding portion of the subterranean formation **241** adjacent the given injector/producer well pair **242**.

Referring now to the flowchart **130** in FIG. 8 and FIG. 9a another advantageous embodiment is now described. Beginning at Block **132**, the method is for hydrocarbon resource recovery in a subterranean formation **341** including a plurality of spaced apart injector/producer well pairs in the subterranean formation, wherein each injector/producer well pair includes a laterally extending producer well **343** and a laterally extending injector well **344** spaced thereabove, and an intermediate well **346** adjacent a given injector/producer well pair. The subterranean formation **341** may include an oil sand formation, for example.

The method includes operating a positioning actuator **355** to position a radio frequency (RF) sensor **347** coupled to the positioning actuator to a predetermined location within the intermediate well **346** (Block **134**). The predetermined location may be failure location in a failed injector/producer well pair, for example. In other words, the given injector/producer well pair **342** may be a failed injector/producer well pair.

The method also includes, at Block **136**, operating the RF sensor **347** at the predetermined location within the intermediate well **346** to selectively sense the corresponding portion of the subterranean formation **341** adjacent the given injector/producer well pair **342**. The sensed data is analyzed using an RF analyzer

348. The data from the RF sensor **347** may be analyzed to establish a profile of hydraulic communication between the given injector/producer well pair **342** along a length thereof, for example. More particularly, data from the RF sensor **347** may be analyzed prior to RF heating, for example, so that fluid injected into the injector well **344** may result in hydrocarbon resources being collected at the producer well **343**, for example, as in SAGD. As will be appreciated by those skilled in the art, the sensed data may be used to build a profile to selectively heat the adjacent subterranean formation and thus soften the hydrocarbon resource to allow the desired hydrocarbon recovery and/or fluid flow.

The method also includes recovering hydrocarbon resources from the plurality of injector/producer well pairs including the given injector/producer well pair **342** (Block **138**). As described above, the hydrocarbon resource may be recovered using SAGD, for example. Other techniques for hydrocarbon resource recovery may be used, as will be appreciated by those skilled in the art. The method ends at Block **140**.

Referring now additionally to FIG. 9b, and the flowchart **150** in FIG. 10, beginning at Block **152**, the method of hydrocarbon resource recovery from a subterranean formation **341** includes forming a plurality of spaced apart injector/producer well pairs in the subterranean formation (Block **154**). The subterranean formation **341** may include an oil sand formation, for example. Each injector/producer well pair **342** includes a laterally extending producer well **343** and a laterally extending injector well **344** spaced thereabove. The method also includes forming an intermediate well **346** adjacent, and more particularly, between, a given injector/producer well pair **342** (Block **156**).

At Block **158**, the method optionally includes positioning a dielectric tubular liner **356** within the intermediate well **346**. The dielectric tubular liner **356** may advantageously improve RF sensing uniformity, as will be appreciated by those skilled in the art.

The method also includes operating a positioning actuator **355** to position an RF sensor **347** coupled to the positioning actuator to predetermined locations within the intermediate well **346**. In particular, the method includes, at Block **160**, operating the positioning actuator **355** to position the RF sensor **347** to predetermined locations over time. In other words, the RF sensor **347** is moveable within the intermediate well **346** along a length thereof by way of the positioning actuator **355**.

The positioning actuator **355** may include a rotatable reel **357** and an electrical coupling arrangement **358** carried by the rotatable reel. The electrical coupling arrangement **358** is coupled to the RF analyzer **348** and may be in the form of slip rings, for example. The positioning actuator **355** may include other arrangements configured to position the RF sensor **347** within the intermediate well **346**.

The RF sensor **347** illustratively includes a coaxial transmission line **332** having a proximal end **333** coupled at the positioning actuator **355**. The RF sensor **347** also includes a dipole antenna **334** coupled to a distal end **335** of the coaxial transmission line **332**.

More particularly, the inner conductor **337** of the coaxial transmission line **332** may be coupled to a conductive tube **359** carried by the outer jacket or insulation **338**, while the outer conductor **339** may extend beyond the end of the inner conductor to define the dipole antenna **334**, for example (FIG. 9b). A dielectric layer **349** is illustratively between the inner and outer conductors **337, 339**. The RF sensor **347** may include other types of transmission lines, for example, triaxial cable, and may also include other types of antennas and antenna coupling arrangements, as will be appreciated by those skilled in the art.

At Block **162**, the method includes operating the RF sensor **347** at the predetermined locations within the intermediate well **346** to selectively sense the corresponding portion of the subterranean formation **341** adjacent the given injector/producer well pair **342**. In other words, the method includes sensing data from the RF sensor **347** when positioned at the predetermined locations over time. Data associated with the subterranean formation **341** may be sensed by the RF sensor **347**, for example, and using the RF analyzer **348** a profile of the adjacent subterranean formation may be determined. The profile of the sensed subterranean formation **341** may be used as a basis for selectively heating the subterranean formation at the predetermined locations within the intermediate well **346** to thus increase hydraulic communication between the given injector/producer well pair **342**, for example.

The RF sensor **347** may cooperate with the RF analyzer **348** to measure and analyze an impedance, for example, of the adjacent subterranean formation. In some embodiments, time domain reflectometry may be used, for example, to sense and analyze an echo time of adjacent portions of the subterranean formation **341**. Other types of sensors may be used in conjunction with or in addition to the RF sensor **347**, such as, for example, an optical sensor, a temperature sensor, etc.

As will be appreciated by those skilled in the art, the method steps may be particularly useful for troubleshooting or repairing the given injector/producer well pair **342** when they have failed. Additionally, moving the RF sensor **347** to different positions along the intermediate well **346** may be particularly useful for localized sensing for use in jump-starting hydrocarbon resource recovery, and/or for increased localized RF heating.

The method further includes recovering hydrocarbon resources from the injector/producer well pairs including the given injector/producer well pair **342** (Block **164**). As described above, the hydrocarbon resource may be recovered using SAGD, for example. Other techniques for hydrocarbon resource recover may be used, for example, solvent assisted techniques, miscible processes, gas drive techniques, and hot-water drive techniques, as will be appreciated by those skilled in the art. The method ends at Block **166**.

The related hydrocarbon resource recovery apparatus **330** for a subterranean formation **341** that includes spaced apart injector/producer well pairs in the subterranean formation, wherein each injector/producer well pair comprising a laterally extending producer well **343** and a laterally extending injector well **344** spaced thereabove, and an intermediate well **346** adjacent a given injector/producer well pair. The hydrocarbon resource recovery apparatus **330** includes a radio frequency (RF) sensor **347** and a positioning actuator **355** coupled to the RF sensor and configured to position the RF sensor to at least one predetermined location within the intermediate well **346**. The hydrocarbon resource apparatus **330** also includes an RF analyzer **348** coupled to the positioning actuator **355**. The RF sensor **347** is configured to be operable to at the at least one predetermined location within the intermediate well **346** to selectively sense at least one corresponding portion of the subterranean formation **341** adjacent the given injector/producer well pair **342.**

Features and components of the various embodiments disclosed herein may be exchanged and substituted for one another as will be appreciated by those skilled in the art. Many modifications and other embodiments of the invention will also come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.

CLAIMS

1. A method of hydrocarbon resource recovery from a subterranean formation comprising:

forming a plurality of spaced apart injector/producer well pairs in the subterranean formation, each injector/producer well pair comprising a laterally extending producer well and a laterally extending injector well spaced thereabove;

determining a failed injector/producer well pair from among the plurality thereof;

repairing the failed injector/producer well pair by at least

forming a repair well adjacent the failed injector/producer well pair, and

applying radio frequency (RF) heating from the repair well to the subterranean formation adjacent the failed injector/producer well pair; and

recovering hydrocarbon resources from the plurality of injector/producer well pairs including the repaired injector/producer well.

2. The method according to Claim 1, wherein determining the failed injector/producer well pair comprises determining the failed injector/producer well pair based upon at least one of a fluid flow and a temperature associated with the failed injector/producer well pair.

3. The method according to Claim 1, wherein applying RF heating comprises applying the RF heating to increase hydraulic communication between the failed injector/producer well pair along a length thereof.

4. The method according to Claim 1, wherein recovering hydrocarbon resources comprises using Steam Assisted Gravity Drainage (SAGD).

5. The method according to Claim 1, wherein applying RF heating comprises:

positioning at least one RF applicator within the repair well; and

supplying RF energy to the at least one RF applicator.

6. The method according to Claim 5, wherein positioning the at least one RF applicator comprises positioning at least RF applicator comprising a plurality of tubular conductors arranged in end-to-end relation and a pair of spaced apart feed conductors extending within the plurality of tubular conductors and coupled thereto.

7. The method according to Claim 6, wherein positioning the at least one RF applicator further comprises positioning at least one RF applicator comprising a dielectric layer on each of the plurality of tubular conductors.

8. The method according to Claim 5, wherein the at least one RF applicator is positioned to at least one predetermined location within the repair well to selectively apply RF heating to at least one corresponding portion of the subterranean formation.

9. The method according to Claim 1, wherein forming the repair well comprises forming the repair well between the injector well and producer well in the failed pair thereof.

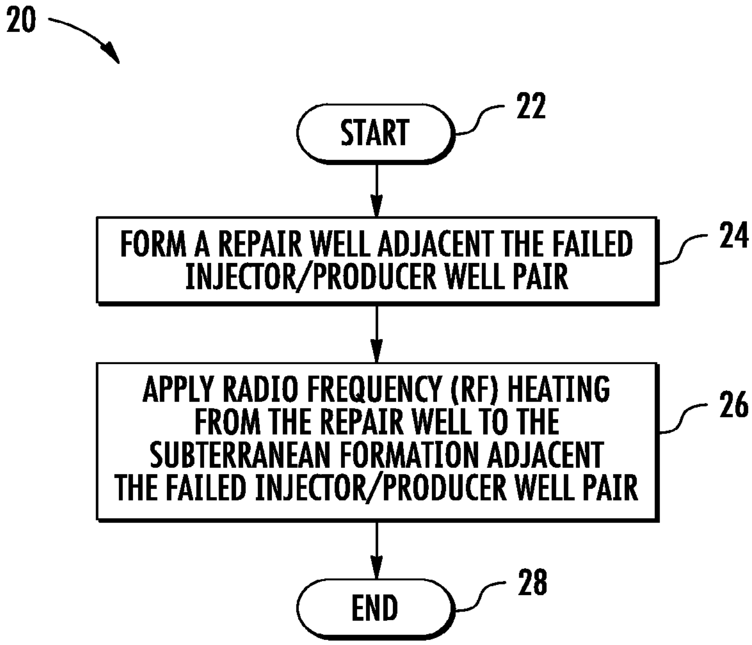

20
START
22
FORM A REPAIR WELL ADJACENT THE FAILED INJECTOR/PRODUCER WELL PAIR
24
APPLY RADIO FREQUENCY (RF) HEATING FROM THE REPAIR WELL TO THE SUBTERRANEAN FORMATION ADJACENT THE FAILED INJECTOR/PRODUCER WELL PAIR
26
END
28

FIG. 1

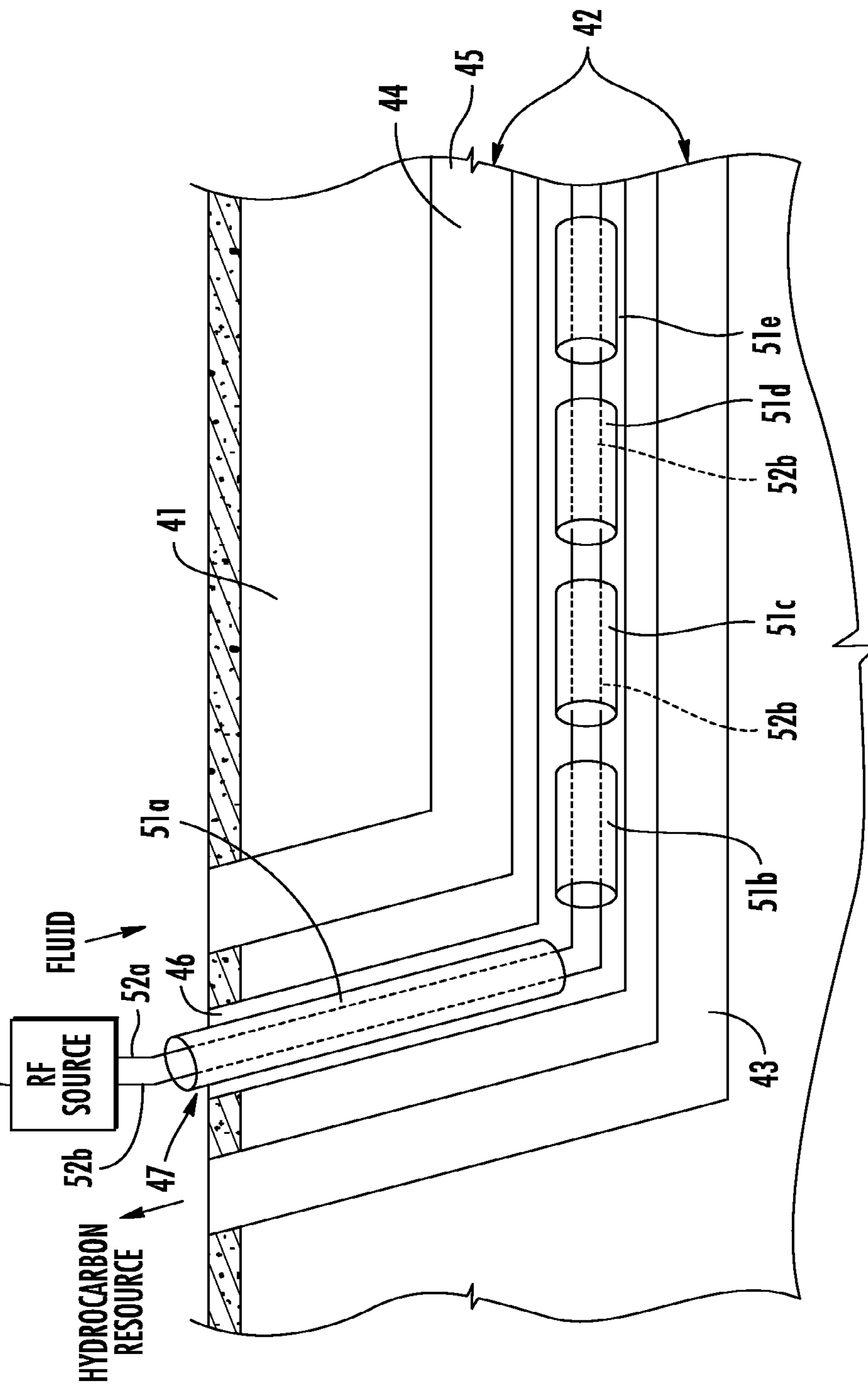

42
45
44
41
51e
51d
52b
51c
52b
51b
51a
FLUID
46
52a
48
RF SOURCE
52b
47
HYDROCARBON RESOURCE
43

FIG. 2

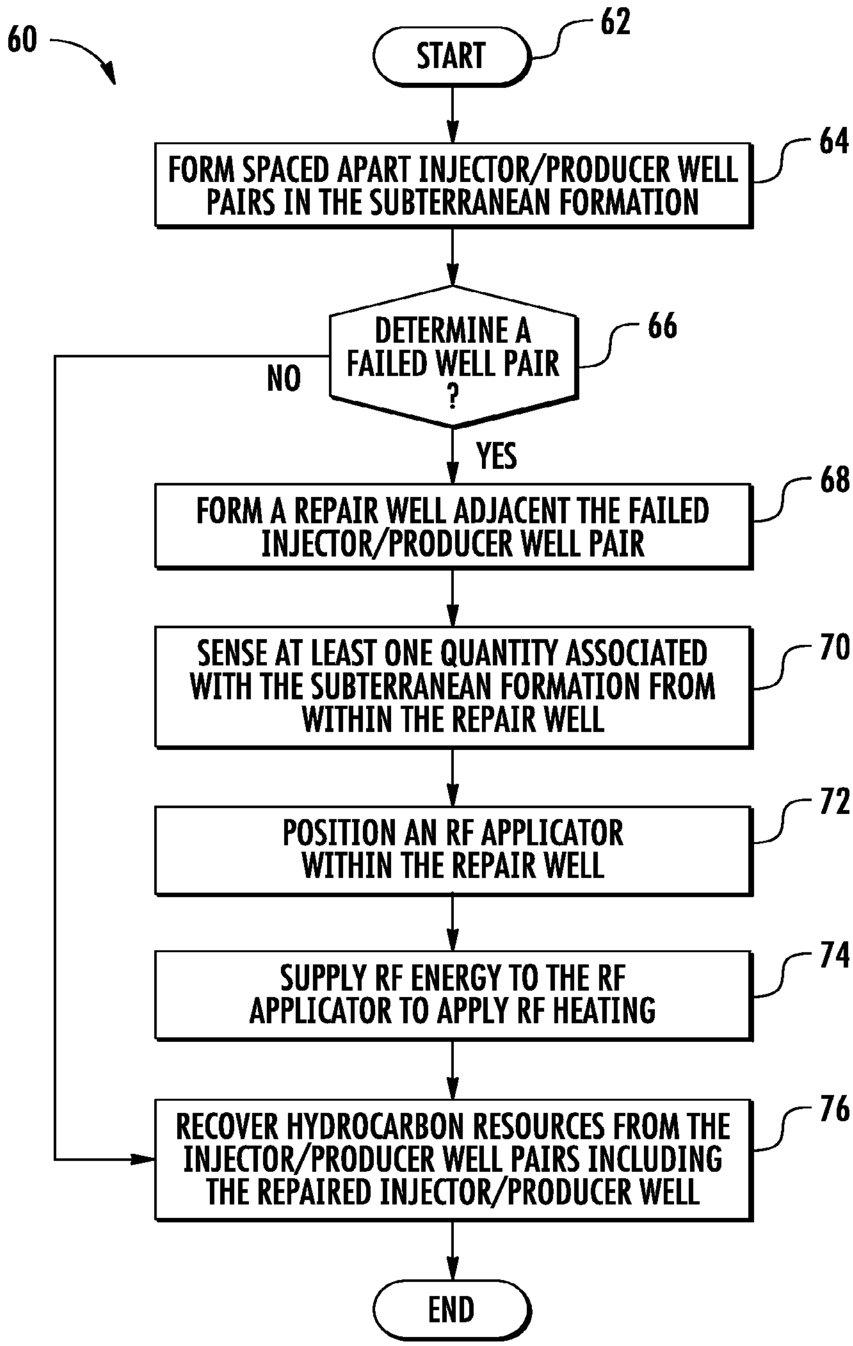

60
START
62
FORM SPACED APART INJECTOR/PRODUCER WELL PAIRS IN THE SUBTERRANEAN FORMATION
64
DETERMINE A FAILED WELL PAIR ?
66
NO
YES
FORM A REPAIR WELL ADJACENT THE FAILED INJECTOR/PRODUCER WELL PAIR
68
SENSE AT LEAST ONE QUANTITY ASSOCIATED WITH THE SUBTERRANEAN FORMATION FROM WITHIN THE REPAIR WELL
70
POSITION AN RF APPLICATOR WITHIN THE REPAIR WELL
72
SUPPLY RF ENERGY TO THE RF APPLICATOR TO APPLY RF HEATING
74
RECOVER HYDROCARBON RESOURCES FROM THE INJECTOR/PRODUCER WELL PAIRS INCLUDING THE REPAIRED INJECTOR/PRODUCER WELL
76
END

FIG. 3

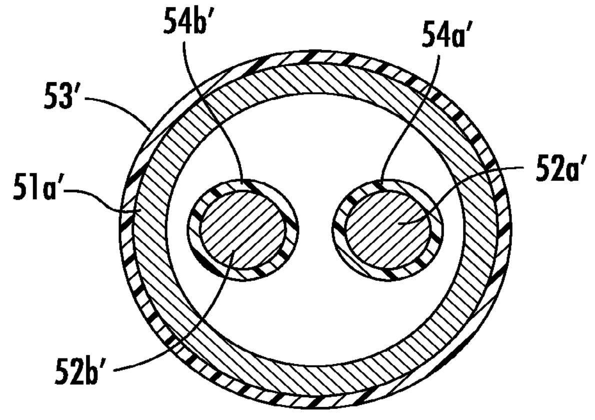

54b'
54a'
53'
52a'
51a'
52b'

FIG. 4

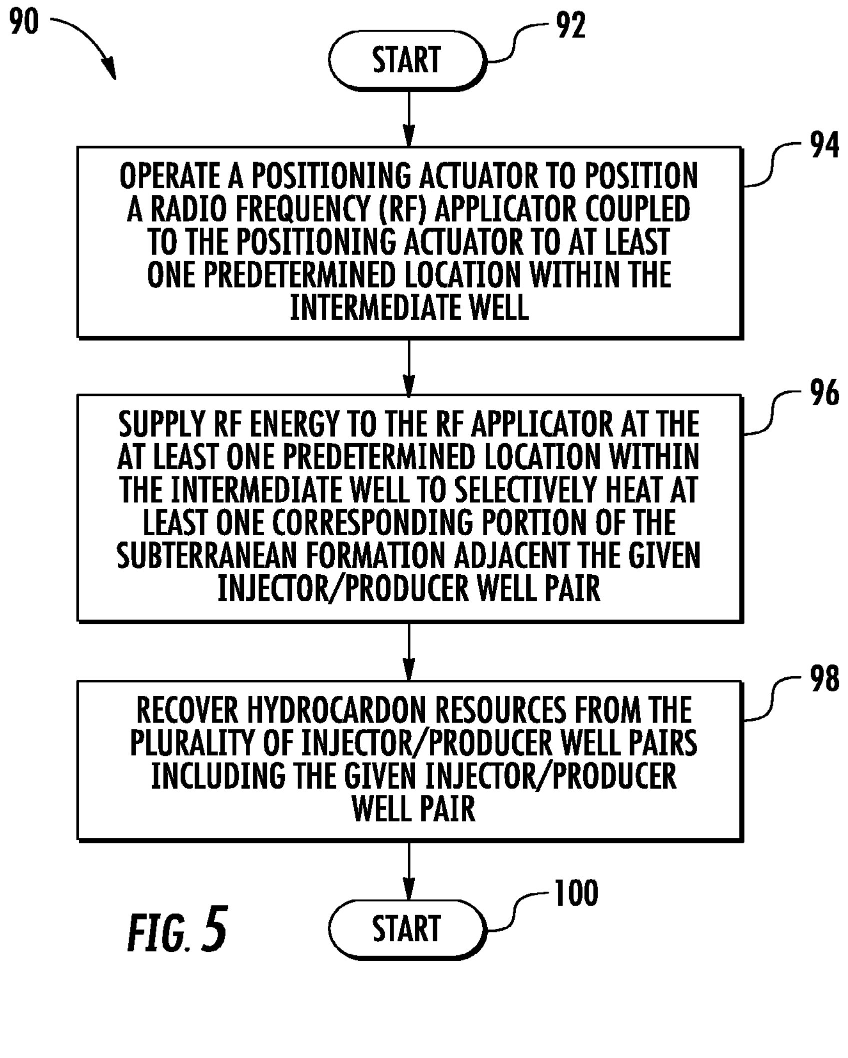

90
START
92
OPERATE A POSITIONING ACTUATOR TO POSITION A RADIO FREQUENCY (RF) APPLICATOR COUPLED TO THE POSITIONING ACTUATOR TO AT LEAST ONE PREDETERMINED LOCATION WITHIN THE INTERMEDIATE WELL
94
SUPPLY RF ENERGY TO THE RF APPLICATOR AT THE AT LEAST ONE PREDETERMINED LOCATION WITHIN THE INTERMEDIATE WELL TO SELECTIVELY HEAT AT LEAST ONE CORRESPONDING PORTION OF THE SUBTERRANEAN FORMATION ADJACENT THE GIVEN INJECTOR/PRODUCER WELL PAIR
96
RECOVER HYDROCARDON RESOURCES FROM THE PLURALITY OF INJECTOR/PRODUCER WELL PAIRS INCLUDING THE GIVEN INJECTOR/PRODUCER WELL PAIR
98
START
100

FIG. 5

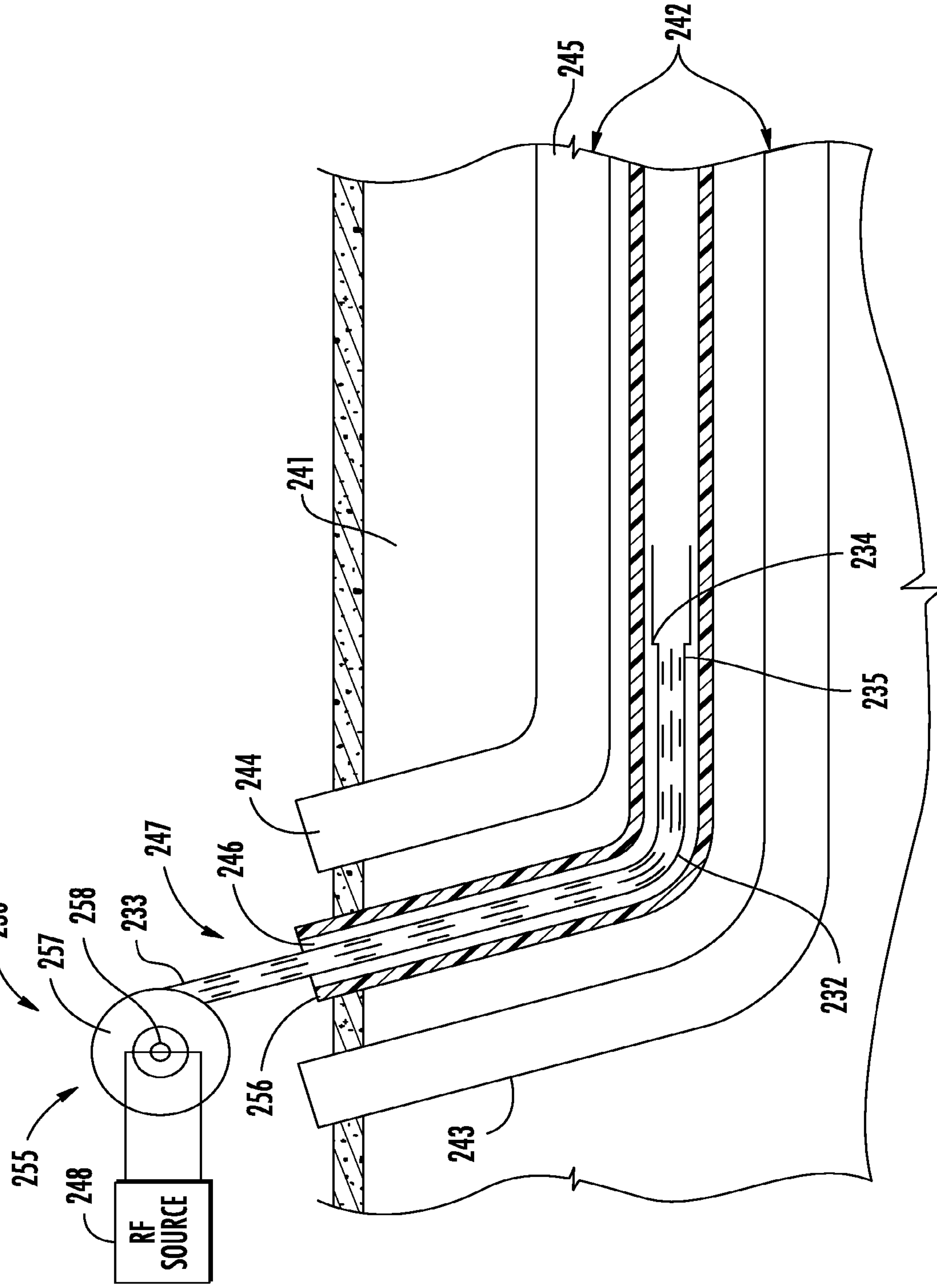

242
245
241
234
235
244
247
246
232
230
257
258
233
256
243
255
248
RF SOURCE

FIG. 6A

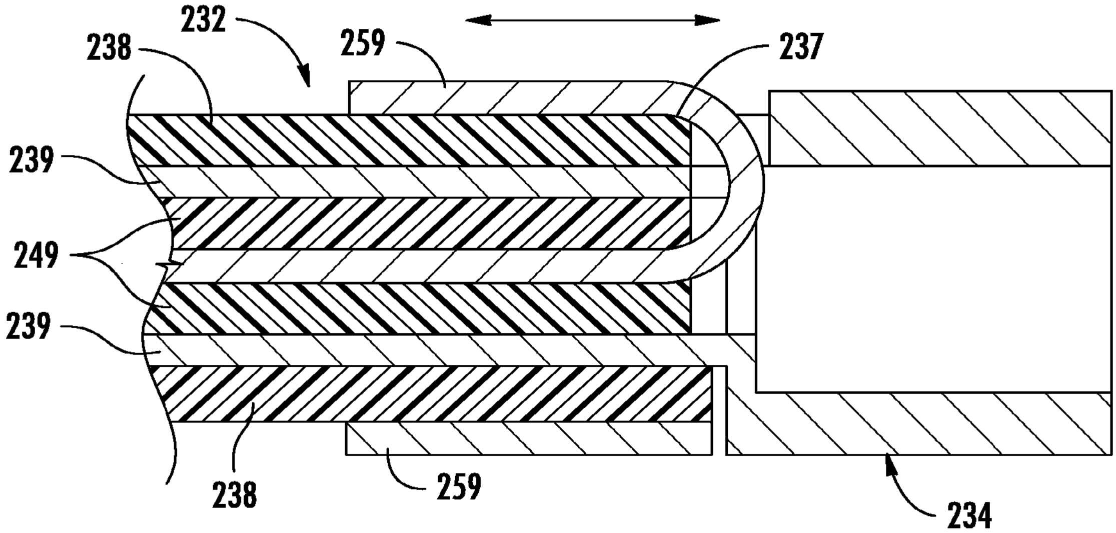


FIG. 6B

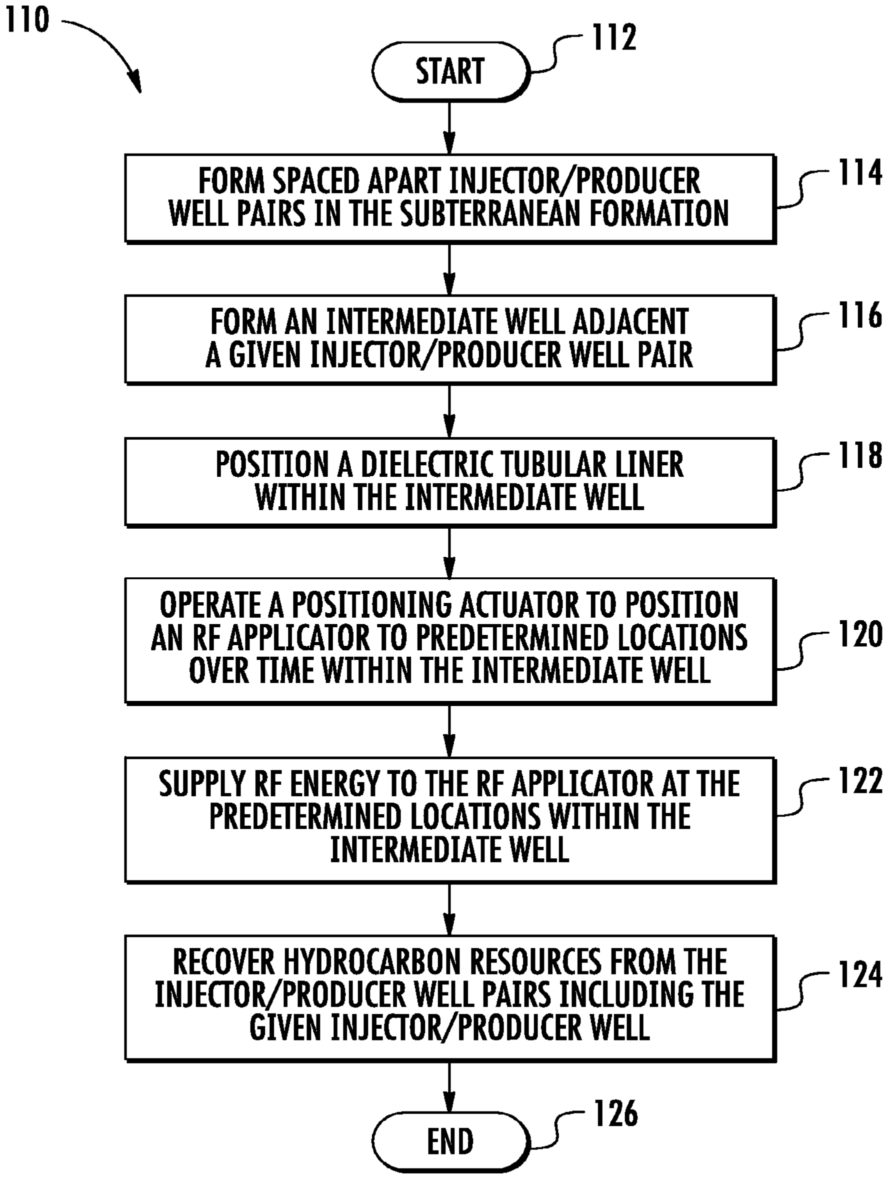

110
START
112
FORM SPACED APART INJECTOR/PRODUCER WELL PAIRS IN THE SUBTERRANEAN FORMATION
114
FORM AN INTERMEDIATE WELL ADJACENT A GIVEN INJECTOR/PRODUCER WELL PAIR
116
POSITION A DIELECTRIC TUBULAR LINER WITHIN THE INTERMEDIATE WELL
118
OPERATE A POSITIONING ACTUATOR TO POSITION AN RF APPLICATOR TO PREDETERMINED LOCATIONS OVER TIME WITHIN THE INTERMEDIATE WELL
120
SUPPLY RF ENERGY TO THE RF APPLICATOR AT THE PREDETERMINED LOCATIONS WITHIN THE INTERMEDIATE WELL
122
RECOVER HYDROCARBON RESOURCES FROM THE INJECTOR/PRODUCER WELL PAIRS INCLUDING THE GIVEN INJECTOR/PRODUCER WELL
124
END
126

FIG. 7

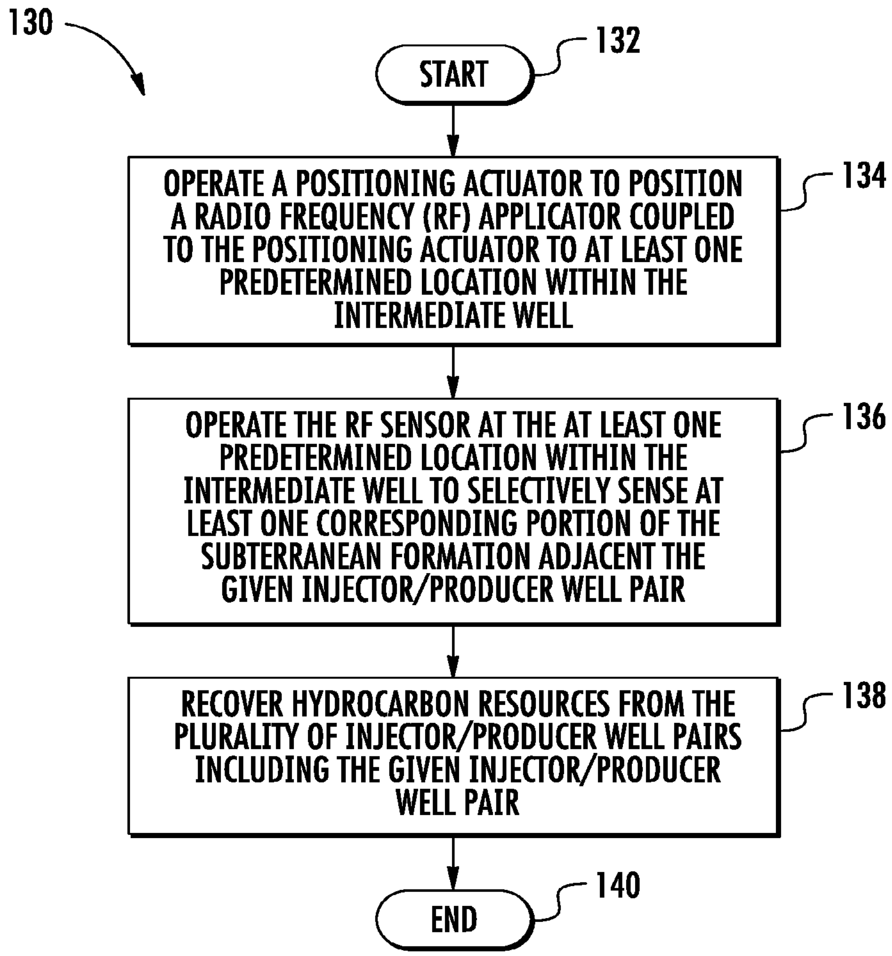
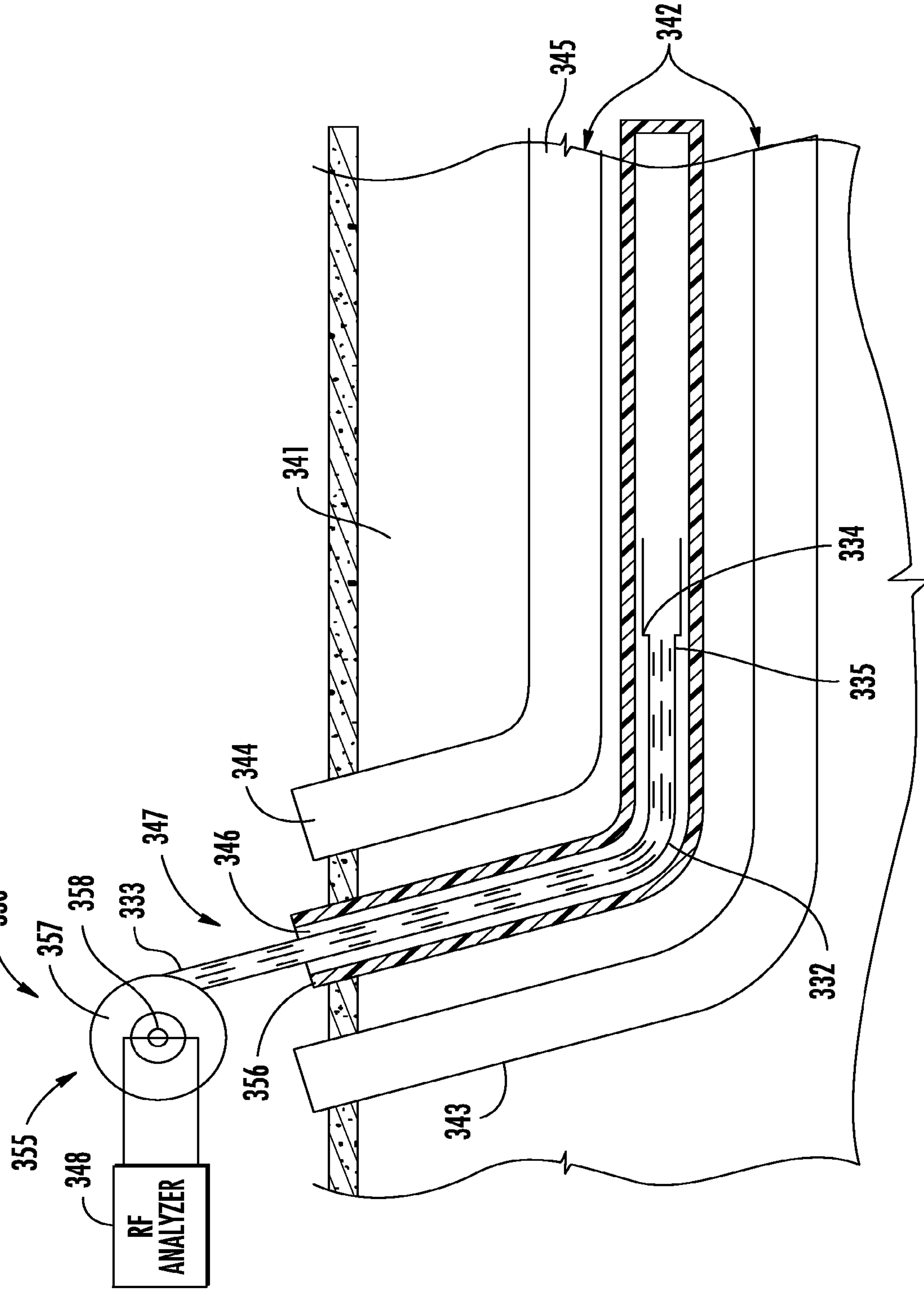

130
START
132
OPERATE A POSITIONING ACTUATOR TO POSITION A RADIO FREQUENCY (RF) APPLICATOR COUPLED TO THE POSITIONING ACTUATOR TO AT LEAST ONE PREDETERMINED LOCATION WITHIN THE INTERMEDIATE WELL
134
OPERATE THE RF SENSOR AT THE AT LEAST ONE PREDETERMINED LOCATION WITHIN THE INTERMEDIATE WELL TO SELECTIVELY SENSE AT LEAST ONE CORRESPONDING PORTION OF THE SUBTERRANEAN FORMATION ADJACENT THE GIVEN INJECTOR/PRODUCER WELL PAIR
136
RECOVER HYDROCARBON RESOURCES FROM THE PLURALITY OF INJECTOR/PRODUCER WELL PAIRS INCLUDING THE GIVEN INJECTOR/PRODUCER WELL PAIR
138
END
140

FIG. 8



330
357
358
333
347
346
344
341
345
342
334
335
332
356
343
355
348
RF ANALYZER

FIG. 9A

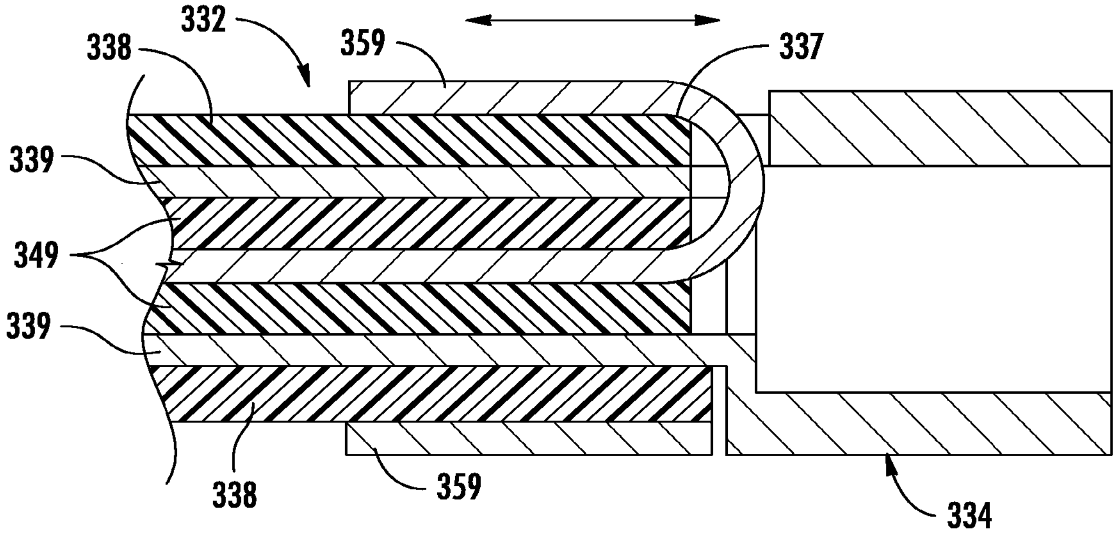


FIG. 9B

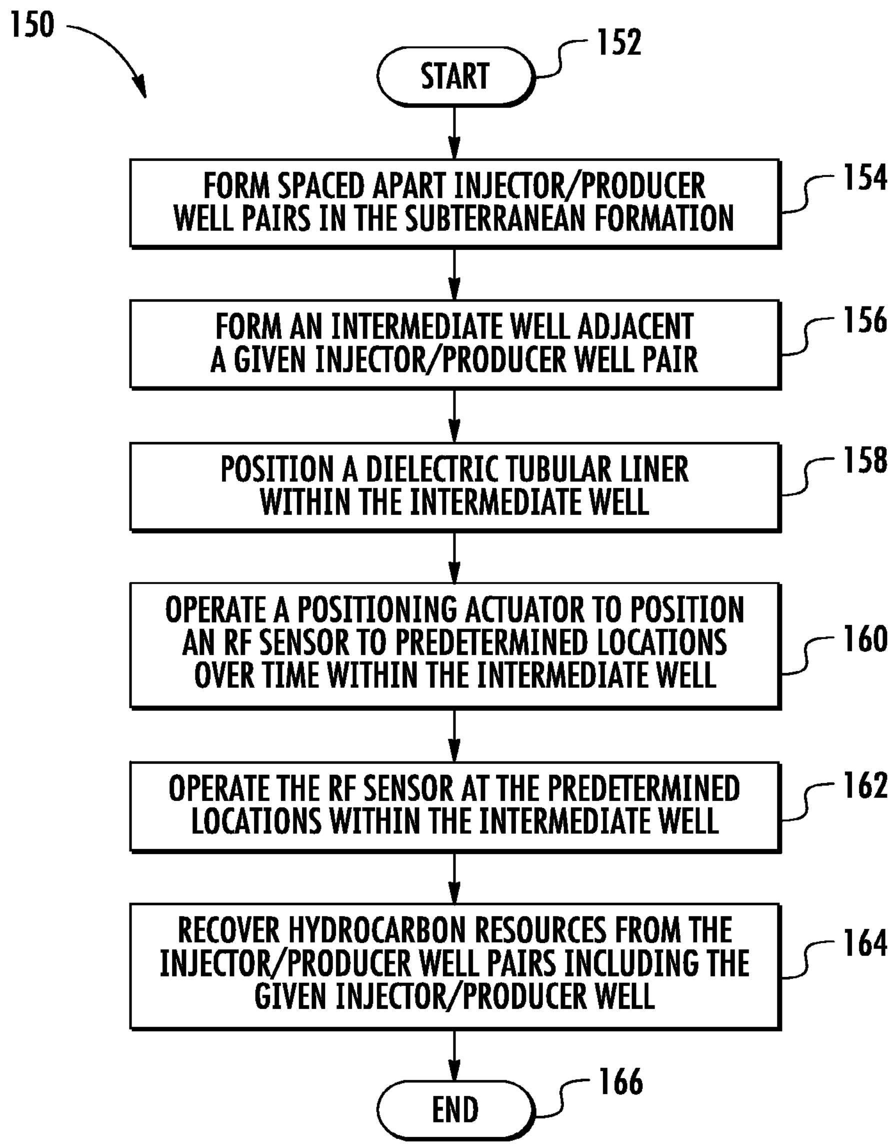

150
START
152
FORM SPACED APART INJECTOR/PRODUCER WELL PAIRS IN THE SUBTERRANEAN FORMATION
154
FORM AN INTERMEDIATE WELL ADJACENT A GIVEN INJECTOR/PRODUCER WELL PAIR
156
POSITION A DIELECTRIC TUBULAR LINER WITHIN THE INTERMEDIATE WELL
158
OPERATE A POSITIONING ACTUATOR TO POSITION AN RF SENSOR TO PREDETERMINED LOCATIONS OVER TIME WITHIN THE INTERMEDIATE WELL
160
OPERATE THE RF SENSOR AT THE PREDETERMINED LOCATIONS WITHIN THE INTERMEDIATE WELL
162
RECOVER HYDROCARBON RESOURCES FROM THE INJECTOR/PRODUCER WELL PAIRS INCLUDING THE GIVEN INJECTOR/PRODUCER WELL
164
END
166

FIG. 10