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(54) DRILLING TOOL FOR DRILLING WEB OF CHANNELS FOR HYDROCARBON RECOVERY

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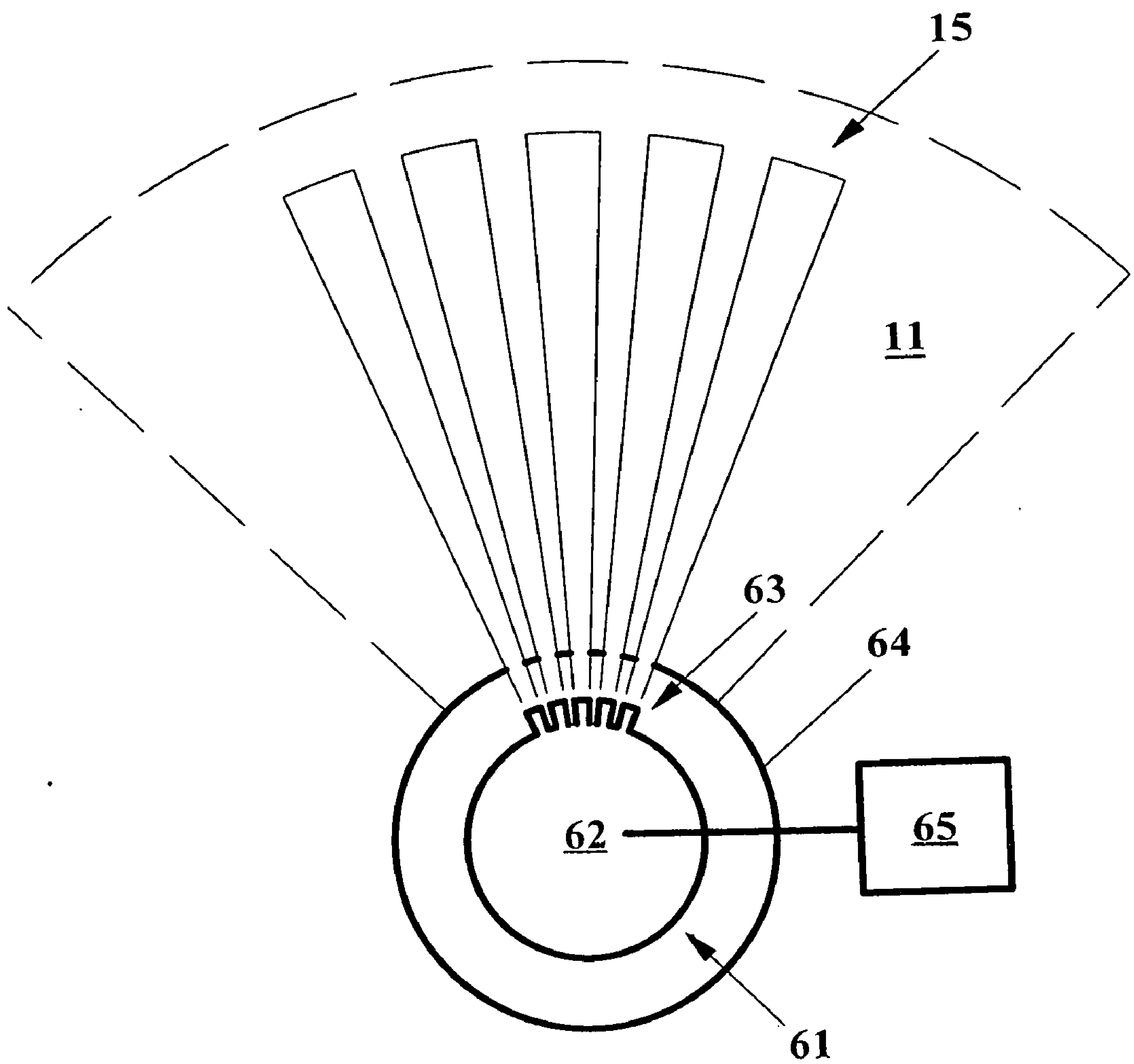
(57) **ABSTRACT**

Hydrocarbons can be recovered from a subterranean reservoir by drilling an injection well bore having an outlet in the reservoir and drilling a production well bore spaced apart from the injection well bore and having an inlet in the reservoir. A drilling tool is capable of being inserted into a well bore to drill a web of channels to form a permeable zone in the reservoir. The drilling tool comprises a drill head adapted to drill a web of channels that radiate out from the well bore to form the permeable zone, and a power source to supply power to the drill head.



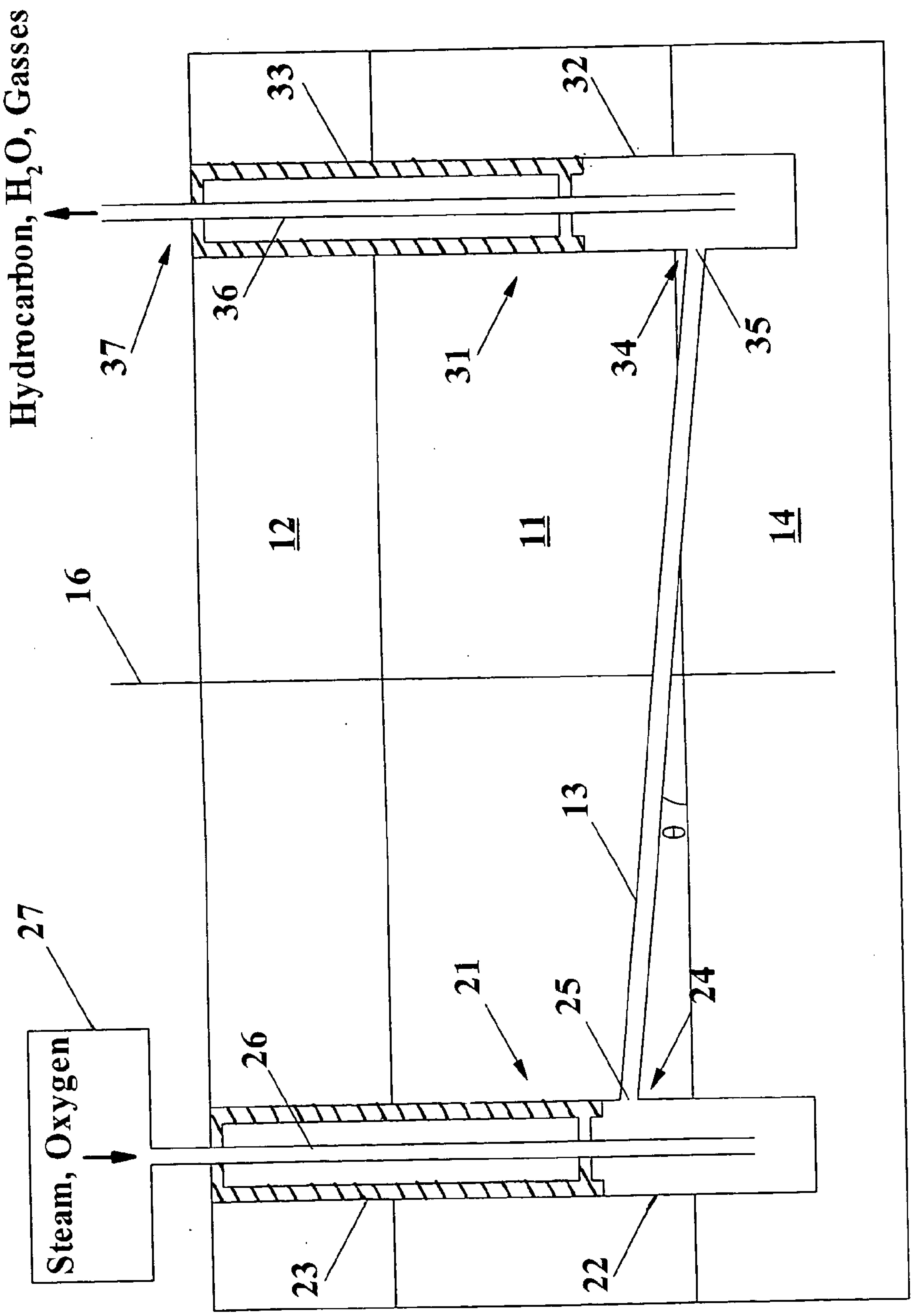

Hydrocarbon, H_2O, Gasses
Steam, Oxygen
37
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Figure 1

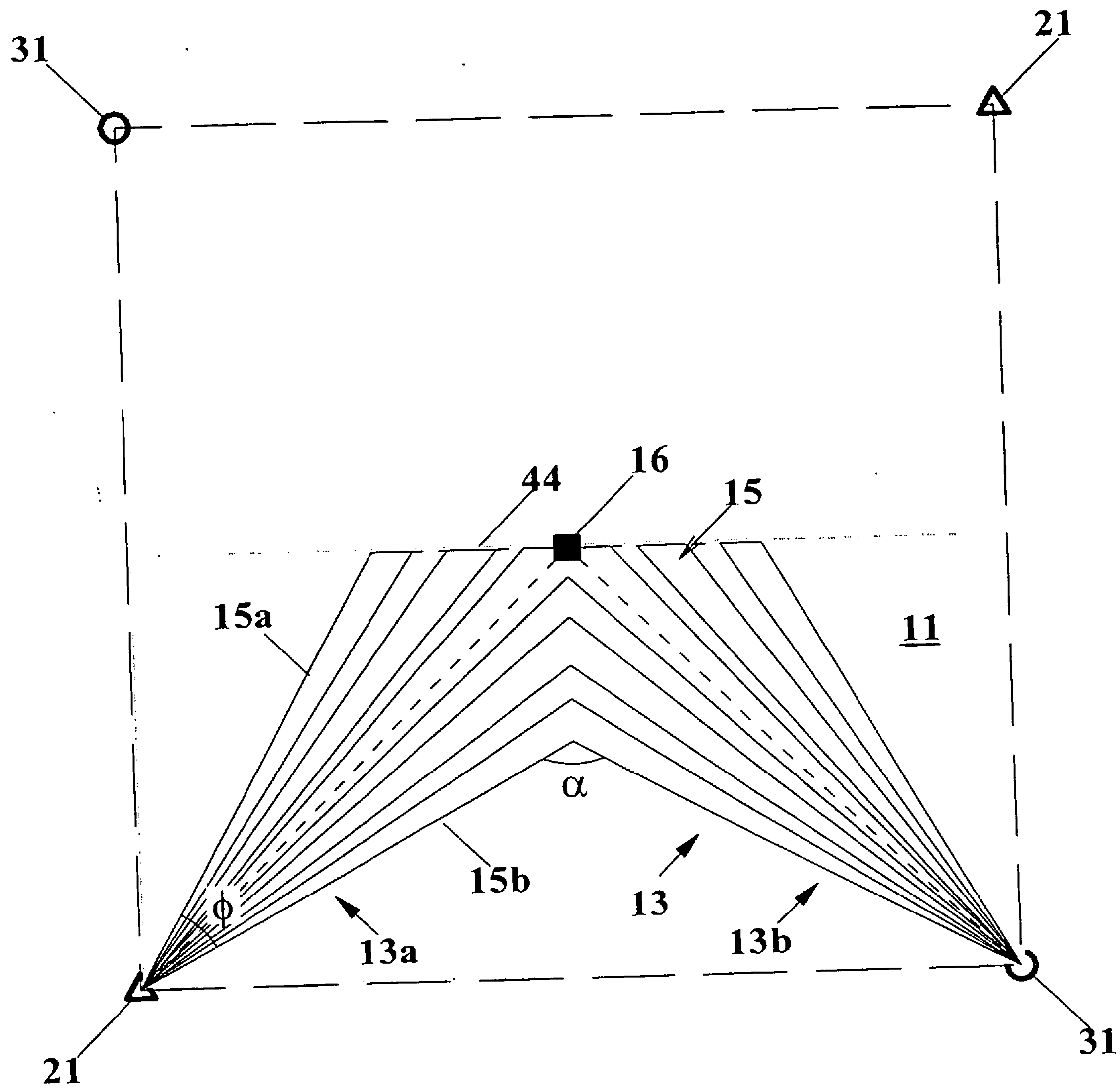
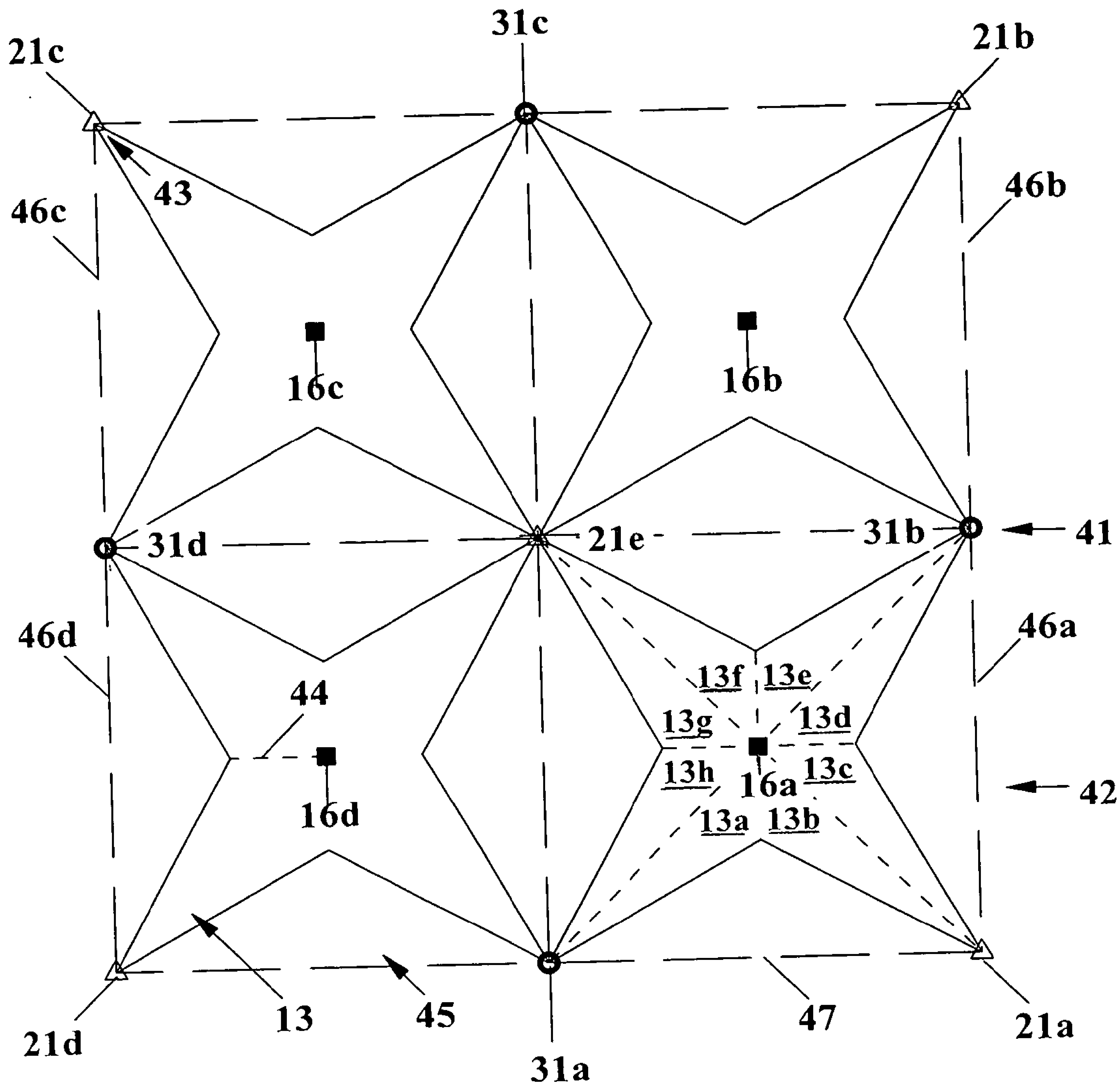


Figure 2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21d
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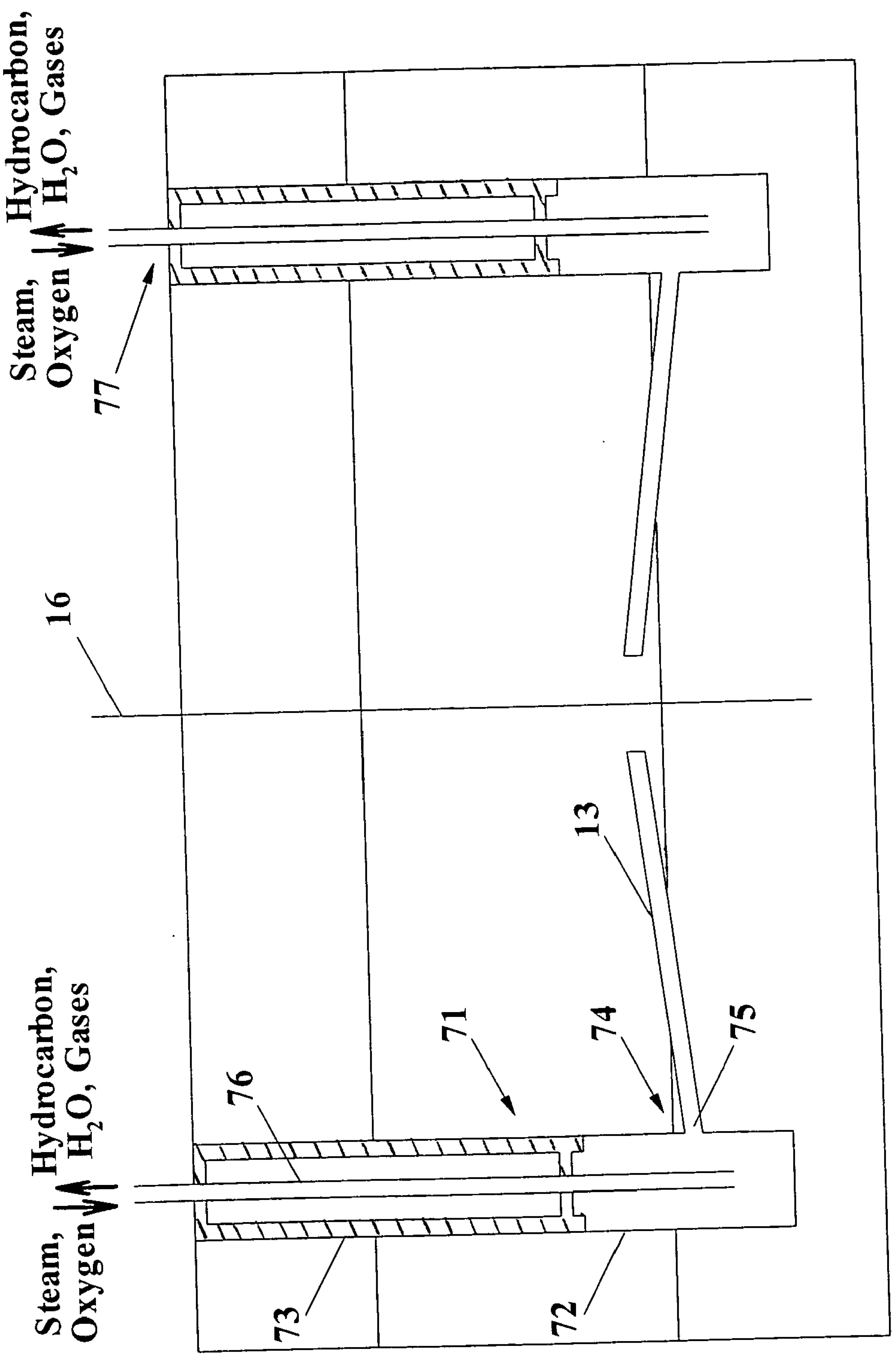
31a

Figure 3


Hydrocarbon, H_2O, Gases
Steam, Oxygen
77
16
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Hydrocarbon, H_2O, Gases
Steam, Oxygen
71
74
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72

Figure 4

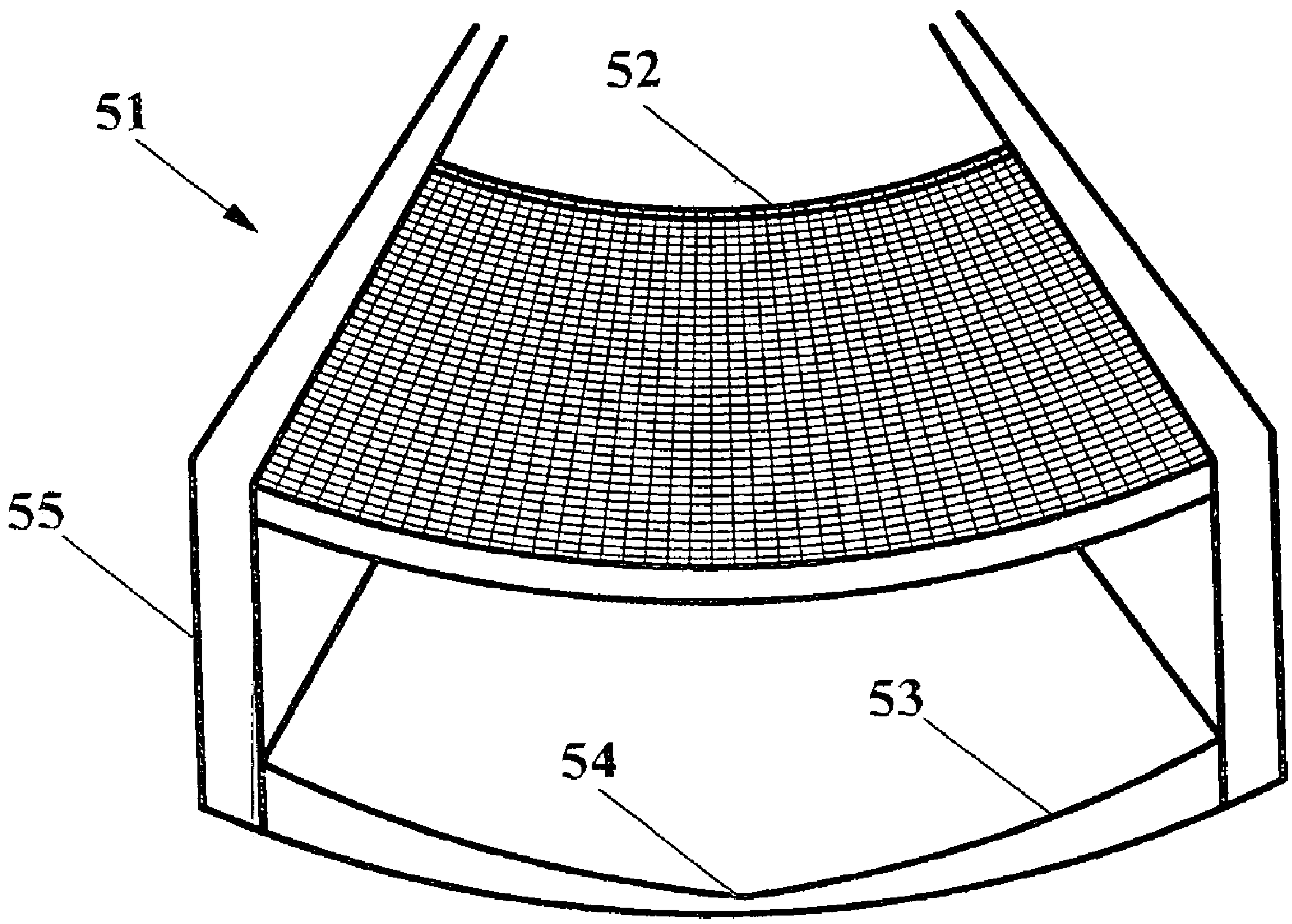

Figure 5

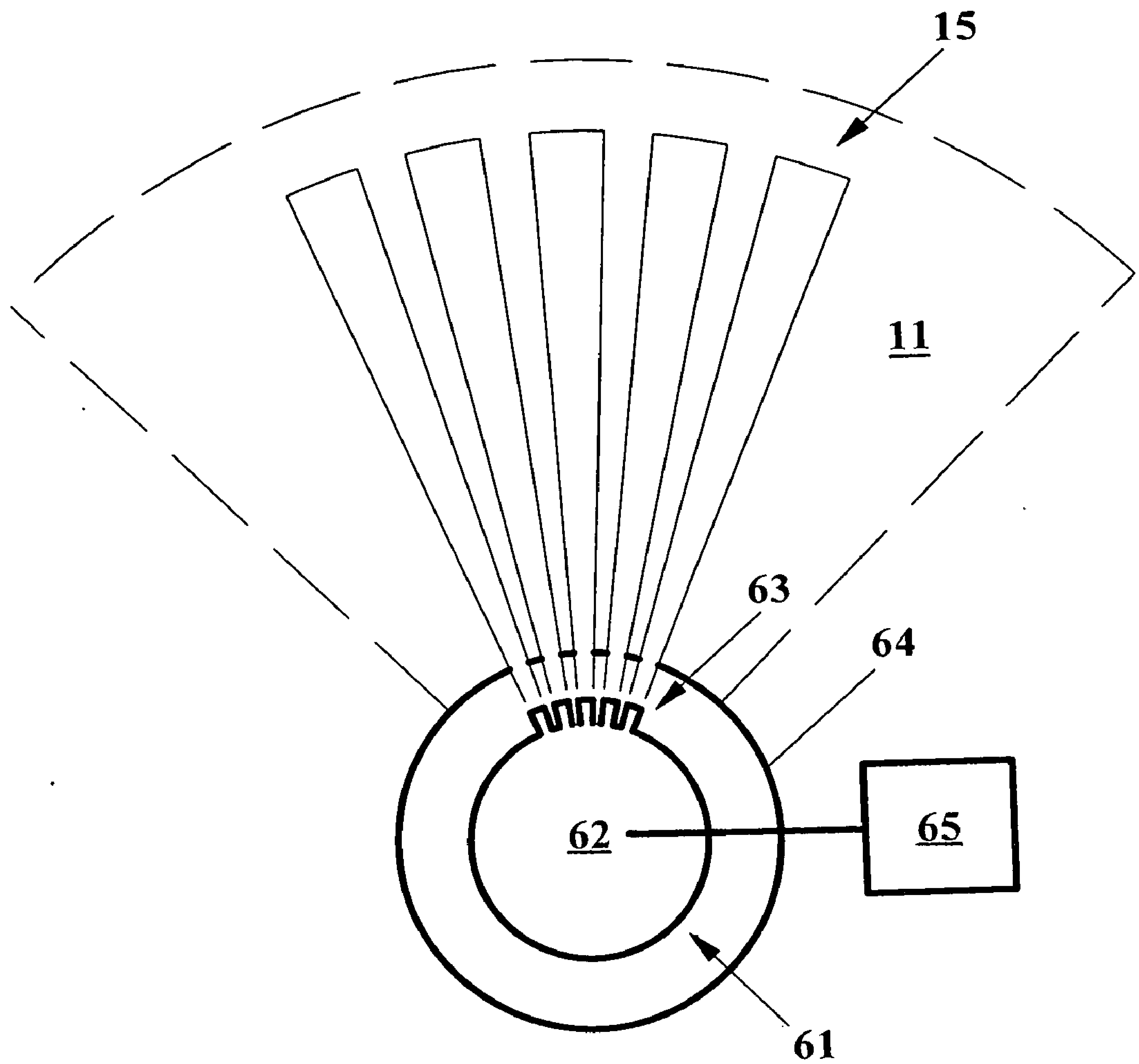

Figure 6

DRILLING TOOL FOR DRILLING WEB OF CHANNELS FOR HYDROCARBON RECOVERY

CROSS REFERENCE

[0001] This application is a divisional application of U.S. Pat. No. ______, application Ser. No. 10/652,351, filed on Aug. 29, 2003, which is incorporated by reference herein in its entirety.

BACKGROUND

[0002] Embodiments of the present invention relate to the recovery of hydrocarbons from a subterranean reservoir.

[0003] Hydrocarbons that are recovered from a subterranean reservoir include oil, gases, gas condensates, shale oil and bitumen. To recover a hydrocarbon, such as oil, from a subterranean formation, a well is typically drilled down to the subterranean oil reservoir and the oil is collected at the well head. The recovery of hydrocarbons that are very heavy or dense, such as for example, the recovery of bitumen from oil sands, are especially difficult as these materials are often thick and viscous at reservoir temperatures, so it is even more difficult to extract them from the subterranean reservoir. For example, bitumen can have a viscosity of greater than 100,000 centipoises, which makes it difficult to flow. Suitable methods for the recovery of these heavier viscous hydrocarbons are desirable to increase the world's supply of energy. Methods for recovering bitumen are particular desirable because there are several trillion barrels of bitumen deposits in the world, of which only about 20% or so are recoverable with currently available technology.

[0004] A conventional method of recovering hydrocarbons from a subterranean oil reservoir is by utilizing both a production well and an injection well. In this method, a vertical production well is drilled down to a hydrocarbon reservoir, and a vertical injection well is drilled at a region spaced apart from the production well. A fluid is injected into the hydrocarbon reservoir via the injection well, and the fluid promotes the flow of hydrocarbons through the reservoir formation and towards the production well for collection. However, a problem with this method is that the injected fluids tend to find a relatively short and direct path between the injection and production wells, and therefore, bypass a significant amount of oil in the so called "blind spot". Furthermore, if the injected fluid, such as steam, is lighter than the reservoir oil, the injected fluid tends to flow through the upper portion of the reservoir and thus bypass a significant amount of oil at the bottom of the reservoir. Due to these unfavorable mechanisms, injected fluids tend to reach the production well at a relatively early time. When this "early breakthrough" of the fluids occurs, the steam-oil ratio increases rapidly and recovery efficiency of the hydrocarbons is reduced.

[0005] In one method of improving the recovery of hydrocarbons using vertical injection and production wells, a horizontal high-permeability web is formed at the bottom of the production well to increase the hydrocarbon recovery area at that region, as described in U.S. Pat. No. 6,012,520, which is incorporated herein by reference in its entirety. The high-permeability web has multiple channels or fracture zones that are formed horizontally about a receiving region of the production well located near the bottom of the reservoir. To recover the hydrocarbons, a neighboring injection well injects steam into a top portion of the reservoir via an injection inlet. The injected steam heats the hydrocarbons in the reservoir, and pushes the hydrocarbons downwards for collection by the high-permeability web of the production well.

[0006] However, while this method increases the recovery area immediately about the production well and displaces the oil in a "gravity stable" manner, it's extraction efficiency per unit area is low for subterranean reservoirs having viscous hydrocarbons that are difficult to flow under typical injection pressures. Oil recovery from these reservoirs, such as oil sands reservoirs, remains difficult and yet highly desirable.

[0007] In one version of a conventional recovery method, a "huff and puff" process is used to recover bitumen from a subterranean oil sands reservoir. In this method, a vertical well bore is drilled to the reservoir and steam is injected towards the bottom of the bore and into the surrounding reservoir. The steam heats the bitumen about the well bore to reduce its viscosity and cause it to flow back to the well bore. When a desired amount of the bitumen has been collected in the bottom of the well bore, the well is pumped off and the oil is collected at the well head. However, the steam typically traverses only the area immediately around the vicinity of well bore which may be only a small portion of the underground reservoir. Thus the amount of oil recovered is limited by the distance the steam can travel before it cools and condenses, and a large portion of the reservoir may not be reached by steam using this method.

[0008] In another conventional method, a Steam Assisted Gravity Drainage (SAGD) process is used to recover bitumen from a subterranean reservoir. In this method, a horizontal production well bore is formed near the bottom of the reservoir. A horizontal steam injection well is formed parallel and above the production well bore. The injected steam heats the bitumen between the wells, as well as above the injection well, and gravitational forces drain the heated bitumen fluids down to the production well for collection. However, this method has problems that are similar to those of the huff and puff method. Namely, after the steam from the injection well reaches the top of the reservoir, the bitumen production becomes limited by the extent to which the steam can laterally expand. As heat losses from the steam to the overburden above the reservoir are high, the lateral expansion is restricted, and a large amount of the reservoir may not be reached by the heated steam.

[0009] Thus, it is desirable to efficiently recover hydrocarbons from a large are of a subterranean reservoir. It is furthermore desirable to recover dense or viscous hydrocarbons with injection and production wells that provide a heated fluid to the subterranean reservoir.

DRAWINGS

[0010] These features, aspects, and advantages of the present invention will become better understood with regard to the following description, appended claims, and accompanying drawings, which illustrate examples of the invention. However, it is to be understood that each of the features can be used in the invention in general, not merely in the context of the particular drawings, and the invention includes any combination of these features, where:

[0011] **FIG. 1** is a schematic sectional side view of an embodiment of an injection and a production well connected by a permeable zone having a predetermined shape;

[0012] **FIG. 2** is a schematic top view of an embodiment of a well pattern showing injection and production wells connected by a permeable zone;

[0013] **FIG. 3** is a schematic top view of a 5-spot well pattern having injection and production wells connected by a permeable zone;

[0014] **FIG. 4** is a schematic sectional side view of another embodiment of a well having a permeable zone;

[0015] **FIG. 5** is a schematic sectional side view of an embodiment of a channel having a porous liner; and

[0016] **FIG. 6** is a schematic top view of a drilling tool adapted to drill multiple conduits to form a permeable zone having a predetermined shape.

DESCRIPTION

[0017] The present invention is used to recover hydrocarbons from a subterranean hydrocarbon reservoir **11**. The hydrocarbons can be in the form of oil, gas, gas condensate, shale oil and bitumen. The recovery method may be particularly beneficial in the recovery of dense hydrocarbons, such as bitumen.

[0018] To recover hydrocarbons from a subterranean hydrocarbon reservoir **11**, a substantially vertical production well **31** is drilled into the ground to receive and recover the hydrocarbons, as shown in **FIG. 1**. The production well **31** comprises a well bore **32** drilled through one or more overlying layers, such as an overburden **12** to a desired depth in or beneath the subterranean hydrocarbon reservoir **11**. A well casing **33** can extend at least partially along the length of the well bore **32** to structurally support the bore **32**. The well bore **32** comprises a hydrocarbon receiving zone **34** having one or more receiving inlets **35** in or about the subterranean reservoir **11**, the inlets **35** comprising, for example, perforations in the well casing **33**, or a portion of the well bore **32** that is otherwise open to the surrounding subterranean formation, such as an open lower end of the well bore **32**. The inlets **35** into the well bore **32** are desirably located towards the bottom of and even underneath the hydrocarbon reservoir **11**.

[0019] Hydrocarbons are collected from the well **31** through a tubing **36** that extends through the well bore **32** to a well head **37** located towards the top of the well bore **32**. The hydrocarbons can be lifted through the tubing **36** by natural pressure, induced pressure from injected steams, or with the assistance of a pump (not shown) to pump the hydrocarbons from the bottom of the bore **32** to the well head.

[0020] A substantially vertical injection well **21** is provided to inject a fluid into at least a portion of the subterranean reservoir **11** to mobilize and promote the flow of hydrocarbons towards the production well **31**. The injection well **21** comprises an injection well bore **22** that is drilled at a location that is spaced apart from the production well **31**. The injection well bore **22** can be drilled to a desired depth in or beneath the hydrocarbon reservoir **11**, and a well casing **23** can be provided that extends along at least a portion of the bore **22** to structurally support the well bore **22**. The injection well bore **22** comprises an injection zone **24** having one or more injection outlets **25** that may be, for example, perforations in the well casing **23** or portions of the well bore that are otherwise open to the surrounding subterranean formation. The injection outlets **25** are desirably located adjacent to the reservoir **11** to provide fluid to the reservoir **11**, and may be near the bottom of the reservoir **11**.

[0021] Typically, a heated fluid is injected by the injection well **21** to heat the hydrocarbons in the reservoir **11**, thereby reducing the viscosity of and mobilizing the hydrocarbons so the hydrocarbons flow through the subterranean reservoir **11** towards the receiving zone **34** of the production well **31**. For example, the heated fluid can comprise a vaporized liquid such as steam that is supplied by an injection fluid supply **27** such as a steam generator, and injected into the subterranean reservoir **11** via tubing **26**. The steam can also be super-heated to provide more thermal energy. As another example, the injected fluid can comprise an oxygen-containing fluid. In this version, an oxygen-containing fluid, such as oxygen gas or air, is supplied by injection fluid supply **27** and is injected into the subterranean reservoir **11** at the injection zone **24**. The combustible fluid and reservoir hydrocarbons can be ignited, for example, by lowering an igniter to the injection zone **24**. Burning hydrocarbons in the reservoir **11** generates heat that reduces the viscosity of the remaining hydrocarbons. Also, the pyrolysis of the hydrocarbons can decompose heavy hydrocarbons into smaller hydrocarbon molecules that flow more easily to the production well **31**, and can also dilute heavier hydrocarbons to promote their flow. The injection fluid may also comprise light hydrocarbons that are easier to ignite to facilitate initiation of the combustion and hydrocarbon burn.

[0022] To improve the recovery of the hydrocarbons, a permeable zone **13** is formed to connect the injection and production wells **21**, **31**. The permeable zone **13** comprises a patterned web of channels **15** in the subterranean reservoir **11** that radiate outwardly from the outlet **25** of the injection well **21** and connect to the inlet **35** of the production well **31**. For example, the permeable zone **13** can comprise a first patterned web of channels **17*a*** that radiates out from the outlet **25** of the injection well **21** and connects to a second patterned web of channels **17*b*** that radiates out from the inlet **35** of the production well **31**. The permeable zone **13** having the patterned web of channels **15** increases the flow of hydrocarbons to the production well **31** by providing a highly permeable and accessible pathway in which the hydrocarbons from the reservoir **11** can flow towards the production well **31**. The permeable zone **13** also provides an extended heated fluid flow area adjacent to the hydrocarbon reservoir **11** to allow heating of a larger portion of the reservoir **11**, and thus, provides for the recovery of a greater number of hydrocarbons from the reservoir **11**. For example, as shown in **FIG. 1**, the permeable zone **13** is formed in a lower section of the subterranean hydrocarbon reservoir **11** such that the hydrocarbons above the permeable zone **13** in the extended region between the injection and production wells **21**, **31** are heated by the fluids injected into the permeable zone **13**. The heated hydrocarbons in the reservoir **11** above the permeable zone **13** are drained via gravity into the zone **13**, in which the heated hydrocarbons flow through to the receiving zone **34** of the connecting production well **31**. Thus, the permeable zone **13** provides enhanced heating of an extended area of the hydrocarbon reservoir **11** and improves flow of the heated hydrocarbons to the production well **31** to increase recovery of the hydrocarbons.

[**0023**] The permeable zone **13** can have a patterned web of channels **15** with a predetermined shape that induces a gravity flow of the mobilized hydrocarbons towards the production well **31**. For example, the permeable zone **13** can be formed about a plane that is angled downwardly from the injection well bore **22** to the production well bore **32**. A suitable angle may be a vertical angle θ, as shown in **FIG. 1**, of from 0° to about 30°, such as at least about 5°, and even from about 5° to about 20°. To provide a connecting permeable zone **13** having a steeper angle, the injection outlets **25** can be located at positions along the injection well bore **22** that are above the receiving inlets **35** of the production well bore **32**. The production well bore **32** can also be drilled into a region below the subterranean reservoir **11**, such as in an underburden **14**, to provide the desired angle.

[**0024**] The permeable zone **13** also desirably fans out from at least one and preferably both of the wells **21**, **31** to provide one or more wedge-like shapes that increase in width with increasing distance from the bore to cover a larger area of the reservoir **11**, as shown in **FIGS. 2 and 3**. By forming a zone **13** that radiates out from the bores with increasing width, an increased area of the hydrocarbon reservoir **11** can be heated by the fluid passed through the fluid flow zone **13**. For example, the permeable zone **13** can fan out from at least one of the well bores **22**, **32** to cover an extended area between the wells **21**, **31**, such as an area about a "blind spot" between the wells. A horizontal angle ϕ carved out by the radiating permeable zone **13**, as shown in **FIG. 2**, may be from about 0° to about 90°, and even from about 30° to about 60°. In one version, as shown in **FIGS. 2 and 3**, the permeable zone **13** comprises a first radiating section **13*a*** having a first patterned web of channels **17*a*** connected to the injection well bore **22** of well **21**, and a second radiating section **13*b*** having a second patterned web of channels **17*b*** connected to the production well bore **32** of well **31**. The first and second sections **13*a*** and **13*b*** of the permeable zone **13** are connected together at a point where the sections **13*a***, **13*b*** are fairly wide, thus, enhancing heating of the regions between the wells **21**, **31**.

[**0025**] The permeable zone **13** can also comprise a predetermined shape that connects the injection wells and production wells to form a convoluted and indirect path, such that the permeable zone **13** extends to cover a larger portion of the hydrocarbon reservoir **11**. For example, as shown in **FIG. 2**, the permeable zone **13** can comprise first and second sections **13*a***, **13*b*** that are angled with respect to each other such that section **13*a*** bisects section **13*b*** with a horizontal angle α of from about 90 to about 180 degrees, such as about 90 degrees to about 150 degrees. The vertical angle can be from about 0 to about 30 degrees, such as from example, about 5 to about 20 degrees. This circuitous and indirect route between the injection and production wells **21**, **31** allows the fluids flowing in the permeable zone **13** to heat regions of the reservoir **11** that are remote from the wells **21**, **31** and that otherwise could be difficult to reach.

[**0026**] The method of recovering hydrocarbons by passing a heated fluid through the permeable zone **13** can be applied to various injection and production well patterns **41**. For example, the method of hydrocarbon recovery can be applied to a 5-spot well pattern **41**, as shown in **FIG. 3**. Although the 5-spot well pattern **41** is used as an example, similar principles could be used to apply the recovery method comprising the permeable zone **13** to configurations having only one or two wells, and also configurations having wells in a 4, 7 or 9 spot pattern. In the exemplary 5-spot well pattern **41**, alternating production and injection wells **31**, **21** are drilled to form an array of wells disposed at the intersection points of an ordered grid pattern **42**, for example, with the wells **31**, **21** located at the intersection points **43** of the pattern **42**. The grid pattern **42** provides extended coverage of a reservoir **11** with multiple hydrocarbon recovery points to increase hydrocarbon production. The intersection points of the grid pattern **42** form one or more squares **46**, and each square, such as the first square **46*a***, has the injection and production wells **21*a,e***, **31*a,b*** arranged in an alternating fashion at the vertices of the square **46*a*** such that the production wells **31*a***, **31*b*** lie facing each other along one diagonal of the square and the injection wells **21*a***, **21*e*** lie facing each other along the other diagonal. In the version shown in **FIG. 3**, four squares **46*a-d*** having this pattern of injection and production wells **21*a*-21*e***, **31*a*-31*d*** are placed together to form the well pattern **41**, with one of the injection wells **21*e*** forming a common vertex or intersection point **43** of all four squares **46*a-d***.

[**0027**] The pairs of injection wells and production wells in each square **46*a-d*** are connected together via one or more permeable zones **13**. The wells can be each interconnected to the others via the permeable zone **13**, as shown in **FIG. 3**. Desirably, the permeable zone **13** connects the injection and production wells in each square **46*a*-46*d*** in an indirect manner to form a convoluted path therebetween. For example, as shown in **FIG. 3**, each square **46*a-d*** comprises a permeable zone **13** having first through eighth triangular sections **13*a-h***. Each section **13*a-h*** fans out with increasing width from a single well **21*a***, **21*e***, **31*a***, **31*b***, and pairs of sections of adjacent injection and productions such as **13*a*** and **13*b*** abut together along a base **44** of each triangular section about the interior region **16*a*** of the square **46*a***, also called the blind spot, to form an interconnected zone **13**. Thus, the sections **13*a-h*** of the permeable zone **13** form a convoluted and circuitous highly-permeable route to allow the fluids flowing in the permeable zone **13** to reach the interior region **16*a***, and thereby heat even remote regions **16**, such as the blind spots.

[**0028**] The permeable zones **13** in each square **46*a-d*** form relatively "open" region of the reservoir **11**, through which the heated fluid can readily passes, and which are spaced apart from one another in the grid pattern **42** by relatively "closed" and unexcavated regions **45** of the reservoir **11** that remain in the areas of each square **46** where the permeable zone **13** has not been formed. The unexcavated regions **45** are typically in areas where the path between the production well **31** and injection well **21** is relatively short and direct, such as along a side **47** of the square **46*a***. For example, the unexcavated regions **45** can comprise obtuse triangles bounded in each square **46*a*** by two sections **13*a,b*** of the permeable zone **13** and the side **47** of the square **46*a***. The relatively closed unexcavated regions **45** force the heated fluid to primarily take a more convoluted path between the wells via the permeable zone **13**, and thereby sweep out a greater region of the reservoir **11**. However, because the distance between the wells in the unexcavated regions **45** is relatively short, the heated fluid gradually seeps into the unexcavated regions **45** and recovers hydrocarbons from these regions as well. Thus, the well pattern **41** having the permeable zones **13** and unexcavated regions **45** of **FIG. 3** provides for the recovery of hydrocarbons from a maximized area in the subterranean reservoir **11** by facilitating the flow of heated fluid to remote or hard to reach areas and controlling a flow of the heated fluid to the more easily accessible areas. This novel configuration prevents the steam from initially taking the shortest path between the outlet of the injection well and the inlet of production well, and instead forces the steam to access a larger area between the wells. At the same time, it allows hydrocarbons in the closed regions to be gradually swept as the open regions expand into them. Thus, the array of wells in a grid pattern with permeable zones therebetween efficiently recovers hydrocarbons from the subterranean region.

[**0029**] In another version, which can be applied, for example, to a "huff and puff" process, a well **71** is setup to operate as both an injection and production well, as shown in **FIG. 4**. The well **71** comprises a well bore **72**, such as a substantially vertical well bore **72**, that extends into the subterranean hydrocarbon reservoir **11**. The well **71** can comprise a well casing **73** and a tubing **76** through which fluids such as steam, oxygen, other gases and hydrocarbons, are flowed. A permeable zone **13** having a predetermined shape is formed that extends upwardly from an injection outlet **75** in an injection and receiving zone **74** of the well bore **72** into the subterranean hydrocarbon reservoir **11**. A suitable vertical angle of the permeable zone **13** may be at least about 5°, such as from about 5° to about 30°, and even from about 10° to about 20°. In operation, heated fluids, such as for example steam or oxygen-containing gases, are introduced into the permeable zone **13** via the injection outlet **75**. The heated fluids are "shut in" the well **71**, to allow heating of the hydrocarbons above the permeable zone **13**. The heated hydrocarbons flow into the permeable zone **13** and drain via gravitational forces along the angled zone **13** into the injection and receiving zone **74** of the well bore **72**. Once a sufficient volume of hydrocarbons has been collected in the bottom of the well bore **72**, the hydrocarbons are produced to a well head **77** of the well **31**, for example by pumping off the well **71**, to allow recovery of the hydrocarbons. The method allows for an extended region of the subterranean reservoir **11** about the well bore **72** to be heated, thereby increasing the recovery of the hydrocarbons from the reservoir **11**.

[**0030**] Methods of forming the permeable zone **13** include, for example, high-power microwave irradiation, high-pressure water jet drilling, mechanical drilling, explosive fracturing, hydraulic fracturing and drilling with lasers. In one version of a microwave irradiation method, a microwave irradiation device such as a high-power microwave antenna is lowered into one or more of the production and injection well bores **32**, **22**. The microwave irradiation device generates microwave beams that irradiate regions of the subterranean reservoir **11** adjacent to the well bore, and the water in the irradiated regions is quickly vaporized by the microwave energy. This rapid generation of large amounts of water vapor induces fractures in the regions irradiated by the microwave beams, causing increases in the permeability of the irradiated region and thereby forming a highly permeable zone **13** comprising a patterned web of channels **15** radiating out from the well bore. The frequencies, directions, intensities, angles and durations of the microwave beams are selected to provide desired characteristics of the permeable zone **13**, such as the desired predetermined shape, including the direction and angle of the permeable zone **13**, and the desired permeability of the zone **13**. A suitable permeability of the irradiated region, and thus the permeable zone **13**, is for example more than about one Darcy. Multiple radiating permeable zones **13** can also be provided by irradiating the subterranean reservoir **11** from the bore in multiple different directions, for example to connect wells in adjacent 5-spot patterns. Microwave methods of irradiation are described in U.S. Pat. No. 5,299,887 to Ensley et al, herein incorporated by reference in its entirety and U.S. Pat. No. 6,012,520 to Yu et al., herein incorporated by reference in its entirety.

[**0031**] The permeable zone **13** can also be formed by at least one of a mechanical and a high pressure water jet drilling method. Methods of drilling with a high pressure water jet drill are described in U.S. Pat. No. 5,413,184 to Landers et al., and U.S. Pat. No. 6,012,520 to Yu et al., both of which are herein incorporated by reference in their entireties. In a method of drilling the permeable zone **13**, a drilling tool is lowered into one or more of the injection well bore **22** and the production well bore **32**. The drilling tool drills multiple channels **15** radiating out from the well bores **22**, **32**, to form a permeable zone **13** having a patterned web of channels, as shown for example in **FIGS. 2 and 3**. The multiple channels **15** provide a highly permeable and extended area into which the hydrocarbons and fluids can flow.

[**0032**] The multiple channels **15** of the patterned web can be formed in the predetermined shape, for example upwardly or downwardly angled, and can also be formed such that a horizontal angle ϕ formed between outermost channels **15***a*, **15***b* is from about 0° to about 90°, and even from about 30° to about 60°. The multiple channels **15** are desirably large enough to provide a good flow of hydrocarbons and fluids through the channels **15**, while remaining small enough such that the portions of the reservoir **11** above the permeable zone **13** are not destabilized. A suitable thickness of a channel **15** may be, for example, from about 1 inch to about 12 inches, such as from about 2 inches to about 6 inches.

[**0033**] The channels **15** can further be stabilized by providing a liner **51** about at least a portion of the channel **15**, as shown for example in **FIG. 5**. The liner **51** may be desirable as the drilling and depletion of the hydrocarbons can lead to unstable conditions in the subterranean reservoir **11**. The liners **51** can be inserted into the channel **15** by lowering the liner **51** into the well bore and extending the liner from the well bore into the channel **15**. The liner **51** comprises a top section **52** that is permeable to the hydrocarbons and fluids, for example the top section **52** can comprise a permeable material such as a highly porous net, a flexible plastic sheet with holes or a synthetic porous media. A bottom section **53** of the liner **51** is shaped to improve the fluid flow through the channel **15**, for example, the bottom section **53** can comprise a substantially impermeable and flexible plastic sheet with a groove **54** to facilitate gravity drainage of the fluids. The two sections **52** and **53** are separated by spaced apart braces **55** that provide structural support for the liner **51** and channel **15**.

[0034] An example of a drilling tool **61** suitable for forming the permeable zone **13** is shown in **FIG. 6**. The drilling tool **61** comprises a drill head **62** that is capable of being inserted into the well bores **22**, **32** and positioned adjacent to the injection zone **24** or receiving zone **34**. The drill head **62** is adapted to drill a permeable zone **13** having the desired predetermined shape, such as a permeable zone **13** that fans out from the well bore **22**, **32** at a horizontal angle of from about 30 degrees to about 60 degrees. The drill head **62** can also be adapted to drill a permeable zone **13** that is angled upwardly or downwardly at an angle of at least about 5 degrees. In one version, the drill head **62** comprises multiple high-pressure water jet nozzles **63** that are positioned to simultaneously drill multiple channels **15** along a predetermined arc of a bore wall **64** by shooting high-pressure water jets at predetermined points along the arc. In another version, the drill head **62** comprises multiple rotating drilling bits **63** that are adapted to simultaneously drill the multiple channels **15** along the arc in the bore wall **64** to form the permeable zone **13** having the predetermined shape. A drilling tool power source **65** supplies power to the drill head **62** to drill the channels **15**.

EXAMPLE

[0035] The following example demonstrates the advantageous process economics of bitumen recovery using a 5-spot well pattern having the permeable zone **13**. In this example, the estimated total reservoir volume within a pattern region that is 25 meters thick and with a distance of about 330 feet between adjacent injection and production wells, as is typical for oil sands in Alberta Canada, is 330 ft×330 ft×25 m×3.28 ft/m=9×10^6 ft^3. The bitumen content is typically 25% by volume of the reservoir region, or 2.2×10^6 ft^3 or 4×10^5 bbl. The heat of combustion of the bitumen is 19,000 BTU/lb and the density of the bitumen is 62 lb/ft^3. Thus, the total heat content of the bitumen in a pattern=19000 BTU/lb×62 lb/ft^3×2.2×10^6 ft^3=2.6×10^{12} BTU.

[0036] The energy required to heat the reservoir via a steam driven recovery process can also be estimated. The oil sands comprising the bitumen typically contain 10% water, 25% bitum and 65% sand grains by volume. The steam driven recovery process operates under a reservoir temperature of 300° F. The enthalpies for steam at 300° F. and water at 70° F. are 1180 and 38 BTU/lb, respectively. The heat capacities for bitumen and sand are 0.60 and 0.19 BTU/lb/° F. Thus, the energy required to heat the reservoir can be estimated as:

$$\text{Water}=0.1\times62\ lb/ft^3\times2.2\times10^6\ ft^3\times(1180-38)\ BTU/lb=1.6\times10^{10}\ BTU.$$

$$\text{Bitumen}=0.25\times62\ lb/ft^3\times2.2\times10^6\ ft^3\times0.6\ BTU/lb/^\circ F.\times(300-70)^\circ F.=4.3\times10^9\ BTU.$$

$$\text{Sand}=0.65\times164\ lb/ft^3\times2.2\times10^6\ ft^3\times0.19\ BTU/lb/^\circ F.\times(300-70)^\circ F.=1.0\times10^{10}\ BTU.$$

[0037] So the total energy is 3.0×10^{10} BTU, which is only about 1.2% of the total heat content of the in-place bitumen.

[0038] For a recovery process involving combustion, the reservoir is assumed to operate at a temperature of about 550° C., which is about 1000° F. So the extra energy required for the combustion process over the steam process is approximately:

$$(0.1\times10\times62+0.25\times0.6\times62+0.65\times0.19\times164)\times2.2\times10^6\times(1000-300)=5.5\times10^{10}\ BTU$$

[0039] So the total energy required for the combustible fluid process is 8.5×10^{10} BTU. Overall, a safe estimate of the energy required for a recovery process with steam or combustion is 1.0×10^{11} BTU, or about 4% of the energy of the bitumen in the reservoir.

[0040] The cost of fabricating the permeable zones **13** can also be estimated. The energy required to fabricate a zone **13** for a 2.5-acre 5-spot well pattern by a high-power microwave method is estimated to be less than about 1% of the energy of the in-place bitumen. As oil sands having bitumen are typically fairly shallow and the unconsolidated sands are easy to drill, the costs of forming a zone **13** via mechanical drilling or high pressure water jet is not expected to exceed 2.5% of the energy of the in-place bitumen. Thus, the process of flowing steam or combustion through a permeable zone **13** in the reservoir is expected to be a highly cost-effective and efficient means of bitumen recovery.

[0041] The above description and examples show an improved method and well configuration for the recovery of dense hydrocarbons, such as bitumen, from a subterranean reservoir **11**, by providing a highly permeable zone **13** having a patterned web of channels radiating out from and connecting injection and production wells **21**, **31**. The highly permeable zone **13** provides better heating of the hydrocarbons in the reservoir **11** by forming an extended heating area adjacent to and beneath portions of the reservoir **11** to quickly and efficiently heat a larger volume of the reservoir **11**. Furthermore, a patterned grid **42** of wells can be provided having interconnecting permeable zones **13** with convoluted flow paths and spaced apart "open" and closed regions to control the flow of the fluids to areas in the reservoir **11** to maximize the recovery of hydrocarbons from the reservoir **11**. Because the cost and energy of fabricating the permeable zone **13** and performing the recovery process is expected to be a small percentage of the overall value and energy content of the hydrocarbons in the reservoir **11**, the permeable zone **13** is expected to provide a highly cost-effective and energy efficient means of recovering the hydrocarbons from the reservoir **11**.

[0042] Although exemplary embodiments of the present invention are shown and described, those of ordinary skill in the art may devise other embodiments which incorporate the present invention, and which are also within the scope of the present invention. For example, other versions of web patterns can be used depending upon terrain, topography, and the viscosity of the hydrocarbon deposits. Therefore, the appended claims should not be limited to the descriptions of the preferred versions, materials, or spatial arrangements described herein to illustrate the invention.

What is claimed is:

1. A drilling tool capable of being inserted into a well bore to drill a web of channels to form a permeable zone in a subterranean reservoir, the drilling tool comprising:

(a) a drill head adapted to drill a web of channels that radiate out from the well bore to form a permeable zone; and

(b) a power source to supply power to the drill head.

2. A tool according to claim 1 wherein the drill head is adapted to drill a permeable zone that fans out from the well bore at a horizontal angle of from about 0° to about 90°.

3. A tool according to claim 2 wherein the drill head is adapted to drill a permeable zone that fans out from the well bore at a horizontal angle of from about 30° to about 60°.

4. A tool according to claim 1 wherein the drill head is adapted to drill a permeable zone that is angled upwardly or downwardly at an angle of at least about 5°.

5. A tool according to claim 1 wherein the drill head is adapted to drill channels having a thickness of from about 1 to about 12 inches.

6. A tool according to claim 4 wherein the drill head is adapted to drill channels having a thickness of from about 2 to about 6 inches.

7. A tool according to claim 1 wherein the drill head comprises rotating drill bits.

8. A tool according to claim 1 wherein the drill head comprises a plurality of rotating drilling bits that are adapted to simultaneously drill multiple channels along an arc of a wall of the bore well.

9. A tool according to claim 1 wherein the drill head comprises a high pressure water jet.

10. A tool according to claim 1 wherein the drill head comprises multiple high-pressure water jet nozzles that are positioned to simultaneously drill multiple channels along a predetermined arc of a wall of the bore well.

11. A tool according to claim 1 wherein the drill head comprises a microwave antenna.

12. A tool according to claim 1 wherein the drill head comprises a laser drill.

13. A drilling tool capable of being inserted into a well bore to drill a web of channels in a subterranean reservoir, the drilling tool comprising:

(a) a drill head adapted to drill a web of channels that radiate out from the well bore such that the horizontal angle formed between outermost channels is from about 0° to about 90°, and the web of channels is at an upward or downward angle of from 0° degree to about 30°; and

(b) a power source to supply power to the drill head.

14. A tool according to claim 13 wherein the drill head is adapted to drill a permeable zone that is angled upwardly or downwardly at an angle of at least about 5°.

15. A tool according to claim 13 wherein the drill head is adapted to drill channels having a thickness of from about 1 to about 12 inches.

16. A tool according to claim 13 wherein the drill head comprises a plurality of rotating drilling bits that are adapted to simultaneously drill multiple channels along an arc of a wall of the bore well.

17. A tool according to claim 13 wherein the drill head comprises a high pressure water jet.

18. A tool according to claim 13 wherein the drill head comprises multiple high-pressure water jet nozzles that are positioned to simultaneously drill multiple channels along a predetermined arc of a wall of the bore well.

19. A tool according to claim 13 wherein the drill head comprises a microwave antenna.

20. A tool according to claim 13 wherein the drill head comprises a laser drill.

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