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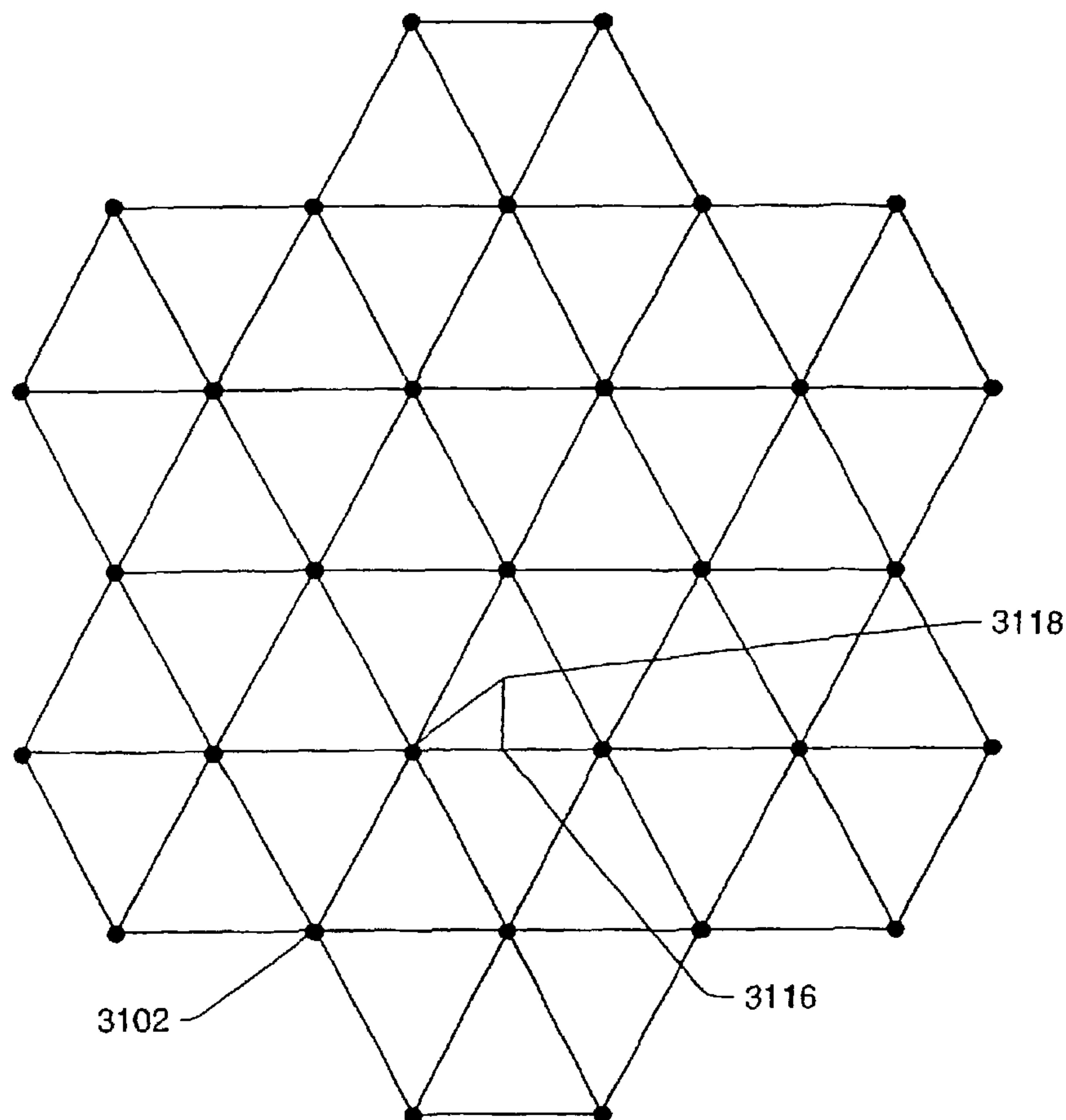
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(54) Title: A METHOD FOR TREATING A HYDROCARBON-CONTAINING FORMATION



(57) Abrégé/Abstract:

The invention provides a method for treating a hydrocarbon-containing formation in situ, comprising applying heat to at least a portion of the formation via heater wells to pyrolyse hydrocarbons present in the formation to yield pyrolysis fluids and recovering the pyrolysis fluids from the formation, in which the heater wells are provided in a triangular pattern.

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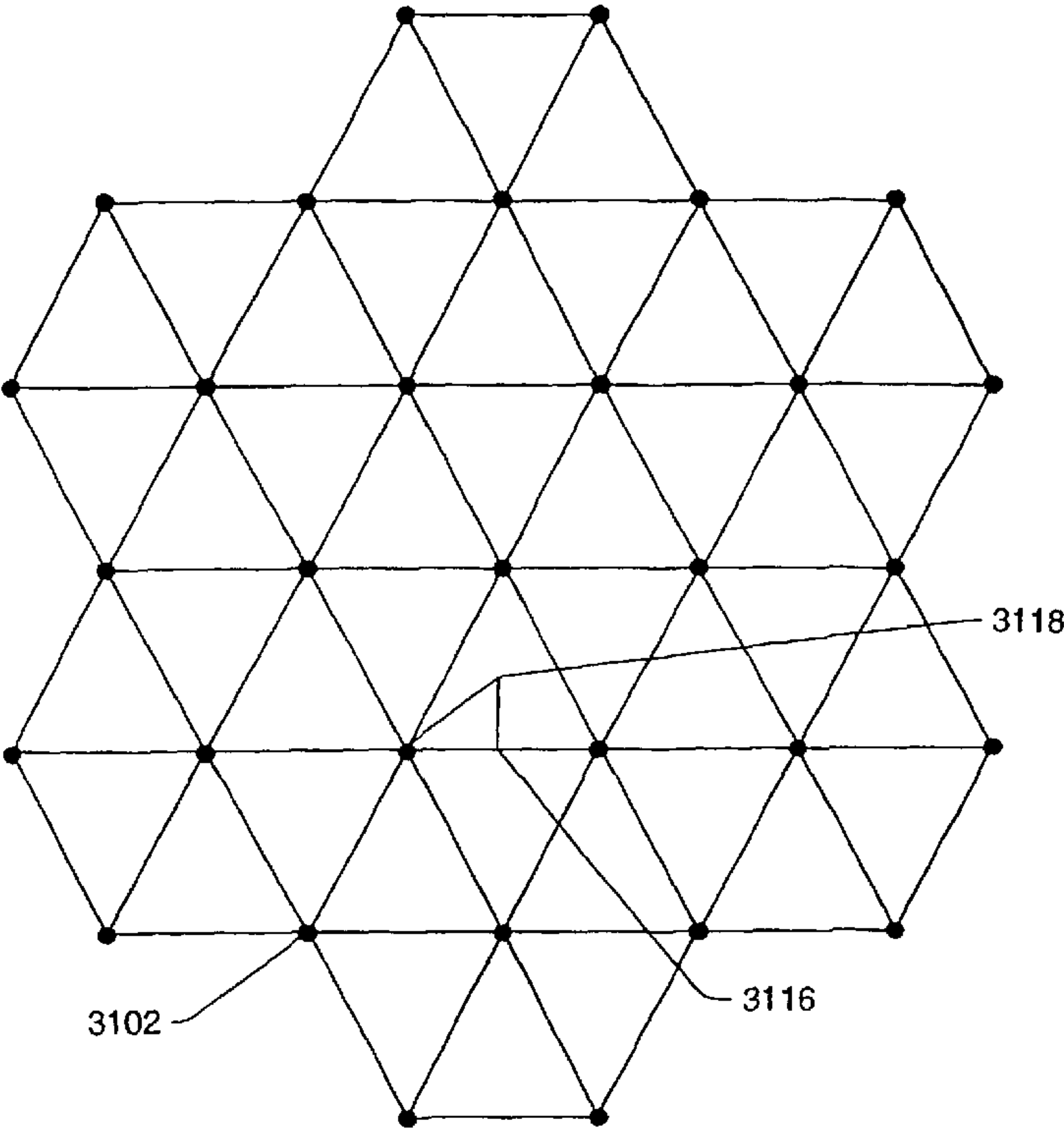
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(54) Title: A METHOD FOR TREATING A HYDROCARBON-CONTAINING FORMATION



(57) Abstract: The invention provides a method for treating a hydrocarbon-containing formation in situ, comprising applying heat to at least a portion of the formation via heater wells to pyrolyse hydrocarbons present in the formation to yield pyrolysis fluids and recovering the pyrolysis fluids from the formation, in which the heater wells are provided in a triangular pattern.

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A METHOD FOR TREATING A HYDROCARBON-CONTAINING  
FORMATION

The invention relates to a method for treating a hydrocarbon containing formation in situ and producing a hydrocarbon fluid from the formation, by pyrolysing hydrocarbons present in the formation.

5        Hydrocarbons obtained from subterranean formations are often used as energy resources, as feedstocks, and as consumer products. Concerns over depletion of available hydrocarbon resources have led to development of processes for more efficient recovery, processing and use  
10       of available hydrocarbon resources. In situ processes may be used to remove hydrocarbon materials from subterranean formations. Chemical and/or physical properties of hydrocarbon material within a subterranean formation may need to be changed to allow hydrocarbon material to be  
15       more easily removed from the subterranean formation. The chemical and physical changes may include in situ reactions that produce removable fluids, solubility changes, phase changes, and/or viscosity changes of the hydrocarbon material within the formation. A fluid may  
20       be, but is not limited to, a gas, a liquid, an emulsion, a slurry and/or a stream of solid particles that has flow characteristics similar to liquid flow.

      Examples of in situ processes utilizing downhole heaters are illustrated in US-A-2634961, US-A-2732195,  
25       US-A-2780450, US-A-2789805, US-A-2923535 and US-A-4886118.

      For example, the application of heat to oil shale formations is described in US-A-2923535 and US-A-4886118.



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Herein, heat is applied to the oil shale formation to pyrolyse kerogen within the oil shale formation. The heat also fractures the formation to increase permeability of the formation. The increased permeability allows hydrocarbon fluids to travel to a production well where the fluid is removed from the oil shale formation.

In the process of US-A-2923535 heat is applied via a number of heater wells. The heater wells are provided in a hexagonal pattern. Production wells are provided in the centre of a number of hexagons. The ratio of heater wells to production wells is about 12 to one. The prior art process refers to a very long time to heat the formation.

The method according to the pre-ambble of claim 1 is known from US-A-2914309. In the known method a triangular pattern of heater wells is used to pre-heat a tar sand formation and form permeable tube walls of hard sand coke around the wells, whereupon the heating elements are removed and a fire flood is initiated in the formation.

The present invention provides a method for treating a hydrocarbon-containing formation in situ, comprising applying heat to at least a portion of the formation via heater wells to pyrolyse hydrocarbons present in the formation to yield pyrolysis fluids and recovering the pyrolysis fluids from the formation, in which the heater wells are provided in a triangular pattern at a distance ranging from 5 m to 25 m.

In the triangular pattern the distance between the heater wells may suitably be constant. The distance may vary depending on properties of the formation, e.g., thermal conductivity, permeability. Preferably, the spacing between heater wells is within a range of 8 m to 15 m.

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One could argue that the heating rate in the method according to the present invention is expected to be

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higher now that the number of heaters is increased. One could state that the triangular pattern is obtained by adding a further heater well in each hexagon. However, it has been found that if the heater density in a triangular pattern (i.e. the number of heater wells per surface unit) is the same as that in a hexagonal pattern, the heating time of a formation in such a triangular pattern is significantly reduced. An important factor in this calculation is the coldest spot.

Although it is possible to recover the pyrolysis fluids via one or more heater wells, it is preferred to employ separate production wells to recover the pyrolysis fluids. Production wells are suitably disposed in the repetitive pattern of units. In certain embodiments, a production well is disposed proximate to a centre of one of a number of triangles, e.g., to the centre of every third triangle arranged in the pattern. A production well, however, can also be disposed in every triangle or within just a few triangles. A production well may be within every 13, 20, or 30 triangles. For example, a ratio of heat sources in the repetitive pattern of units to production wells in the repetitive pattern of units may be more than 5, e.g., from 5 to 24, preferably at least 12, e.g., from 12 to 24. In addition, the placement of production well may vary depending on the heat generated by one or more heat sources and the characteristics of the formation (such as permeability). Furthermore, three or more production wells may be located within an area defined by a repetitive pattern of units. For example, the unit of production wells may be a triangular pattern. Production wells, however, may be disposed in another pattern within a repetitive pattern. In certain embodiments heater wells may be arranged



horizontally, while production wells may be disposed vertically. In such situations, location of production wells may not depend on location of heater wells.

5 In addition, one or more monitoring wells can be disposed within a repetitive pattern of units. The monitoring wells may be configured as described herein. For example, the wells may be configured with one or more devices that may be configured to measure a temperature, a pressure, and/or a property of a fluid. Monitoring  
10 wells may be located within an area defined by repetitive pattern of triangles. Monitoring wells may be located in the formation in a unit of monitoring wells, which may be arranged in a triangular pattern. Monitoring wells, however, may be disposed in any of the other patterns as  
15 described herein within repetitive pattern of units. In certain embodiments, heater wells may be arranged horizontally, while monitoring wells may be disposed vertically. In such situations, location of monitoring wells may not depend on location of heater wells.

20 The hydrocarbon containing formation or the portion thereof which is subjected to the in situ heat treatment may have a width of for example at least 0.5 m, or at least 1.5 m, or at least 2.4 m, or even at least 3.0 m. The width may be up to 100 m, or up to 1000 m, or even up  
25 to 2000 m, or more. The hydrocarbon containing formation or the portion thereof which is subjected to the in situ heat treatment may have a layer thickness of, for example, at least 2 m, more typically in the range of from 4 m to 100 m, more typically from 6 m to 60 m. The  
30 overburden of the hydrocarbon containing formation may have a thickness of, for example, at least 10 m, more typically in the range of from 20 m to 800 m or to 1000 m or more.



The triangular pattern of heat sources is especially advantageous in the treatment of a hydrocarbon-containing formation having a thickness of about 10 meters or more. The thickness may be up to 100 m, or 1000 m, or even  
5 2000 m. For a thinner hydrocarbon containing formation, e.g., about 10 meters thick or less, e.g., to at least 2 m, a line and/or staggered line pattern of heat sources may be configured to treat the hydrocarbon containing formation.

10 The spacing between heat sources may affect the composition of fluids produced from a hydrocarbon containing formation. In an embodiment, a computer-implemented method may be used to determine optimum heat  
15 source spacings within a hydrocarbon containing formation. For example, at least one property of a portion of hydrocarbon containing formation can usually be measured. The measured property includes, but is not be limited to, vitrinite reflectance, hydrogen content,  
20 atomic hydrogen to carbon ratio, oxygen content, atomic oxygen to carbon ratio, water content, thickness of the hydrocarbon containing formation, and/or the amount of stratification of the hydrocarbon containing formation into separate layers of rock and hydrocarbons.

In certain embodiments a computer-implemented method  
25 includes providing at least one measured property to a computer system. One or more sets of heat source spacings in the formation may also be provided to the computer system. For example, a spacing between heat sources can be less than about 25 m. Alternatively, a spacing between  
30 heat sources can be less than about 15 m. The spacing between heat sources is suitably within the range of from 5 m to 20 m, preferably from 8 m to 15 m. Positioning of equidistant heat sources, in a triangular pattern, is

preferred, as it tends to provide more uniform heating to the formation in comparison to other patterns such as hexagons. In addition, a triangular pattern tends to provide faster heating to a predetermined temperature in comparison to other patterns such as hexagons.

The method may also include determining properties of fluids produced from the portion as a function of time for each set of heat source spacings. The produced fluids include, but are not limited to, formation fluids such as pyrolyzation fluids and synthesis gas. In this manner, the determined properties include, but are not be limited to, API gravity, carbon number distribution, olefin content, hydrogen content, carbon monoxide content, and/or carbon dioxide content. The determined set of properties of the produced fluid may be compared to a set of selected properties of a produced fluid. In this manner, sets of properties that match the set of selected properties may be determined. Furthermore, heat source spacings may be matched to heat source spacings associated with desired properties.

The comparison of patterns of heat sources was evaluated for the same heater well density and the same heating input regime. For example, a number of heat sources per unit area in a triangular pattern is the same as the number of heat sources per unit area in the 10 m hexagonal pattern if the space between heat sources is increased to about 12.2 m in the triangular pattern.

Suitably, heat sources are provided in the heater wells. Any type of heat source can be used. Electrical heaters may be used to heat the subterranean formation by radiation and/or conduction. An electrical heater may resistively heat an element. Examples of electrical heating elements are described in US-A-2548360,



US-A-4716960, US-A-5060287, US-A-5065818. US-A-6023554 describes an electrical heating element that is positioned within a casing. The heating element generates radiant energy that heats the casing. A granular solid fill material may be placed between the casing and the formation. The casing may conductively heat the fill material, which in turn conductively heats the formation. It may be advantageous to employ uncased well bores for the heat sources.

US-A-4570715 describes an electrical heating element. The heating element has an electrically conductive core, a surrounding layer of insulating material, and a surrounding metallic sheath. The conductive core may have a relatively low resistance at high temperatures. The insulating material may have electrical resistance, compressive strength and heat conductivity properties that are relatively high at high temperatures. The insulating layer may inhibit arcing from the core to the metallic sheath. The metallic sheath may have tensile strength and creep resistance properties that are relatively high at high temperatures.

Combustion of a fuel can also be used to heat a formation. In certain instances, combusting a fuel to heat a formation is more economical than using electricity to heat a formation. Several different types of heaters may use fuel combustion as a heat source that heats a formation. The combustion may take place in the formation, in a well and/or near the surface. Combustion in the formation may be a fire-flood. An oxidant may be pumped into the formation. The oxidant may be ignited to advance a fire front towards a production well. Oxidant pumped into the formation may flow through the formation along fracture lines in the formation. Ignition of the



oxidant may not result in the fire front flowing uniformly through the formation.

A flameless combustor may be used to combust a fuel within a well. US-A-5255742, US-A-5404952, US-A-5862858 and US-A-5899269 describe flameless combustors. Flameless combustion may be accomplished by preheating a fuel and combustion air to a temperature above an auto-ignition temperature of the mixture. The fuel and combustion air may be mixed in a heating zone to combust.

Heat may be supplied to a formation from a surface heater. The surface heater may produce combustion gases that are circulated through well bores to heat the formation. Alternately, a surface burner may be used to heat a heat transfer fluid that is passed through a well bore to heat the formation. Examples of fired heaters, or surface burners that may be used to heat a subterranean formation, are illustrated in US-A-6056057 and US-A-6079499.

Hydrocarbon containing formations can be selected for in situ treatment based on properties of at least a portion of the formation such that it leads to the production of high quality fluids from the formation. The hydrocarbon-containing formation may be oil shale, coal, tar sands, heavy hydrocarbons-containing formations with high viscosity, bituminous formations and the like. Preferably, hydrocarbon-containing formations which include kerogen may be assessed or selected for treatment based on a vitrinite reflectance of the kerogen.

Vitrinite reflectance is often related to the elemental hydrogen to carbon ratio of a kerogen and the elemental oxygen to carbon ratio of the kerogen. Preferably the vitrinite reflectance is in the range of from 0.2% to 3.0%, more preferably from 0.5% to 2.0%. Such ranges of

vitritinite reflectance tend to indicate that relatively higher quality hydrocarbon fluids will be produced from the formation.

5 The hydrocarbon containing formation may be selected for treatment based on the elemental hydrogen content of the kerogen in the hydrocarbon containing formation. For example, a method of treating a hydrocarbon containing formation may typically include selecting a hydrocarbon containing formation for treatment having kerogen with an  
10 elemental hydrogen content greater than 2 weight%, in particular greater than 3 weight%, or more in particular greater than 4 weight% when measured on a dry, ash-free basis. Preferably, the hydrocarbon containing formation has kerogen with an elemental hydrogen to carbon ratio in  
15 the range of from 0.5 to 2, in particular from 0.70 to 1.7. The elemental hydrogen content may significantly affect the composition of hydrocarbon fluids produced, for example through the formation of molecular hydrogen.

20 The hydrocarbon containing formation is heated to a temperature at which pyrolysis can take place. The pyrolysis temperature range may include temperatures up to, for example, 900 °C. A majority of hydrocarbon fluids may be produced within a pyrolysis temperature range of from 250 °C to 400 °C, more preferably in the range of  
25 from 260 °C to 375 °C. A temperature sufficient to pyrolyse heavy hydrocarbons in a hydrocarbon containing formation of relatively low permeability may be within a range from 270 °C to 375 °C. In other embodiments, a temperature sufficient to pyrolyse heavy hydrocarbons may  
30 be within a range from 300 °C to 375 °C. If a hydrocarbon containing formation is heated throughout the entire pyrolysis temperature range, the formation may produce only small amounts of hydrogen towards the upper limit of



the pyrolysis temperature range. After the available hydrogen is depleted, little hydrocarbon production from the formation may occur.

5 The temperature may be measured at any location within the hydrocarbon containing formation, for example at a midpoint between two adjacent heat sources, or at a production well.

10 Preferably, the hydrocarbon containing formation or the portions thereof designated for pyrolysis is heated at a low heating rate. In general the heating rate will be at most 50 °C/day. Typically, the heating rate is less than 10 °C/day, more typically less than 3 °C/day, in particular less than 0.7 °C/day. Frequently the rate of heating will be more than 0.01 °C/day, in particular more than 0.1 °C/day. In particular, such low heating rates  
15 are applied in the pyrolysis temperature range. More in particular, heated portions of the hydrocarbon containing formation may be heated at such a rate for a time greater than 50% of the time needed to span the pyrolysis  
20 temperature range, preferably more than 75% of the time needed to span the pyrolysis temperature range, or more preferably more than 90% of the time needed to span the pyrolysis temperature range.

25 The rate at which a hydrocarbon containing formation is heated may affect the quantity and quality of the hydrocarbon fluids produced from the hydrocarbon containing formation. For example, heating at high heating rates may produce a larger quantity of fluids from a hydrocarbon containing formation. The products of  
30 such a process, however, may be of a significantly lower quality than when heating using lower heating rates. Further, controlling the heating rate at less than



3 °C/day generally provides better control of the temperature within the hydrocarbon containing formation.

5 Heating of a hydrocarbon containing formation to the pyrolysis temperature range may occur before substantial permeability has been generated within the hydrocarbon containing formation. An initial lack of permeability may prevent the transport of generated fluids from a pyrolysis zone within the formation. In this manner, as heat is initially transferred from the heat source to the hydrocarbon containing formation, the fluid pressure within the hydrocarbon containing formation may increase proximate to the heat source.

10 The pressure generated by expansion of the hydrocarbon fluids or other fluids generated in the formation can initially increase, as an open path to the production well or any other pressure sink may not yet exist in the formation. In addition, the fluid pressure may exceed the lithostatic pressure, so that fractures in the hydrocarbon containing formation may form from the heat sources to the production wells. The generation of fractures within the heated portion then reduces the pressure, due to the production of hydrocarbon fluids through the production wells.

20 To maintain pressure within the carbon containing formation during the production of hydrocarbon fluids, a backpressure may be maintained at the production well. The pressure may be controlled by means of valves and/or by injecting gases into the hydrocarbon containing formation, for example hydrogen, carbon dioxide, carbon monoxide, nitrogen or methane, or water or steam. Injecting hydrogen is particularly preferred.

30 Valves may be configured to maintain, alter, and/or control the pressure within the hydrocarbon containing

formation. For example, heat sources disposed within the hydrocarbon containing formation may be coupled to a valve. The valve may be configured to release fluid from the formation through the heat source or for the  
5 injection of a gas into the hydrocarbon containing formation. Alternatively, a pressure valve may be coupled to the production wells. Fluids released by the valves may be collected and transported to a surface unit for further processing and/or treatment.

10 In accordance with this invention the pressure is controlled during pyrolysis and during the production of the hydrocarbon fluid from the formation. Typically, a pressure of at least 1.0 bar is applied, more typically at least 1.5 bar, in particular at least 1.8 bar. In  
15 particular, when the pyrolysis temperature is at least 300 °C, a pressure of at least 1.6 bar may be applied. The upper limit of the pressure may be determined by the structure and the weight of the overburden. Frequently, under practical conditions, the pressure is less than  
20 70 bar, more frequently less than 60 bar or even less than 50 bar. The pressure may advantageously be controlled within a range of from 2 bar to 18 bar or 20 bar, or alternatively within a range of from 20 bar to 36 bar.

25 In a preferred embodiment, as indicated hereinbefore, a partial pressure of hydrogen is maintained. Typically the partial pressure is at least 0.5 bar, for example up to 20 bar, more typically in the range of from 1 bar to 10 bar, in particular in the range of from 5 bar to  
30 7 bar. Maintaining a hydrogen partial pressure within the formation in particular increases the API gravity of produced hydrocarbon fluids and reduces the production of long chain hydrocarbon fluids.



At least 20%, typically at least 25%, preferably at least 35% of the initial total organic carbon content of the hydrocarbon containing formation, or the portion thereof subjected to pyrolysis may be transformed into hydrocarbon fluids.

In certain embodiments, after the pyrolysis, synthesis gas may be produced from hydrocarbons remaining within the hydrocarbon containing formation. The pyrolysis may produce a relatively high, substantially uniform permeability throughout the hydrocarbon containing formation or the pyrolysed portion thereof. Such a relatively high, substantially uniform permeability allows the generation of synthesis gas with lower injection costs and minimum fingering and by-passing of substantial portions of the formation. The portion also has a large surface area and/or a large surface area/volume. The large surface area may allow synthesis gas producing reactions to be substantially at equilibrium conditions during synthesis gas generation. The relatively high, substantially uniform permeability can result in a relatively high recovery efficiency of synthesis gas, as compared to synthesis gas generation in a hydrocarbon containing formation, which has not been subjected to pyrolysis.

Pyrolysis of at least some hydrocarbon containing material in some embodiments convert 20% of carbon initially available. Synthesis gas generation may convert at least an additional 10% and typically up to an additional 70% of the carbon initially available. In this manner, in situ production of synthesis gas from a hydrocarbon containing formation may allow conversion of larger amounts of carbon initially available within the portion.



Synthesis gas may be produced from the formation prior to or subsequent to producing the hydrocarbon fluid from the formation. The synthesis gas, although generally defined as a mixture of hydrogen ( $H_2$ ) and carbon monoxide (CO), may comprise additional components such as water, carbon dioxide ( $CO_2$ ), methane and other gases.

The synthesis gas generation may be commenced before and/or after hydrocarbon fluid production decreases to an uneconomical level. In this manner, heat provided to pyrolyse may also be used to generate synthesis gas. For example, if a portion of the formation is  $375\text{ }^{\circ}\text{C}$  after pyrolysis, then less additional heat is generally required to heat such portion to a temperature sufficient to support synthesis gas generation. In certain instances heat may be provided from one or more heat sources to heat the formation to a temperature sufficient to allow synthesis gas generation (for example in the range of from  $400\text{ }^{\circ}\text{C}$  to  $1200\text{ }^{\circ}\text{C}$  or higher). At the upper end of the temperature range, the generated synthesis gas may include mostly  $H_2$  and CO, in for example a 1:1 mole ratio. At the lower end of this temperature range, the generated synthesis gas may have a higher  $H_2$  to CO ratio.

Heating wells, heating sources and production wells within the formation for pyrolysing and producing hydrocarbon fluids from the formation may be utilized during synthesis gas production as an injection well to introduce synthesis gas producing fluid, as a production well, or as a heat source to heat the formation. Heat sources for the synthesis gas production may include any of the heat sources as disclosed hereinbefore. Alternatively, heating may include transferring heat from a heat transfer fluid, for example steam or combustion

products from a burner, flowing within a plurality of wellbores within the formation.

5 A synthesis gas generating fluid, for example liquid water, steam, carbon dioxide, air, oxygen, hydrocarbons, and mixtures thereof, may be provided to the formation. For example, the synthesis gas generating fluid mixture may include steam and oxygen. The synthesis gas  
10 generating fluid may include aqueous fluid produced by pyrolysis of hydrocarbon containing material within another portion of the formation. Providing the synthesis gas generating fluid may alternatively include raising a water table of the formation to allow water to flow into it. Synthesis gas generating fluid may also be provided through an injection wellbore. The synthesis gas  
15 generating fluid will generally react with carbon in the formation to form  $H_2$ , water (as liquid or as steam),  $CO_2$ , and/or CO.

Carbon dioxide may be separated from the synthesis gas and may be re-injected into the formation with the  
20 synthesis gas generating fluid. By a shift of the prevailing chemical equilibrium reactions, carbon dioxide added to the synthesis gas generating fluid may substantially inhibit further production of carbon dioxide during the synthesis gas generation. The carbon  
25 dioxide may also react with carbon in the formation to generate carbon monoxide.

Hydrocarbons such as ethane may be added to the synthesis gas generating fluid. When introduced into the formation, the hydrocarbons may crack to form hydrogen  
30 and/or methane. The presence of methane in the produced synthesis gas may increase its heating value.

Synthesis gas generating reactions are typically endothermic reactions. Heat may be added to the formation



during synthesis gas production to keep the formation temperature at the desired level. Heat may be added from heat sources and/or from introducing synthesis gas generating fluid which has a higher temperature than the temperature of the formation. As an alternative, an oxidant may be added to the synthesis gas generating fluid, for example air, oxygen enriched air, oxygen, hydrogen peroxide, other oxidizing fluids, or combinations thereof. The oxidant may react with carbon within the formation to generate heat, and to result in production of CO<sub>2</sub> and/or CO. In a preferred embodiment oxygen and water (or steam) are provided to the formation, for example in a mole ratio of from 1:2 to 1:10, preferably from 1:3 to 1:7, for example 1:4.

The hydrocarbon containing formation may be maintained at a relatively high pressure during synthesis gas production. Synthesis gas may be generated in a wide pressure range, for example between 1 bar and 100 bar, more typically between 2 bar and 80 bar, especially between 5 bar and 60 bar. High operating pressures may result in an increased production of H<sub>2</sub>. High operating pressures may allow generation of electricity by passing produced synthesis gas through a turbine, and they may allow for smaller collection conduits to transport produced synthesis gas.

The synthesis gas may be generated in a wide temperature range, such as between 400 °C and 1200 °C, more typically between 600 °C and 1000 °C. At a relatively low synthesis gas generation temperature a synthesis gas may be produced which has a high H<sub>2</sub> to CO ratio. A relatively high formation temperature may produce a synthesis gas having a H<sub>2</sub> to CO ratio that approaches 1, and the stream may include mostly (and in



some cases substantially only) H<sub>2</sub> and CO. At a formation temperature of about 700 °C, the formation may produce a synthesis gas having a H<sub>2</sub> to CO ratio of 2. Typically synthesis gas may be generated which has a H<sub>2</sub> to CO mole ratio in the range of from 1:4 to 8:1, more typically in the range of from 1:2 to 4:1, in particular in the range of from 1:1 to 2.5:1. Certain embodiments may include blending a first synthesis gas with a second synthesis gas to produce synthesis gas of a desired composition. The first and the second synthesis gases may be produced from different portions of the formation.

The hydrocarbon containing formation or the portion thereof which has been subjected to pyrolysis and optionally to synthesis gas generation may be allowed to cool or may be cooled to form a cooled, spent formation. After production of hydrocarbon fluids and/or synthesis gas, a fluid (e.g., carbon dioxide) may be sequestered within the formation. To store a significant amount of fluid within the formation, the temperature of the formation will often need to be less than 100 °C, for example down to 20 °C. Water may be introduced into the formation to generate steam and reduce the temperature of the formation. The steam may be removed from the formation. The steam may be utilized for various purposes, for example for heating another portion of the formation, for generating synthesis gas in an adjacent portion of the formation, or as a steam flood in an oil reservoir. After the formation is cooled, fluid may be pressurized and sequestered in the formation. Sequestering fluid within the formation may result in a significant reduction or elimination of fluid that is released to the environment due to operation of the present in situ process. The spent formation is

especially useful for this purpose, because it has a structure of large porosity and large permeability for fluids, in particular gases.

5 The fluid to be sequestered may be injected under pressure, for example in the range of from 5 bar to 50 bar, into the cooled, spent formation and adsorbed onto hydrocarbon containing material in the formation. Subsequent addition of water to the formation may inhibit desorption of the carbon dioxide. An example of a method  
10 for sequestering carbon dioxide is illustrated in US-A-5566756.

The synthesis gases described herein may be converted to hydrocarbons, which include methanol, or to other products, such as ammonia. For example, a Fischer-Tropsch  
15 hydrocarbon synthesis process may be configured to convert synthesis gas to paraffins. The synthesis gas may also be used in a catalytic methanation process to produce methane. Alternatively, the synthesis gas may be used for production of methanol, gasoline and diesel  
20 fuel, ammonia, and middle distillates.

The synthesis gas may also be used as a source of energy. For example, it may be used as a combustion fuel, to heat the hydrocarbon containing formation or to make steam and then run turbines for the generation of  
25 electricity. Synthesis gas may be used to generate electricity by reducing the pressure of the synthesis gas in turbines, or using the temperature of the synthesis gas to make steam and then run turbines. Synthesis gas may also be used in an energy generation unit such as a  
30 molten carbonate fuel cell, a solid oxide fuel cell, or other type of fuel cell.

The H<sub>2</sub> to CO mole ratio for synthesis gas used as a feed gas for a Fischer-Tropsch reaction is typically



about 2:1. The Fischer-Tropsch process typically produces branched and unbranched paraffins, which may be converted by hydrocracking to produce hydrocarbon products which include for example diesel, jet fuel and naphtha products. Examples of methods for conversion of synthesis gas to hydrocarbons in a Fischer-Tropsch process are illustrated in US-A-4096163, US-A-4594468, US-A-6085512 and US-A-6172124.

It may be desirable for the composition of produced synthesis gas, which may be used as a feed gas for a catalytic methanation process, to have a H<sub>2</sub> to CO mole ratio of 3:1 to 4:1. Examples of a catalytic methanation process are illustrated in US-A-3992148, US-A-4130575 and US-A-4133825.

Examples of processes for production of methanol from synthesis gas are illustrated in US-A-4407973, US-A-4927857 and US-A-4994093.

Examples of process for producing engine fuels are illustrated in US-A-4076761, US-A-4138442 and US-A-4605680.

Fig. 1 shows a triangular pattern according to the invention; and

Fig. 2 shows a hexagonal pattern.

In Fig. 1 the heater wells 3102 are provided at each corner point. Production wells can be provided in one or more of the triangles that are formed by three heater wells. On comparison of the temperatures of those at points 3116 and 3118, it appears that point 3118 is the coldest spot. Fig. 2 shows the prior art configuration in which the heater wells 3106 are positioned at the corners of each hexagon. As shown in Fig. 2, point 3112 is located at the centre of a side of the hexagonal pattern midway between heaters. Point 3114 is located at the



centre of a hexagonal pattern. It appears that in these cases point 3114 represents the coldest spot. Production wells are usually provided in the centre of one or more hexagons.

5     EXAMPLE

Calculations were made on the heating for a triangular pattern with a 12.2 m spacing in a typical Green River oil shale. A temperature profile of the triangular pattern is more uniform than a temperature profile of the hexagonal pattern. For instance, a temperature variation within the triangular pattern after 3 years of heating is 20 °C less than a temperature variation within the square pattern and 50 °C less than a temperature variation within the hexagonal pattern. For a chemical process, where reaction rate is proportional to an exponent of temperature, even 20 °C difference is substantial.

The coldest spot for each pattern is located at a pattern centre. The difference between an average pattern temperature and temperature of the coldest spot represents how uniform the temperature distribution for a given pattern is. The more uniform the heating, the better the product quality that may be made. The larger the volume fraction of resource that is overheated, the more undesirable product composition will be made. The difference between an average temperature of a pattern and temperature of the coldest spot is less for the triangular pattern than for hexagonal pattern. Again, there is a substantial difference between triangular and hexagonal patterns.

Another way to assess the uniformity of temperature distribution is to compare temperatures of the coldest

spot of a pattern with a point located at the centre of a side of a pattern midway between heaters.

5 A triangular pattern of heat sources may have, for example, a shorter total process time than hexagonal pattern of heat sources for the same heater well density. A total process time may include a time required for an average temperature of a heated portion of a formation to reach a target temperature and a time required for a temperature at a coldest spot within the heated portion  
10 to reach the target temperature. For example, heat may be provided to the portion of the formation until an average temperature of the heated portion reaches the target temperature. After the average temperature of the heated portion reaches the target temperature, an energy supply to the heat sources may be reduced such that less or minimal heat may be provided to the heated portion. An example of a target temperature may be approximately 340 °C. The target temperature, however, may vary depending on, for example, formation composition and/or  
15 formation conditions such as pressure.  
20

A comparison between the average pattern temperature and temperatures at the coldest spots for each pattern, as a function of time when heaters are turned off after average temperature reaches a target value shows that an  
25 average temperature of formation reaches a target temperature in approximately 3 years (about 340 °C). A temperature at the coldest point within the triangular pattern reaches the target temperature (about 340 °C) 0.8 years later. In this manner, a total process time for such a triangular pattern is about 3.8 years when the  
30 heat input is discontinued when the target average temperature is reached. A temperature at the coldest point within the triangular pattern reaches the target



temperature (about 340 °C) before a temperature at the coldest point within the hexagonal pattern reaches the target temperature. A temperature at the coldest point within the hexagonal pattern reaches the target

5 temperature after an additional time of about 2 years when the heaters are turned off upon reaching the target average temperature. Therefore, a total process time for a hexagonal pattern is about 5.0 years. In this manner, a total process time for heating a portion of a formation  
10 with a triangular pattern is 1.2 years less (approximately 25%) than a total process time for heating a portion of a formation with a hexagonal pattern. In a preferred mode, the power to the heaters may be reduced or turned off when the average temperature of the pattern  
15 reaches a target level. This prevents overheating the resource, which wastes energy and produces lower product quality. The triangular pattern has the most uniform temperatures and the least overheating. Although a capital cost of such a triangular pattern may be  
20 approximately the same as a capital cost of the hexagonal pattern, the triangular pattern may accelerate oil production and requires a shorter total process time. In this manner, such a triangular pattern may be more economical than a hexagonal pattern.

25 A spacing of heat sources in a triangular pattern, which may yield the same process time as a hexagonal pattern having about a 10.0 m space between heat sources, may be equal to approximately 14.3 m. In this manner, the total process time of a hexagonal pattern may be achieved  
30 by using about 26% less heat sources than may be included in such a hexagonal pattern. In this manner, such a triangular pattern may have substantially lower capital



and operating costs. As such, this triangular pattern may also be more economical than a hexagonal pattern.

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1. A method for treating a hydrocarbon-containing formation in situ, comprising applying heat to at least a portion of the formation via heater wells which are provided in a triangular pattern to pyrolyse hydrocarbons present in the formation to yield pyrolysis fluids and recovering pyrolysis fluids from the formation, characterized in that the heater wells are placed at a distance ranging from 5 m to 25 m and are operated to heat a majority of hydrocarbons in the portion of the formation surrounded by the heater wells to a pyrolysis temperature in the range between 250 and 400 °C.

2. A method according to claim 1, in which the distance between the heater wells in the triangular pattern is constant.

3. A method according to claim 1 or 2, in which the heater wells are placed at a distance ranging from 8 m to 15 m.

4. A method according to any one of claims 1 to 3, in which separate production wells to recover the pyrolysis fluids are employed.

5. Method according to claim 4, in which the ratio of heater wells to production wells is at least 12 to 1.

6. A method according to any one of claims 1 to 5, in which the hydrocarbon-containing formation having a thickness of at least 5 m, preferably at least 10 m.

7. A method according to any one of claims 1 to 6, in which the hydrocarbon-containing formation includes kerogen.

- 25 -

8. A method according to claim 7, in which the hydrocarbon-containing formation has a vitrinite reflectance in the range of from 0.2% to 3.0%.

9. A method according to any one of claims 1 to 8, in which the pyrolysis temperature is up to 900 °C, preferably within the range of from 250 °C to 400 °C.

10. A method according to any one of claims 1 to 9, in which the pressure is at least 1.0 bar (0.1 Mpa), preferably at least 1.5 bar, and the pressure does not exceed 70 bar (7Mpa).

11. A method according to any one of claims 1 to 10, in which after the pyrolysis, synthesis gas is produced from hydrocarbons remaining within the hydrocarbon-containing formation.

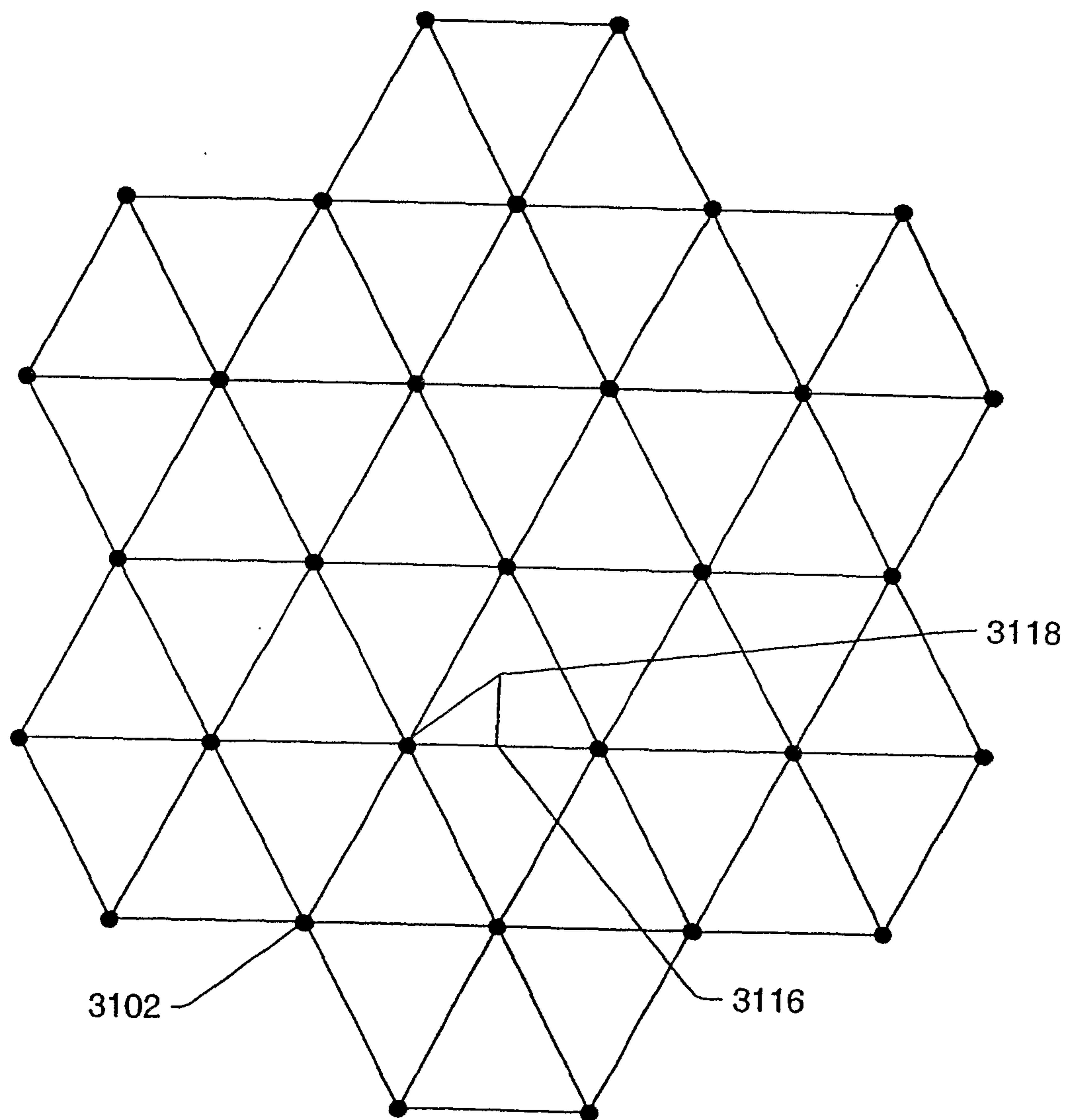
12. A method according to any one of claims 1 to 10, wherein in the heated portion of the formation a hydrogen partial pressure is maintained of at least 0.5 bar and less than 20 bar, preferably in a range from 1 bar to 10 bar.

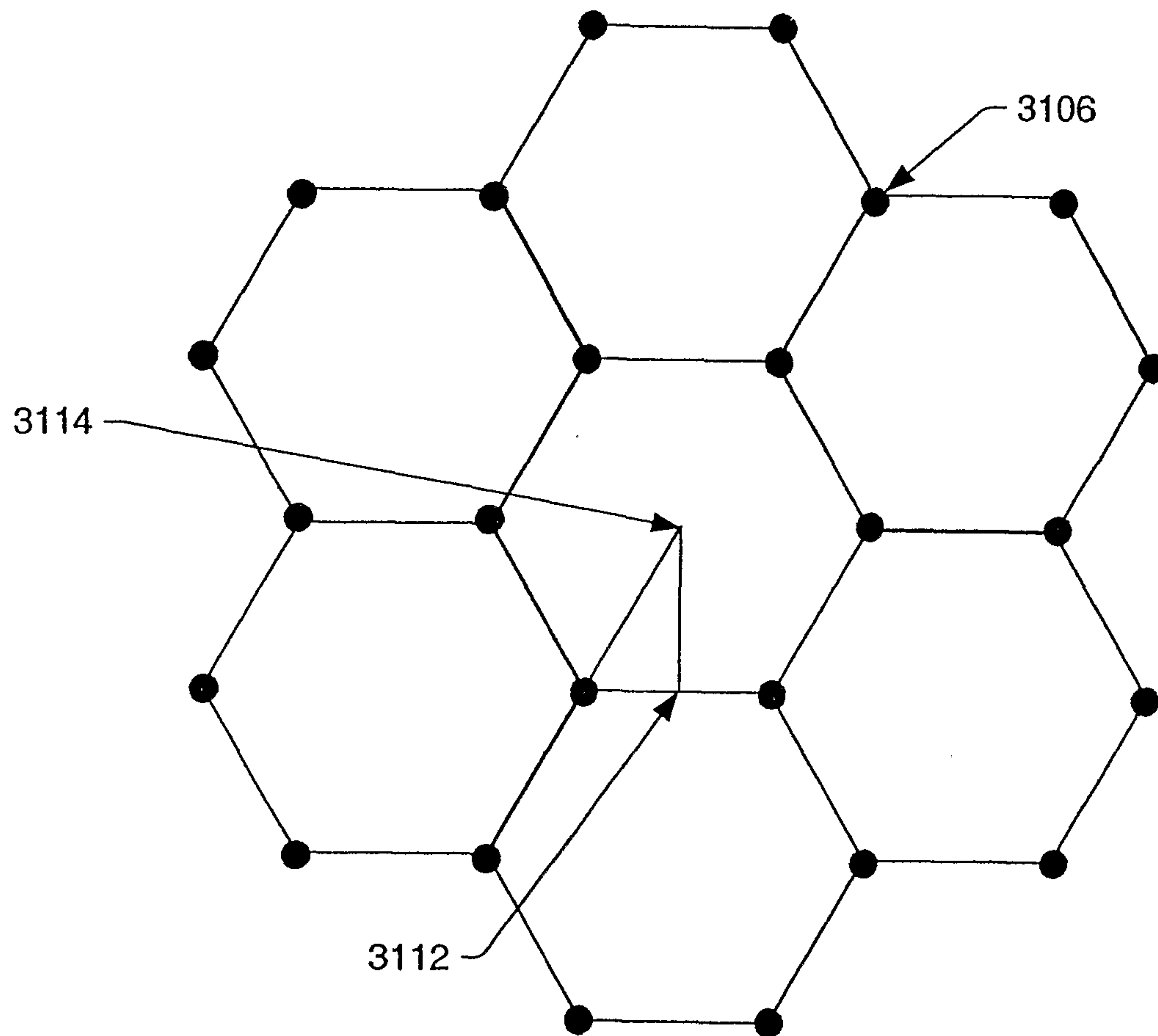
13. A method according to any one of claims 1 to 10, wherein a heating rate of the heated portion of the formation is controlled such that the heating rate is less than 3 °C per day, preferably less than 0.7 °C per day.

14. A method according to any one of claims 1-13, wherein the heater wells are at least partly uncased.

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*FIG. 1*

*FIG. 2*

