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(54) Title: IN SITU THERMAL PROCESSING OF A HYDROCARBON CONTAINING FORMATION USING A NATURAL DISTRIBUTED COMBUSTOR

(57) Abstract: An in situ process for treating a hydrocarbon containing formation is provided. The process may include providing heat from one or more heat sources to at least a portion of the formation. Heat sources may include a natural distributed combustor. The natural distributed combustor may include an oxidizing fluid source to provide oxidizing fluids to a reaction zone in the formation to generate heat within the reaction zone. The heat may be allowed to transfer from the reaction zone to a selected section of the formation such that heat from one or more heat sources pyrolyzes at least some hydrocarbons within the selected section. Hydrocarbons may be produced from the formation.



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IN SITU THERMAL PROCESSING OF A HYDROCARBON CONTAINING FORMATION USING A NATURAL DISTRIBUTED COMBUSTOR

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BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to methods and systems for production of hydrocarbons, hydrogen, and/or other products from various hydrocarbon containing formations. Certain embodiments relate to in situ conversion of hydrocarbons to produce hydrocarbons, hydrogen, and/or novel product streams from underground hydrocarbon containing formations using natural distributed combustors.

2. Description of Related Art

Hydrocarbons obtained from subterranean (e.g., sedimentary) formations are often used as energy resources, as feedstocks, and as consumer products. Concerns over depletion of available hydrocarbon resources and over declining overall quality of produced hydrocarbons have led to development of processes for more efficient recovery, processing and/or use 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 more easily removed from the subterranean formation. The chemical and physical changes may include in situ reactions that produce removable fluids, composition changes, solubility changes, density changes, phase changes, and/or viscosity changes of the hydrocarbon material within the formation. A fluid may 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 U.S. Patent Nos. 2,634,961 to Ljungstrom, 2,732,195 to Ljungstrom, 2,780,450 to Ljungstrom, 2,789,805 to Ljungstrom, 2,923,535 to Ljungstrom, and 4,886,118 to Van Meurs et al.

A heat source may be used to heat a subterranean formation. Electric heaters and/or electric heat elements are described in U.S. Patent No. 2,548,360 to Germain, U.S. Patent No. 4,716,960 to Eastlund et al., U.S. Patent No. 5,065,818 to Van Egmond and U.S. Patent No. 4,570,715 to Van Meurs et al.

Combustion of a fuel may be used to heat a formation. Combusting a fuel to heat a formation may be 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 fireflood. An oxidizer may be pumped into the formation. The oxidizer may be ignited to advance a fire front towards a production well. Oxidizer pumped into the formation may flow through the formation along fracture lines in the formation. Ignition of the oxidizer may not result in the fire front flowing uniformly through the formation.

SUMMARY OF THE INVENTION

In an embodiment, hydrocarbons within a hydrocarbon containing formation (e.g., a formation containing coal, oil shale, heavy hydrocarbons, or a combination thereof) may be converted in situ within the formation to yield a mixture of relatively high quality hydrocarbon products, hydrogen, and/or other products. One or more heat sources may be used to heat a portion of the hydrocarbon containing formation to temperatures that allow pyrolysis

of the hydrocarbons. Hydrocarbons, hydrogen, and other formation fluids may be removed from the formation through one or more production wells. In some embodiments, formation fluids may be removed in a vapor phase. In other embodiments, formation fluids may be removed in liquid and vapor phases or in a liquid phase. Temperature and pressure in at least a portion of the formation may be controlled during pyrolysis to yield improved products from the formation.

In an embodiment, a natural distributed combustor may provide heat to a hydrocarbon containing formation. The natural distributed combustor may include a heater positioned in an opening in the formation. The heater may provide heat to at least a portion of the formation. The natural distributed combustor may include an oxidizing fluid source. The oxidizing fluid source may provide an oxidizing fluid to a reaction zone of the formation to generate heat in the reaction zone. A portion of the reaction zone may have been previously heated by the heater. The natural distributed combustor may include a first conduit positioned in the opening. The first conduit may provide the oxidizing fluid from the oxidizing fluid source to the reaction zone in the formation. The oxidizing fluid may oxidize at least some hydrocarbons in the reaction zone to generate heat. Heat generated in the reaction zone may transfer from the reaction zone to the formation.

In an embodiment, oxidizing fluid may transport through the reaction zone substantially by diffusion. The rate of diffusion may be controlled by a temperature of the reaction zone. In some embodiments, the oxidizing fluid may be substantially inhibited from flowing from the reaction zone into a surrounding portion of the formation. Heat may be allowed to transfer substantially by conduction from the reaction zone to the formation. Heat generated by oxidation may be allowed to transfer from the reaction zone to a pyrolysis zone in the formation. Heat allowed to transfer to the pyrolysis zone may pyrolyze at least some hydrocarbons in a pyrolysis zone of the formation.

In certain embodiments, the flow of oxidizing fluid may be controlled along at least a segment of the first conduit to control a temperature along at least a segment of the first conduit. The flow may be controlled to control a heating rate in at least a section of the formation. The first conduit may include orifices to provide the oxidizing fluid into the opening. In some embodiments, the first conduit may include critical flow orifices that control a flow of the oxidizing fluid to control the rate of oxidation in the formation.

In certain embodiments, molecular hydrogen may be provided to the reaction zone. At least some of the provided hydrogen may be produced in the reaction zone. At least some of the provided molecular hydrogen may be produced in the heated portion of the formation. Molecular hydrogen may be provided to the reaction zone to inhibit production of carbon dioxide.

In an embodiment, a natural distributed combustor may include a second conduit. The second conduit may remove an oxidation product from the formation. The second conduit may remove an oxidation product to maintain a substantially constant temperature in the formation. The second conduit may control the concentration of oxygen in the opening such that the oxygen concentration is substantially constant. The first conduit may include orifices that direct oxidizing fluid in a direction substantially opposite a direction oxidation products are removed with orifices on the second conduit. The second conduit may have a greater concentration of orifices toward an upper end of the second conduit. The second conduit may allow heat from the oxidation product to transfer to the oxidizing fluid in the first conduit. The pressure of the fluids within the first and second conduits may be controlled such that a concentration of the oxidizing fluid along the length of the first conduit is substantially uniform.

In an embodiment, an in situ method for providing heat to a hydrocarbon containing formation may include heating a portion of the formation to a temperature sufficient to support reaction of hydrocarbons within the

portion with an oxidizing fluid. Oxidizing fluid may be provided to a reaction zone in the formation. The oxidizing fluid may be allowed to react with at least a portion of the hydrocarbons in the reaction zone to generate heat in the reaction zone. Heat generated in the reaction zone may be transferred to the formation.

BRIEF DESCRIPTION OF THE DRAWINGS

Advantages of the present invention may become apparent to those skilled in the art with the benefit of the following detailed description of the preferred embodiments and upon reference to the accompanying drawings in which:

FIG. 1 depicts an illustration of stages of heating a hydrocarbon containing formation.

FIG. 2 depicts a schematic view of an embodiment of a portion of an in situ conversion system for treating a hydrocarbon containing formation.

FIG. 3 depicts an embodiment of a natural distributed combustor heat source.

FIG. 4 illustrates a cross-sectional representation of an embodiment of a natural distributed combustor having a second conduit.

FIG. 5 depicts a schematic representation of an embodiment of a heater well positioned within a hydrocarbon containing formation.

FIG. 6 depicts a portion of an overburden of a formation with a natural distributed combustor heat source.

FIG. 7 depicts an embodiment of a natural distributed combustor heat source.

FIG. 8 depicts an embodiment of a natural distributed combustor heat source.

FIG. 9 depicts an embodiment of a natural distributed combustor system for heating a formation.

FIG. 10 depicts an embodiment of a natural distributed combustor system for heating a formation.

While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and may herein be described in detail. The drawings may not be to scale. It should be understood, however, that the drawings and detailed description thereto are not intended to limit the invention to the particular form disclosed, but on the contrary, the intention is to cover all modifications, equivalents and alternatives falling within the spirit and scope of the present invention as defined by the appended claims.

DETAILED DESCRIPTION OF THE INVENTION

The following description generally relates to systems and methods for treating a hydrocarbon containing formation (e.g., a formation containing coal (including lignite, sapropelic coal, etc.), oil shale, carbonaceous shale, shungites, kerogen, bitumen, oil, kerogen and oil in a low permeability matrix, heavy hydrocarbons, asphaltites, natural mineral waxes, formations wherein kerogen is blocking production of other hydrocarbons, etc.). Such formations may be treated to yield relatively high quality hydrocarbon products, hydrogen, and other products.

“Hydrocarbons” are generally defined as molecules formed primarily by carbon and hydrogen atoms. Hydrocarbons may also include other elements, such as, but not limited to, halogens, metallic elements, nitrogen, oxygen, and/or sulfur.

A “formation” includes one or more hydrocarbon containing layers, one or more non-hydrocarbon layers, an overburden, and/or an underburden. An “overburden” and/or an “underburden” includes one or more different types of impermeable materials. For example, overburden and/or underburden may include rock, shale, mudstone, or wet/tight carbonate (i.e., an impermeable carbonate without hydrocarbons). In some embodiments of in situ

conversion processes, an overburden and/or an underburden may include a hydrocarbon containing layer or hydrocarbon containing layers that are relatively impermeable and are not subjected to temperatures during in situ conversion processing that results in significant characteristic changes of the hydrocarbon containing layers of the overburden and/or underburden. For example, an underburden may contain shale or mudstone. In some cases, the overburden and/or underburden may be somewhat permeable.

A "heat source" is any system for providing heat to at least a portion of a formation substantially by conductive and/or radiative heat transfer. For example, a heat source may include electric heaters such as an insulated conductor, an elongated member, and/or a conductor disposed within a conduit. A heat source may also include heat sources that generate heat by burning a fuel external to or within a formation, such as surface burners, downhole gas burners, flameless distributed combustors, and natural distributed combustors. In addition, it is envisioned that in some embodiments heat provided to or generated in one or more heat sources may be supplied by other sources of energy. The other sources of energy may directly heat a formation, or the energy may be applied to a transfer media that directly or indirectly heats the formation. It is to be understood that one or more heat sources that are applying heat to a formation may use different sources of energy. For example, for a given formation some heat sources may supply heat from electric resistance heaters, some heat sources may provide heat from combustion, and some heat sources may provide heat from one or more other energy sources (e.g., chemical reactions, solar energy, wind energy, biomass, or other sources of renewable energy). A chemical reaction may include an exothermic reaction (e.g., an oxidation reaction). A heat source may include a heater that provides heat to a zone proximate and/or surrounding a heating location such as a heater well.

A "heater" is any system for generating heat in a well or a near wellbore region. Heaters may be, but are not limited to, electric heaters, burners, combustors that react with material in or produced from a formation (e.g., natural distributed combustors), and/or combinations thereof. A "unit of heat sources" refers to a number of heat sources that form a template that is repeated to create a pattern of heat sources within a formation.

"Natural distributed combustor" refers to a heater that uses an oxidant to oxidize at least a portion of the carbon in the formation to generate heat, and wherein the oxidation takes place in a vicinity proximate a wellbore. Most of the combustion products produced in the natural distributed combustor are removed through the wellbore.

"Orifices," refer to openings (e.g., openings in conduits) having a wide variety of sizes and cross-sectional shapes including, but not limited to, circles, ovals, squares, rectangles, triangles, slits, or other regular or irregular shapes.

Hydrocarbons in formations may be treated in various ways to produce many different products. In certain embodiments, such formations may be treated in stages. FIG. 1 illustrates several stages of heating a hydrocarbon containing formation. FIG. 1 also depicts an example of yield (barrels of oil equivalent per ton) (y axis) of formation fluids from a hydrocarbon containing formation versus temperature (°C) (x axis) of the formation.

Desorption of methane and vaporization of water occurs during stage 1 heating. Heating of the formation through stage 1 may be performed as quickly as possible. For example, when a hydrocarbon containing formation is initially heated, hydrocarbons in the formation may desorb adsorbed methane. The desorbed methane may be produced from the formation. If the hydrocarbon containing formation is heated further, water within the hydrocarbon containing formation may be vaporized. Water may occupy, in some hydrocarbon containing formations, between about 10 % to about 50 % of the pore volume in the formation. In other formations, water may occupy larger or smaller portions of the pore volume. Water typically is vaporized in a formation between about 160 °C and about 285 °C for pressures of about 6 bars absolute to 70 bars absolute. In some embodiments, the

pressure in a formation may be maintained during an in situ conversion process between about 2 bars absolute and about 70 bars absolute. In some embodiments, the vaporized water may produce wettability changes in the formation and/or increase formation pressure. The wettability changes and/or increased pressure may affect pyrolysis reactions or other reactions in the formation. In certain embodiments, the vaporized water may be produced from the formation. In other embodiments, the vaporized water may be used for steam extraction and/or distillation in the formation or outside the formation. Removing the water from and increasing the pore volume in the formation may increase the storage space for hydrocarbons within the pore volume.

After stage 1 heating, the formation may be heated further, such that a temperature within the formation reaches (at least) an initial pyrolyzation temperature (e.g., a temperature at the lower end of the temperature range shown as stage 2). Hydrocarbons within the formation may be pyrolyzed throughout stage 2. A pyrolysis temperature range may vary depending on types of hydrocarbons within the formation. A pyrolysis temperature range may include temperatures between about 250 °C and about 900 °C. A pyrolysis temperature range for producing desired products may extend through only a portion of the total pyrolysis temperature range. In some embodiments, a pyrolysis temperature range for producing desired products may include temperatures between about 250 °C to about 400 °C. If a temperature of hydrocarbons in a formation is slowly raised through a temperature range from about 250 °C to about 400 °C, production of pyrolysis products may be substantially complete when the temperature approaches 400 °C. Heating the hydrocarbon containing formation with a plurality of heat sources may establish thermal gradients around the heat sources that slowly raise the temperature of hydrocarbons in the formation through a pyrolysis temperature range.

In some in situ conversion embodiments, a temperature of the hydrocarbons to be subjected to pyrolysis may not be slowly increased throughout a temperature range from about 250 °C to about 400 °C. The hydrocarbons in the formation may be heated to a desired temperature (e.g., about 325 °C). Other temperatures may be selected as the desired temperature. Energy input into the formation from the heat sources may be adjusted to maintain the temperature in the formation substantially at the desired temperature. The hydrocarbons may be maintained substantially at the desired temperature until pyrolysis declines such that production of desired formation fluids from the formation becomes uneconomical.

In an in situ conversion process embodiment, a heating rate may be controlled to minimize costs associated with heating a selected section. The costs may include, for example, input energy costs and equipment costs. In certain embodiments, a cost associated with heating a selected section may be minimized by reducing a heating rate when the cost associated with heating is relatively high and increasing the heating rate when the cost associated with heating is relatively low. For example, a heating rate of about 330 watts/m may be used when the associated cost is relatively high, and a heating rate of about 1640 watts/m may be used when the associated cost is relatively low. In certain embodiments, heating rates may be varied between about 300 watts/m and about 800 watts/m when the associated cost is relatively high and between about 1000 watts/m and 1800 watts/m when the associated cost is relatively low. The cost associated with heating may be relatively high at peak times of energy use, such as during the daytime. For example, energy use may be high in warm climates during the daytime in the summer due to energy use for air conditioning. Low times of energy use may be, for example, at night or during weekends, when energy demand tends to be lower. In an embodiment, the heating rate may be varied from a higher heating rate during low energy usage times, such as during the night, to a lower heating rate during high energy usage times, such as during the day.

As shown in FIG. 2, in addition to heat sources 100, one or more production wells 106 will typically be placed within the portion of the hydrocarbon containing formation. Formation fluids may be produced through production well 106. In some embodiments, production well 106 may include a heat source. The heat source may heat the portions of the formation at or near the production well and allow for vapor phase removal of formation fluids. The need for high temperature pumping of liquids from the production well may be reduced or eliminated. Avoiding or limiting high temperature pumping of liquids may significantly decrease production costs. Providing heating at or through the production well may: (1) inhibit condensation and/or refluxing of production fluid when such production fluid is moving in the production well proximate the overburden, (2) increase heat input into the formation, and/or (3) increase formation permeability at or proximate the production well. In some in situ conversion process embodiments, an amount of heat supplied to production wells is significantly less than an amount of heat applied to heat sources that heat the formation.

Because permeability and/or porosity increases in the heated formation, produced vapors may flow considerable distances through the formation with relatively little pressure differential. Increases in permeability may result from a reduction of mass of the heated portion due to vaporization of water, removal of hydrocarbons, and/or creation of fractures. Fluids may flow more easily through the heated portion. In some embodiments, production wells may be provided in upper portions of hydrocarbon layers.

Fluid generated within a hydrocarbon containing formation may move a considerable distance through the hydrocarbon containing formation as a vapor. The considerable distance may be over 1000 m depending on various factors (e.g., permeability of the formation, properties of the fluid, temperature of the formation, and pressure gradient allowing movement of the fluid). Due to increased permeability in formations subjected to in situ conversion and formation fluid removal, production wells may only need to be provided in every other unit of heat sources or every third, fourth, fifth, or sixth units of heat sources.

During an in situ process, production wells may be operated such that the production wells are at a lower pressure than other portions of the formation. In some embodiments, a vacuum may be drawn at the production wells. Maintaining the production wells at lower pressures may inhibit fluids in the formation from migrating outside of the in situ treatment area.

Certain embodiments may include controlling the heat provided to at least a portion of the formation such that production of less desirable products in the portion may be substantially inhibited. Controlling the heat provided to at least a portion of the formation may also increase the uniformity of permeability within the formation. For example, controlling the heating of the formation to inhibit production of less desirable products may, in some embodiments, include controlling the heating rate to less than a selected amount (e.g., 10 °C, 5 °C, 3 °C, 1 °C, 0.5 °C, or 0.1 °C) per day.

In some embodiments, superposition (e.g., overlapping) of heat from one or more heat sources may result in substantially uniform heating of a portion of a hydrocarbon containing formation. Since formations during heating will typically have temperature profiles throughout them, in the context of this patent "substantially uniform" heating means heating such that the temperatures in a majority of the section do not vary by more than 100 °C from the assessed average temperature in the majority of the selected section (volume) being treated.

Substantially uniform heating of the hydrocarbon containing formation may result in a substantially uniform increase in permeability. For example, uniformly heating may generate a series of substantially uniform fractures within the heated portion due to thermal stresses generated in the formation. Heating substantially uniformly may generate pyrolysis fluids from the portion in a substantially homogeneous manner. Water removed

due to vaporization and production may result in increased permeability of the heated portion. In addition to creating fractures due to thermal stresses, fractures may also be generated due to fluid pressure increase. As fluids are generated within the heated portion a fluid pressure within the heated portion may also increase. As the fluid pressure approaches a lithostatic pressure of the heated portion, fractures may be generated. Substantially uniform heating and homogeneous generation of fluids may generate substantially uniform fractures within the heated portion. In some embodiments, a permeability of a heated section of a hydrocarbon containing formation may not vary by more than a factor of about 10.

Formation fluids including pyrolyzation fluids may be produced from the formation. The pyrolyzation fluids may include, but are not limited to, hydrocarbons, hydrogen, carbon dioxide, carbon monoxide, hydrogen sulfide, ammonia, nitrogen, water, and mixtures thereof. As the temperature of the formation increases, the amount of condensable hydrocarbons in the produced formation fluid tends to decrease. At high temperatures, the formation may produce mostly methane and/or hydrogen. If a hydrocarbon containing formation is heated throughout an entire pyrolysis range, the formation may produce only small amounts of hydrogen towards an upper limit of the pyrolysis range. After all of the available hydrogen is depleted, a minimal amount of fluid production from the formation will typically occur.

Certain embodiments for treating heavy hydrocarbons in a relatively low permeability formation may include providing heat from one or more heat sources to pyrolyze some of the heavy hydrocarbons and then to vaporize a portion of the heavy hydrocarbons. The heat sources may pyrolyze at least some heavy hydrocarbons in a selected section of the formation and may pressurize at least a portion of the selected section. During the heating, the pressure within the formation may increase substantially. The pressure in the formation may be controlled such that the pressure in the formation may be maintained to produce a fluid of a desired composition. Pyrolyzation fluid may be removed from the formation as vapor from one or more heater wells by using the back pressure created by heating the formation.

After pyrolysis of hydrocarbons, a large amount of carbon and some hydrogen may still be present in the formation. A significant portion of remaining carbon in the formation can be produced from the formation in the form of synthesis gas. Synthesis gas generation may take place during stage 3 heating depicted in FIG. 1. Stage 3 may include heating a hydrocarbon containing formation to a temperature sufficient to allow synthesis gas generation. For example, synthesis gas may be produced within a temperature range from about 400 °C to about 1200 °C. The temperature of the formation when the synthesis gas generating fluid is introduced to the formation may determine the composition of synthesis gas produced within the formation. If a synthesis gas generating fluid is introduced into a formation at a temperature sufficient to allow synthesis gas generation, synthesis gas may be generated within the formation. The generated synthesis gas may be removed from the formation through a production well or production wells. A large volume of synthesis gas may be produced during generation of synthesis gas.

FIG. 2 shows a schematic view of an embodiment of a portion of an in situ conversion system for treating a hydrocarbon containing formation. Heat sources 100 may be placed within at least a portion of the hydrocarbon containing formation. Heat sources 100 may include, for example, electric heaters such as insulated conductors, conductor-in-conduit heaters, surface burners, flameless distributed combustors, and/or natural distributed combustors. Heat sources 100 may also include other types of heaters. Heat sources 100 may provide heat to at least a portion of a hydrocarbon containing formation. Energy may be supplied to the heat sources 100 through supply lines 116. The supply lines may be structurally different depending on the type of heat source or heat

sources being used to heat the formation. Supply lines for heat sources may transmit electricity for electric heaters, may transport fuel for combustors, or may transport heat exchange fluid that is circulated within the formation.

Production wells 106 may be used to remove formation fluid from the formation. Formation fluid produced from production wells 106 may be transported through collection piping 118 to treatment facilities 120.

5 Formation fluids may also be produced from heat sources 100. For example, fluid may be produced from heat sources 100 to control pressure within the formation adjacent to the heat sources. Fluid produced from heat sources 100 may be transported through tubing or piping to collection piping 118 or the produced fluid may be transported through tubing or piping directly to treatment facilities 120. Treatment facilities 120 may include separation units, reaction units, upgrading units, fuel cells, turbines, storage vessels, and other systems and units for processing
10 produced formation fluids.

An in situ conversion system for treating hydrocarbons may include barrier wells 122. In some embodiments, barriers may be used to inhibit migration of fluids (e.g., generated fluids and/or groundwater) into and/or out of a portion of a formation undergoing an in situ conversion process. Barriers may include, but are not limited to naturally occurring portions (e.g., overburden and/or underburden), freeze wells, frozen barrier zones,
15 low temperature barrier zones, grout walls, sulfur wells, dewatering wells, injection wells, a barrier formed by a gel produced in the formation, a barrier formed by precipitation of salts in the formation, a barrier formed by a polymerization reaction in the formation, sheets driven into the formation, or combinations thereof.

Formation fluid produced from a hydrocarbon containing formation during treatment may include a mixture of different components. To increase the economic value of products generated from the formation, formation fluid may be treated using a variety of treatment processes. Processes utilized to treat formation fluid
20 may include distillation (e.g., atmospheric distillation, fractional distillation, and/or vacuum distillation), condensation (e.g., fractional), cracking (e.g., thermal cracking, catalytic cracking, fluid catalytic cracking, hydrocracking, residual hydrocracking, and/or steam cracking), reforming (e.g., thermal reforming, catalytic reforming, and/or hydrogen steam reforming), hydrogenation, coking, solvent extraction, solvent dewaxing,
25 polymerization (e.g., catalytic polymerization and/or catalytic isomerization), visbreaking, alkylation, isomerization, deasphalting, hydrodesulfurization, catalytic dewaxing, desalting, extraction (e.g., of phenols, other aromatic compounds, etc.), and/or stripping.

Formation fluids may undergo treatment processes in a first in situ treatment area as the formation fluid is generated and produced, in a second in situ treatment area where a specific treatment process occurs, and/or in
30 surface treatment units. A "surface treatment unit" is a unit used to treat at least a portion of formation fluid at the surface. Surface treatment units may include, but are not limited to, reactors (e.g., hydrotreating units, cracking units, ammonia generating units, fertilizer generating units, and/or oxidizing units), separating units (e.g., air separating units, liquid-liquid extraction units, adsorption units, absorbers, ammonia recovery and/or generating units, vapor/liquid separating units, distillation columns, reactive distillation columns, and/or condensing units),
35 reboiling units, heat exchangers, pumps, pipes, storage units, and/or energy producing units (e.g., fuel cells and/or gas turbines). Multiple surface treatment units used in series, in parallel, and/or in a combination of series and parallel are referred to as a surface facility configuration. Surface facility configurations may vary dramatically due to a composition of formation fluid as well as the products being generated.

Surface treatment configurations may be combined with treatment processes in various surface treatment
40 systems to generate a multitude of products. Products generated at a site may vary with local and/or global market

conditions, formation characteristics, proximity of formation to a purchaser, and/or available feedstocks. Generated products may be utilized on site, transferred to another site for use, and/or sold to a purchaser.

The composition of products generated may be altered by controlling conditions within a treatment area and/or within one or more surface treatment units. Conditions within the treatment area and/or one or more surface treatment units which affect product composition include, but are not limited to, average temperature, fluid pressure, partial pressure of H_2 , temperature gradients, composition of formation material, heating rates, and composition of fluids entering the treatment area and/or the surface treatment unit. Many different surface facility configurations exist for the synthesis and/or separation of specific components from formation fluid.

Controlling formation conditions to control the pressure of hydrogen in the produced fluid may result in improved qualities of the produced fluids. In some embodiments, it may be desirable to control formation conditions so that the partial pressure of hydrogen in a produced fluid is greater than about 0.5 bars absolute, as measured at a production well.

In one embodiment, a method of treating a hydrocarbon containing formation in situ may include adding hydrogen to the selected section after a temperature of the selected section is at least about 270 °C. Other embodiments may include controlling a temperature of the formation by selectively adding hydrogen to the formation.

In an embodiment, a portion of a hydrocarbon containing formation may be heated to increase a partial pressure of H_2 . In some embodiments, an increased H_2 partial pressure may include H_2 partial pressures in a range from about 0.5 bars to about 7 bars. Alternatively, an increased H_2 partial pressure range may include H_2 partial pressures in a range from about 5 bars to about 7 bars. For example, a majority of hydrocarbon fluids may be produced wherein a H_2 partial pressure is within a range of about 5 bars to about 7 bars. A range of H_2 partial pressures within the pyrolysis H_2 partial pressure range may vary depending on, for example, temperature and pressure of the heated portion of the formation.

Maintaining a H_2 partial pressure within the formation of greater than atmospheric pressure may increase an API value of produced condensable hydrocarbon fluids. Maintaining an increased H_2 partial pressure may increase an API value of produced condensable hydrocarbon fluids to greater than about 25° or, in some instances, greater than about 30°. Maintaining an increased H_2 partial pressure within a heated portion of a hydrocarbon containing formation may increase a concentration of H_2 within the heated portion. The H_2 may be available to react with pyrolyzed components of the hydrocarbons. Reaction of H_2 with the pyrolyzed components of hydrocarbons may reduce polymerization of olefins into tars and other cross-linked, difficult to upgrade, products. Therefore, production of hydrocarbon fluids having low API gravity values may be inhibited.

An in situ conversion process may generate significant amounts of H_2 and hydrocarbon fluids within the formation. Generation of hydrogen within the formation, and pressure within the formation sufficient to force hydrogen into a liquid phase within the formation, may produce a reducing environment within the formation without the need to introduce a reducing fluid (e.g., H_2 and/or non-condensable saturated hydrocarbons) into the formation. A hydrogen component of formation fluid produced from the formation may be separated and used for desired purposes. The desired purposes may include, but are not limited to, fuel for fuel cells, fuel for combustors, and/or a feed stream for surface hydrogenation units.

In an embodiment, a method for treating a hydrocarbon containing formation in situ may include adding hydrogen to a selected section of the formation when the selected section is at or undergoing certain conditions. For example, the hydrogen may be added through a heater well or production well located in or proximate the selected

section. Since hydrogen is sometimes in relatively short supply (or relatively expensive to make or procure), hydrogen may be added when conditions in the formation optimize the use of the added hydrogen. For example, hydrogen produced in a section of a formation undergoing synthesis gas generation may be added to a section of the formation undergoing pyrolysis. The added hydrogen in the pyrolysis section of the formation may promote formation of aliphatic compounds and inhibit formation of olefinic compounds that reduce the quality of hydrocarbon fluids produced from formation.

In some embodiments, hydrogen may be added to the selected section after an average temperature of the formation is at a pyrolysis temperature (e.g., when the selected section is at least about 270 °C). In some embodiments, hydrogen may be added to the selected section after the average temperature is at least about 290 °C, 320 °C, 375 °C, or 400 °C. Hydrogen may be added to the selected section before an average temperature of the formation is about 400 °C. In some embodiments, hydrogen may be added to the selected section before the average temperature is about 300 °C or about 325 °C.

The average temperature of the formation may be controlled by selectively adding hydrogen to the selected section of the formation. Hydrogen added to the formation may react in exothermic reactions. The exothermic reactions may heat the formation and reduce the amount of energy that needs to be supplied from heat sources to the formation. In some embodiments, an amount of hydrogen may be added to the selected section of the formation such that an average temperature of the formation does not exceed about 400 °C.

A valve may maintain, alter, and/or control a pressure within a heated portion of a hydrocarbon containing formation. For example, a heat source disposed within a hydrocarbon containing formation may be coupled to a valve. The valve may release fluid from the formation through the heat source. In addition, a pressure valve may be coupled to a production well within the hydrocarbon containing formation. In some embodiments, fluids released by the valves may be collected and transported to a surface unit for further processing and/or treatment.

An in situ conversion process for hydrocarbons may include providing heat to a portion of a hydrocarbon containing formation and controlling a temperature, rate of temperature increase, and/or pressure within the heated portion. A temperature and/or a rate of temperature increase of the heated portion may be controlled by altering the energy supplied to heat sources in the formation.

Hydrocarbons to be subjected to in situ conversion may be located under a large area. The in situ conversion system may be used to treat small portions of the formation, and other sections of the formation may be treated as time progresses. In an embodiment of a system for treating a formation (e.g., an oil shale formation), a field layout for 24 years of development may be divided into 24 individual plots that represent individual drilling years. Each plot may include 120 "tiles" (repeating matrix patterns) wherein each plot is made of 6 rows by 20 columns of tiles. Each tile may include 1 production well and 12 or 18 heater wells. The heater wells may be placed in an equilateral triangle pattern with a well spacing of about 12 m. Production wells may be located in centers of equilateral triangles of heater wells, or the production wells may be located approximately at a midpoint between two adjacent heater wells.

Exact placement of heater wells, production wells, etc. will depend on variables specific to the formation (e.g., thickness of the layer or composition of the layer), project economics, etc. In certain embodiments, heater wells may be substantially horizontal while production wells may be vertical, or vice versa. In some embodiments, wells may be aligned along dip or strike or oriented at an angle between dip and strike.

The spacing between heat sources may vary depending on a number of factors. The factors may include, but are not limited to, the type of a hydrocarbon containing formation, the selected heating rate, and/or the selected

average temperature to be obtained within the heated portion. In some well pattern embodiments, the spacing between heat sources may be within a range of about 5 m to about 25 m. In some well pattern embodiments, spacing between heat sources may be within a range of about 8 m to about 15 m.

5 In certain embodiments, one or more conduits may be provided to supply additional components (e.g., nitrogen, carbon dioxide, reducing agents such as gas containing hydrogen, etc.) to formation openings, to bleed off fluids, and/or to control pressure. Formation pressures tend to be highest near heating sources. Providing pressure control equipment in heat sources may be beneficial. In some embodiments, adding a reducing agent proximate the heating source assists in providing a more favorable pyrolysis environment (e.g., a higher hydrogen partial pressure). Since permeability and porosity tend to increase more quickly proximate the heating source, it is often
10 optimal to add a reducing agent proximate the heating source so that the reducing agent can more easily move into the formation.

In an embodiment, a hydrocarbon containing formation may be heated with a natural distributed combustor system located in the formation. The generated heat may be allowed to transfer to a selected section of the formation. A natural distributed combustor may oxidize hydrocarbons in a formation in the vicinity of a wellbore to
15 provide heat to a selected section of the formation.

A temperature sufficient to support oxidation may be at least about 200 °C or 250 °C. The temperature sufficient to support oxidation will tend to vary depending on many factors (e.g., a composition of the hydrocarbons in the hydrocarbon containing formation, water content of the formation, and/or type and amount of oxidant). Some water may be removed from the formation prior to heating. For example, the water may be pumped from the formation by
20 dewatering wells. The heated portion of the formation may be near or substantially adjacent to an opening in the hydrocarbon containing formation. The opening in the formation may be a heater well formed in the formation. The heated portion of the hydrocarbon containing formation may extend radially from the opening to a width of about 0.3 m to about 1.2 m. The width, however, may also be less than about 0.9 m. A width of the heated portion may vary with time. In certain embodiments, the variance depends on factors including a width of formation necessary to generate
25 sufficient heat during oxidation of carbon to maintain the oxidation reaction without providing heat from an additional heat source.

After the portion of the formation reaches a temperature sufficient to support oxidation, an oxidizing fluid may be provided into the opening to oxidize at least a portion of the hydrocarbons at a reaction zone or a heat source zone within the formation. Oxidation of the hydrocarbons will generate heat at the reaction zone. The generated heat will in
30 most embodiments transfer from the reaction zone to a pyrolysis zone in the formation. In certain embodiments, the generated heat transfers at a rate between about 650 watts per meter and 1650 watts per meter as measured along a depth of the reaction zone. Upon oxidation of at least some of the hydrocarbons in the formation, energy supplied to the heater for initially heating the formation to the temperature sufficient to support oxidation may be reduced or turned off. Energy input costs may be significantly reduced using natural distributed combustors, thereby providing a significantly
35 more efficient system for heating the formation.

In an embodiment, a conduit may be disposed in the opening to provide oxidizing fluid into the opening. The conduit may have flow orifices or other flow control mechanisms (i.e., slits, venturi meters, valves, etc.) to allow the oxidizing fluid to enter the opening. The term "orifices" includes openings having a wide variety of cross-sectional shapes including, but not limited to, circles, ovals, squares, rectangles, triangles, slits, or other
40 regular or irregular shapes. The flow orifices may be critical flow orifices in some embodiments. The flow orifices

may provide a substantially constant flow of oxidizing fluid into the opening, regardless of the pressure in the opening.

In some embodiments, the number of flow orifices may be limited by the diameter of the orifices and a desired spacing between orifices for a length of the conduit. For example, as the diameter of the orifices decreases, the number of flow orifices may increase, and vice versa. In addition, as the desired spacing increases, the number of flow orifices may decrease, and vice versa. The diameter of the orifices may be determined by a pressure in the conduit and/or a desired flow rate through the orifices. For example, for a flow rate of about 1.7 standard cubic meters per minute and a pressure of about 7 bars absolute, an orifice diameter may be about 1.3 mm with a spacing between orifices of about 2 m. Smaller diameter orifices may plug more readily than larger diameter orifices.

Orifices may plug for a variety of reasons. The reasons may include, but are not limited to, contaminants in the fluid flowing in the conduit and/or solid deposition within or proximate the orifices.

In some embodiments, the number and diameter of the orifices are chosen such that a more even or nearly uniform heating profile will be obtained along a depth of the opening in the formation. A depth of a heated formation that is intended to have an approximately uniform heating profile may be greater than about 300 m, or even greater than about 600 m. Such a depth may vary, however, depending on, for example, a type of formation to be heated and/or a desired production rate.

In some embodiments, flow orifices may be disposed in a helical pattern around the conduit within the opening. The flow orifices may be spaced by about 0.3 m to about 3 m between orifices in the helical pattern. In some embodiments, the spacing may be about 1 m to about 2 m or, for example, about 1.5 m.

The flow of oxidizing fluid into the opening may be controlled such that a rate of oxidation at the reaction zone is controlled. Transfer of heat between incoming oxidant and outgoing oxidation products may heat the oxidizing fluid. The transfer of heat may also maintain the conduit below a maximum operating temperature of the conduit.

FIG. 3 depicts an embodiment of a natural distributed combustor. A flow of oxidizing fluid 130 may be controlled along a length of opening 132 or reaction zone 134. Opening 132 may be referred to as an "elongated opening," such that reaction zone 134 and opening 132 may have a common boundary along a determined length of the opening. The flow of oxidizing fluid may be controlled using one or more orifices 136 (the orifices may be critical flow orifices). The flow of oxidizing fluid may be controlled by a diameter of orifices 136, a number of orifices 136, and/or by a pressure within inner conduit 138 (a pressure behind orifices 136). Controlling the flow of oxidizing fluid may control a temperature at a face of reaction zone 134 in opening 132. For example, an increased flow of oxidizing fluid 130 will tend to increase a temperature at the face of reaction zone 134. Increasing the flow of oxidizing fluid into the opening tends to increase a rate of oxidation of hydrocarbons in the reaction zone. Since the oxidation of hydrocarbons is an exothermic reaction, increasing the rate of oxidation tends to increase the temperature in the reaction zone.

In certain natural distributed combustor embodiments, the flow of oxidizing fluid 130 may be varied along the length of inner conduit 138 (e.g., using critical flow orifices 136) such that the temperature at the face of reaction zone 134 is variable. The temperature at the face of reaction zone 134, or within opening 132, may be varied to control a rate of heat transfer within reaction zone 134 and/or a heating rate within selected section 140. Increasing the temperature at the face of reaction zone 134 may increase the heating rate within selected section 140. A property of oxidation product 144 may be monitored (e.g., oxygen content, nitrogen content, temperature,

etc.). The property of oxidation product 144 may be monitored and used to control input properties (e.g., oxidizing fluid input) into the natural distributed combustor.

A rate of diffusion of oxidizing fluid 130 through reaction zone 134 may vary with a temperature of and adjacent to the reaction zone. In general, the higher the temperature, the faster a gas will diffuse because of the increased energy in the gas. A temperature within the opening may be assessed (e.g., measured by a thermocouple) and related to a temperature of the reaction zone. The temperature within the opening may be controlled by controlling the flow of oxidizing fluid into the opening from inner conduit 138. For example, increasing a flow of oxidizing fluid into the opening may increase the temperature within the opening. Decreasing the flow of oxidizing fluid into the opening may decrease the temperature within the opening. In an embodiment, a flow of oxidizing fluid may be increased until a selected temperature below the metallurgical temperature limits of the equipment being used is reached. For example, the flow of oxidizing fluid can be increased until a working temperature limit of a metal used in a conduit placed in the opening is reached. The temperature of the metal may be directly measured using a thermocouple or other temperature measurement device.

In a natural distributed combustor embodiment, production of carbon dioxide within reaction zone 134 may be inhibited. An increase in a concentration of hydrogen in the reaction zone may inhibit production of carbon dioxide within the reaction zone. The concentration of hydrogen may be increased by transferring hydrogen into the reaction zone. In an embodiment, hydrogen may be transferred into the reaction zone from selected section 140. Hydrogen may be produced during the pyrolysis of hydrocarbons in the selected section. Hydrogen may transfer by diffusion and/or convection into the reaction zone from the selected section. In addition, additional hydrogen may be provided into opening 132 or another opening in the formation through a conduit placed in the opening. The additional hydrogen may transfer into the reaction zone from opening 132.

In some natural distributed combustor embodiments, heat may be supplied to the formation from a second heat source in the wellbore of the natural distributed combustor. For example, an electric heater (e.g., an insulated conductor heater or a conductor-in-conduit heater) used to preheat a portion of the formation may also be used to provide heat to the formation along with heat from the natural distributed combustor. In addition, an additional electric heater may be placed in an opening in the formation to provide additional heat to the formation. The electric heater may be used to provide heat to the formation so that heat provided from the combination of the electric heater and the natural distributed combustor is maintained at a constant heat input rate. Heat input into the formation from the electric heater may be varied as heat input from the natural distributed combustor varies, or vice versa. Providing heat from more than one type of heat source may allow for substantially uniform heating of the formation.

In certain in situ conversion process embodiments, up to 10%, 25%, or 50% of the total heat input into the formation may be provided from electric heaters. A percentage of heat input into the formation from electric heaters may be varied depending on, for example, electricity cost, natural distributed combustor heat input, etc. Heat from electric heaters can be used to compensate for low heat output from natural distributed combustors to maintain a substantially constant heating rate in the formation. If electrical costs rise, more heat may be generated from natural distributed combustors to reduce the amount of heat supplied by electric heaters. In some embodiments, heat from electric heaters may vary due to the source of electricity (e.g., solar or wind power). In such embodiments, more or less heat may be provided by natural distributed combustors to compensate for changes in electrical heat input.

In a heat source embodiment, an electric heater may be used to inhibit a natural distributed combustor from "burning out." A natural distributed combustor may "burn out" if a portion of the formation cools below a temperature sufficient to support combustion. Additional heat from the electric heater may be needed to provide heat to the portion and/or another portion of the formation to heat a portion to a temperature sufficient to support oxidation of hydrocarbons and maintain the natural distributed combustor heating process.

In some natural distributed combustor embodiments, electric heaters may be used to provide more heat to a formation proximate an upper portion and/or a lower portion of the formation. Using the additional heat from the electric heaters may compensate for heat losses in the upper and/or lower portions of the formation. Providing additional heat with the electric heaters proximate the upper and/or lower portions may produce more uniform heating of the formation. In some embodiments, electric heaters may be used for similar purposes (e.g., provide heat at upper and/or lower portions, provide supplemental heat, provide heat to maintain a minimum combustion temperature, etc.) in combination with other types of fueled heaters, such as flameless distributed combustors or downhole combustors.

In some in situ conversion process embodiments, exhaust fluids from a fueled heater (e.g., a natural distributed combustor or downhole combustor) may be used in an air compressor located at a surface of the formation proximate an opening used for the fueled heater. The exhaust fluids may be used to drive the air compressor and reduce a cost associated with compressing air for use in the fueled heater. Electricity may also be generated using the exhaust fluids in a turbine or similar device. In some embodiments, fluids (e.g., oxidizing fluid and/or fuel) used for one or more fueled heaters may be provided using a compressor or a series of compressors. A compressor may provide oxidizing fluid and/or fuel for one heater or more than one heater. In addition, oxidizing fluid and/or fuel may be provided from a centralized facility for use in a single heater or more than one heater.

Pyrolysis of hydrocarbons, or other heat-controlled processes, may take place in heated selected section 140. Selected section 140 may be at a temperature between about 270 °C and about 400 °C for pyrolysis. The temperature of selected section 140 may be increased by heat transfer from reaction zone 134.

A temperature within opening 132 may be monitored with a thermocouple disposed in opening 132. Alternatively, a thermocouple may be coupled to conduit 142 and/or disposed on a face of reaction zone 134. Power input or oxidant introduced into the formation may be controlled based upon the monitored temperature to maintain the temperature in a selected range. The selected range may vary or be varied depending on location of the thermocouple, a desired heating rate of hydrocarbon layer 108, and other factors. If a temperature within opening 132 falls below a minimum temperature of the selected temperature range, the flow rate of oxidizing fluid 130 may be increased to increase combustion and thereby increase the temperature within opening 132.

In certain embodiments, one or more natural distributed combustors may be placed along strike of a hydrocarbon layer and/or horizontally. Placing natural distributed combustors along strike or horizontally may reduce pressure differentials along the heated length of the heat source. Reduced pressure differentials may make the temperature generated along a length of the heater more uniform and easier to control.

In some embodiments, presence of air or oxygen (O₂) in oxidation product 144 may be monitored. Alternatively, an amount of nitrogen, carbon monoxide, carbon dioxide, oxides of nitrogen, oxides of sulfur, etc. may be monitored in oxidation product 144. Monitoring the composition and/or quantity of exhaust products (e.g., oxidation product 144) may be useful for heat balances, for process diagnostics, process control, etc.

FIG. 4 illustrates a cross-sectional representation of an embodiment of a natural distributed combustor having a second conduit 146 disposed in opening 132 in hydrocarbon layer 108. Second conduit 146 may be used

to remove oxidation products from opening 132. Second conduit 146 may have orifices 136 disposed along its length. In certain embodiments, oxidation products are removed from an upper region of opening 132 through orifices 136 disposed on second conduit 146. Orifices 136 may be disposed along the length of conduit 146 such that more oxidation products are removed from the upper region of opening 132.

5 In certain natural distributed combustor embodiments, orifices 136 on second conduit 146 may face away from orifices 136 on conduit 138. The orientation may inhibit oxidizing fluid provided through conduit 138 from passing directly into second conduit 146.

10 In some embodiments, conduit 146 may have a higher density of orifices 136 (and/or relatively larger diameter orifices 136) towards the upper region of opening 132. The preferential removal of oxidation products from the upper region of opening 132 may produce a substantially uniform concentration of oxidizing fluid along the length of opening 132. Oxidation products produced from reaction zone 134 tend to be more concentrated proximate the upper region of opening 132. The large concentration of oxidation products 144 in the upper region of opening 132 tends to dilute a concentration of oxidizing fluid 130 in the upper region. Removing a significant portion of the more concentrated oxidation products from the upper region of opening 132 may produce a more
15 uniform concentration of oxidizing fluid 130 throughout opening 132. Having a more uniform concentration of oxidizing fluid throughout the opening may produce a more uniform driving force for oxidizing fluid to flow into reaction zone 134. The more uniform driving force may produce a more uniform oxidation rate within reaction zone 134, and thus produce a more uniform heating rate in selected section 140 and/or a more uniform temperature within opening 132.

20 In a natural distributed combustor embodiment, the concentration of air and/or oxygen in the reaction zone may be controlled. A more even distribution of oxygen (or oxygen concentration) in the reaction zone may be desirable. The rate of reaction may be controlled as a function of the rate in which oxygen diffuses in the reaction zone. The rate of oxygen diffusion correlates to the oxygen concentration. Thus, controlling the oxygen concentration in the reaction zone (e.g., by controlling oxidizing fluid flow rates, the removal of oxidation products
25 along some or all of the length of the reaction zone, and/or the distribution of the oxidizing fluid along some or all of the length of the reaction zone) may control oxygen diffusion in the reaction zone and thereby control the reaction rates in the reaction zone.

In the embodiment 170 is placed in opening 132. Conductor 170 may extend from first end 148 of opening 132 to second end 150 of opening 132. In certain embodiments, conductor 170 may be placed in opening
30 132 within hydrocarbon layer 108. One or more low resistance sections 174 may be coupled to conductor 170 and used in overburden 158. In some embodiments, conductor 170 and/or low resistance sections 174 may extend above the surface of the formation.

In some heat source embodiments, an electric current may be applied to conductor 170 to increase a temperature of the conductor. Heat may transfer from conductor 170 to heated portion 152 of hydrocarbon layer
35 108. Heat may transfer from conductor 170 to heated portion 152 substantially by radiation. Some heat may also transfer by convection or conduction. Current may be provided to the conductor until a temperature within heated portion 152 is sufficient to support the oxidation of hydrocarbons within the heated portion. As shown in FIG. 5, oxidizing fluid may be provided into conductor 170 from oxidizing fluid source 154 at one or both ends 148, 150 of opening 132. A flow of the oxidizing fluid from conductor 170 into opening 132 may be controlled by orifices 136.
40 The orifices may be critical flow orifices. The flow of oxidizing fluid from orifices 136 may be controlled by a

diameter of the orifices, a number of orifices, and/or by a pressure within conductor 170 (i.e., a pressure behind the orifices).

Reaction of oxidizing fluids with hydrocarbons in reaction zone 134 may generate heat. The rate of heat generated in reaction zone 134 may be controlled by a flow rate of the oxidizing fluid into the formation, the rate of diffusion of oxidizing fluid through the reaction zone, and/or a removal rate of oxidation products from the formation. In an embodiment, oxidation products from the reaction of oxidizing fluid with hydrocarbons in the formation are removed through one or both ends of opening 132. In some embodiments, a conduit may be placed in opening 132 to remove oxidation products. All or portions of the oxidation products may be recycled and/or reused in other oxidation type heaters (e.g., natural distributed combustors, surface burners, downhole combustors, etc.). Heat generated in reaction zone 134 may transfer to a surrounding portion (e.g., selected section) of the formation. The transfer of heat between reaction zone 134 and selected section may be substantially by conduction. In certain embodiments, the transferred heat may increase a temperature of the selected section above a minimum mobilization temperature of the hydrocarbons and/or a minimum pyrolysis temperature of the hydrocarbons.

In some heat source embodiments, a conduit may be placed in the opening. The opening may extend through the formation contacting a surface of the earth at a first location and a second location. Oxidizing fluid may be provided to the conduit from the oxidizing fluid source at the first location and/or the second location after a portion of the formation that has been heated to a temperature sufficient to support oxidation of hydrocarbons by the oxidizing fluid.

FIG. 6 illustrates an embodiment of a section of overburden with a natural distributed combustor as described in FIG. 3. Overburden casing 156 may be disposed in overburden 158 of hydrocarbon layer 108. Overburden casing 156 may be surrounded by materials (e.g., an insulating material such as cement) that inhibit heating of overburden 158. Overburden casing 156 may be made of a metal material such as, but not limited to, carbon steel or 304 stainless steel.

Overburden casing 156 may be placed in reinforcing material 160 in overburden 158. Reinforcing material 160 may be, but is not limited to, cement, gravel, sand, and/or concrete. Packing material 162 may be disposed between overburden casing 156 and opening 132 in the formation. Packing material 162 may be any substantially non-porous material (e.g., cement, concrete, grout, etc.). Packing material 162 may inhibit flow of fluid outside of conduit 142 and between opening 132 and surface 110. Inner conduit 138 may introduce fluid into opening 132 in hydrocarbon layer 108. Conduit 142 may remove combustion product (or excess oxidation fluid) from opening 132 in hydrocarbon layer 108. Diameter of conduit 142 may be determined by an amount of the combustion product produced by oxidation in the natural distributed combustor. For example, a larger diameter may be required for a greater amount of exhaust product produced by the natural distributed combustor heater.

In some heat source embodiments, a portion of the formation adjacent to a wellbore may be heated to a temperature and at a heating rate that converts hydrocarbons to coke or char adjacent to the wellbore by a first heat source. Coke and/or char may be formed at temperatures above about 400 °C. In the presence of an oxidizing fluid, the coke or char will oxidize. The wellbore may be used as a natural distributed combustor subsequent to the formation of coke and/or char. Heat may be generated from the oxidation of coke or char.

FIG. 7 illustrates an embodiment of a natural distributed combustor heater. Insulated conductor 164 may be coupled to conduit 166 and placed in opening 132 in hydrocarbon layer 108. Insulated conductor 164 may be disposed internal to conduit 166 (thereby allowing retrieval of insulated conductor 164), or, alternately, coupled to an external surface of conduit 166. Insulating material for the conductor may include, but is not limited to, mineral

coating and/or ceramic coating. Conduit 166 may have critical flow orifices 136 disposed along its length within opening 132. Electrical current may be applied to insulated conductor 164 to generate radiant heat in opening 132. Conduit 166 may serve as a return for current. Insulated conductor 164 may heat portion 152 of hydrocarbon layer 108 to a temperature sufficient to support oxidation of hydrocarbons.

5 Oxidizing fluid source 154 may provide oxidizing fluid into conduit 166. Oxidizing fluid may be provided into opening 132 through critical flow orifices 136 in conduit 166. Oxidizing fluid may oxidize at least a portion of the hydrocarbon layer in reaction zone 134. A portion of heat generated at reaction zone 134 may transfer to selected section 140 by convection, radiation, and/or conduction. Oxidation product may be removed through a separate conduit placed in opening 132 or through opening 168 in overburden casing 156.

10 FIG. 8 illustrates an embodiment of a natural distributed combustor heater with an added fuel conduit. Fuel conduit 170 may be placed in opening 132. Fuel conduit may be placed adjacent to conduit 172 in certain embodiments. Fuel conduit 170 may have critical flow orifices 174 along a portion of the length within opening 132. Conduit 172 may have critical flow orifices 136 along a portion of the length within opening 132. The critical flow orifices 174, 136 may be positioned so that a fuel fluid provided through fuel conduit 170 and an oxidizing fluid provided through conduit 172 do not react to heat the fuel conduit and the conduit. Heat from reaction of the fuel fluid with oxidizing fluid may heat fuel conduit 170 and/or conduit 172 to a temperature sufficient to begin melting metallurgical materials in fuel conduit 170 and/or conduit 172 if the reaction takes place proximate fuel conduit 170 and/or conduit 172. Critical flow orifices 174 on fuel conduit 170 and critical flow orifices 136 on conduit 172 may be positioned so that the fuel fluid and the oxidizing fluid do not react proximate the conduits. For example, conduits 170 and 172 may be positioned such that orifices that spiral around the conduits are oriented in opposite directions.

 Reaction of the fuel fluid and the oxidizing fluid may produce heat. In some embodiments, the fuel fluid may be methane, ethane, hydrogen, or synthesis gas that is generated by in situ conversion in another part of the formation. The produced heat may heat portion 152 to a temperature sufficient to support oxidation of hydrocarbons. Upon heating of portion 152 to a temperature sufficient to support oxidation, a flow of fuel fluid into opening 132 may be turned down or may be turned off. In some embodiments, the supply of fuel may be continued throughout the heating of the formation.

25 The oxidizing fluid may oxidize at least a portion of the hydrocarbons at reaction zone 134. Generated heat may transfer heat to selected section 140 by radiation, convection, and/or conduction. An oxidation product may be removed through a separate conduit placed in opening 132 or through opening 168 in overburden casing 156.

 FIG. 9 illustrates an embodiment of a system that may heat a hydrocarbon containing formation. Electric heater 176 may be disposed within opening 132 in hydrocarbon layer 108. Opening 132 may be formed through overburden 158 into hydrocarbon layer 108. Opening 132 may be at least about 5 cm in diameter. Opening 132 may, as an example, have a diameter of about 13 cm. Electric heater 176 may heat at least portion 152 of hydrocarbon layer 108 to a temperature sufficient to support oxidation (e.g., about 260 °C). Portion 152 may have a width of about 1 m. An oxidizing fluid may be provided into the opening through conduit 142 or any other appropriate fluid transfer mechanism. Conduit 142 may have critical flow orifices 136 disposed along a length of the conduit.

40 Conduit 142 may be a pipe or tube that provides the oxidizing fluid into opening 132 from oxidizing fluid source 154. In an embodiment, a portion of conduit 142 that may be exposed to high temperatures is a stainless

steel tube and a portion of the conduit that will not be exposed to high temperatures (i.e., a portion of the tube that extends through the overburden) is carbon steel. The oxidizing fluid may include air or any other oxygen containing fluid (e.g., hydrogen peroxide, oxides of nitrogen, ozone). Mixtures of oxidizing fluids may be used. An oxidizing fluid mixture may be a fluid including fifty percent oxygen and fifty percent nitrogen. In some
5 embodiments, the oxidizing fluid may include compounds that release oxygen when heated, such as hydrogen peroxide. The oxidizing fluid may oxidize at least a portion of the hydrocarbons in the formation.

FIG. 10 illustrates an embodiment of a system that heats a hydrocarbon containing formation. Heat exchanger 178 may be disposed external to opening 132 in hydrocarbon layer 108. Opening 132 may be formed through overburden 158 into hydrocarbon layer 108. Heat exchanger 178 may provide heat from another surface
10 process, or it may include a heater (e.g., an electric or combustion heater). Oxidizing fluid source 154 may provide an oxidizing fluid to heat exchanger 178. Heat exchanger 178 may heat an oxidizing fluid (e.g., above 200 °C or to a temperature sufficient to support oxidation of hydrocarbons). The heated oxidizing fluid may be provided into opening 132 through conduit 180. Conduit 180 may have critical flow orifices 136 disposed along a length of the conduit. The heated oxidizing fluid may heat, or at least contribute to the heating of, at least portion 152 of the
15 formation to a temperature sufficient to support oxidation of hydrocarbons. The oxidizing fluid may oxidize at least a portion of the hydrocarbons in the formation. After temperature in the formation is sufficient to support oxidation, use of heat exchanger 178 may be reduced or phased out.

An embodiment of a natural distributed combustor may include a surface combustor (e.g., a flame-ignited heater). A fuel fluid may be oxidized in the combustor. The oxidized fuel fluid may be provided into an opening in
20 the formation from the heater through a conduit. Oxidation products and unreacted fuel may return to the surface through another conduit. In some embodiments, one of the conduits may be placed within the other conduit. The oxidized fuel fluid may heat, or contribute to the heating of, a portion of the formation to a temperature sufficient to support oxidation of hydrocarbons. Upon reaching the temperature sufficient to support oxidation, the oxidized fuel fluid may be replaced with an oxidizing fluid. The oxidizing fluid may oxidize at least a portion of the
25 hydrocarbons at a reaction zone within the formation.

An electric heater may heat a portion of the hydrocarbon containing formation to a temperature sufficient to support oxidation of hydrocarbons. The portion may be proximate or substantially adjacent to the opening in the formation. The portion may radially extend a width of less than approximately 1 m from the opening. An oxidizing fluid may be provided to the opening for oxidation of hydrocarbons. Oxidation of the hydrocarbons may heat the
30 hydrocarbon containing formation in a process of natural distributed combustion. Electrical current applied to the electric heater may subsequently be reduced or may be turned off. Natural distributed combustion may be used in conjunction with an electric heater to provide a reduced input energy cost method to heat the hydrocarbon containing formation compared to using only an electric heater.

Further modifications and alternative embodiments of various aspects of the invention may be apparent to
35 those skilled in the art in view of this description. Accordingly, this description is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the general manner of carrying out the invention. It is to be understood that the forms of the invention shown and described herein are to be taken as the presently preferred embodiments. Elements and materials may be substituted for those illustrated and described herein, parts and processes may be reversed, and certain features of the invention may be utilized independently, all as would be
40 apparent to one skilled in the art after having the benefit of this description of the invention. Changes may be made

in the elements described herein without departing from the spirit and scope of the invention as described in the following claims.

WHAT IS CLAIMED:

1. A system configurable to provide heat to a hydrocarbon containing formation, comprising:
a heater configurable to be placed in an opening in the formation, wherein the heater is configurable to
5 provide heat to at least a portion of the formation during use;
an oxidizing fluid source configurable to provide an oxidizing fluid to a reaction zone of the formation to
generate heat in the reaction zone during use;
a first conduit configurable to be placed in the opening, wherein the first conduit is configurable to provide
the oxidizing fluid from the oxidizing fluid source to the reaction zone in the formation during use; and
10 wherein the system is configurable to allow the generated heat to transfer from the reaction zone to the
formation during use.
2. The system of claim 1, wherein at least a portion of the reaction zone has been previously heated by the
heater during use.
15
3. The system according to one or more of claims 1 to 2, wherein the oxidizing fluid oxidizes at least some
hydrocarbons in the reaction zone during use.
4. The system according to one or more of claims 1 to 3, wherein the oxidizing fluid is substantially inhibited
20 from flowing from the reaction zone into a surrounding portion of the formation during use.
5. The system according to one or more of claims 1 to 4, wherein the system is configurable to allow the
oxidizing fluid to be transported through the reaction zone substantially by diffusion during use.
- 25 6. The system according to one or more of claims 1 to 5, wherein the system is configurable to allow the
generated heat to transfer from the reaction zone to a pyrolysis zone in the formation during use.
7. The system according to one or more of claims 1 to 6, wherein the system is configurable to allow the
generated heat to transfer substantially by conduction from the reaction zone to the formation during use.
30
8. The system according to one or more of claims 1 to 7, wherein the flow of oxidizing fluid can be
controlled along at least a segment of the first conduit such that a temperature can be controlled along at least a
segment of the first conduit during use.
- 35 9. The system according to one or more of claims 1 to 8, wherein a flow of oxidizing fluid can be controlled
along at least a segment of the first conduit such that a heating rate in at least a section of the formation can be
controlled.

10. The system according to one or more of claims 1 to 9, wherein the oxidizing fluid is configurable to move through the reaction zone substantially by diffusion during use, wherein a rate of diffusion can be controlled by a temperature of the reaction zone.
- 5 11. The system according to one or more of claims 1 to 10, wherein the first conduit comprises orifices, and wherein the orifices are configurable to provide the oxidizing fluid into the opening during use.
12. The system according to one or more of claims 1 to 11, wherein the first conduit comprises critical flow orifices, and wherein the critical flow orifices are configurable to control a flow of the oxidizing fluid such that a
10 rate of oxidation in the formation is controlled during use.
13. The system according to one or more of claims 1 to 12, wherein the flow of at least some of the oxidizing fluid can be controlled along at least a segment of the first conduit.
- 15 14. The system according to one or more of claims 1 to 13, wherein at least the portion of the formation extends radially from the opening a distance of less than approximately 3 m.
15. The system according to one or more of claims 1 to 14, wherein the reaction zone extends radially from the opening a distance of less than approximately 3 m.
20
16. The system according to one or more of claims 1 to 15, wherein the system is configurable to allow transferred heat to pyrolyze at least some hydrocarbons in a pyrolysis zone of the formation.
17. The system according to one or more of claims 1 to 16, wherein the system is configurable to provide
25 molecular hydrogen to the reaction zone during use.
18. The system of claim 17, wherein at least some of the provided hydrogen is produced in a pyrolysis zone during use.
- 30 19. The system according to one or more of claims 17 to 18, wherein at least some of the provided hydrogen is produced in the reaction zone during use.
20. The system according to one or more of claims 17 to 19, wherein at least some of the provided hydrogen is produced in at least the heated portion of the formation during use.
35
21. The system according to one or more of claims 17 to 20, wherein the system is configurable to provide hydrogen to the reaction zone during use such that production of carbon dioxide in the reaction zone is inhibited.

22. The system according to one or more of claims 1 to 21, further comprising a second conduit configurable to be placed in the opening, wherein the second conduit is further configurable to remove an oxidation product during use.

23. The system of claim 22, wherein the second conduit is further configurable to remove an oxidation product during use such that the reaction zone comprises a substantially uniform temperature profile.

24. The system according to one or more of claims 22 to 23, wherein the second conduit is configurable to control the concentration of oxygen in the opening during use such that the concentration of oxygen in the opening is substantially constant in the opening.

25. The system according to one or more of claims 22 to 24, wherein the second conduit comprises orifices that remove the oxidation product from a direction substantially opposite the first conduit.

26. The system according to one or more of claims 22 to 25, wherein the second conduit comprises orifices, and wherein the second conduit comprises a greater concentration of orifices toward an upper end of the second conduit.

27. The system according to one or more of claims 22 to 26, wherein the first conduit comprises orifices that direct oxidizing fluid in a direction substantially opposite the second conduit.

28. The system according to one or more of claims 22 to 27, wherein the second conduit is further configurable to allow heat within the oxidation product to transfer to the oxidizing fluid in the first conduit during use.

29. The system according to one or more of claims 22 to 28, wherein a pressure of the oxidizing fluid in the first conduit and a pressure of the oxidation product in the second conduit are controlled during use such that a concentration of the oxidizing fluid along the length of the first conduit is substantially uniform.

30. A system configured to provide heat to a hydrocarbon containing formation according to one or more of claims 1 to 29, comprising:
a heater configured to be placed in an opening in the formation, wherein the heater is configured to provide heat to at least a portion of the formation during use;
an oxidizing fluid source configured to provide an oxidizing fluid to a reaction zone of the formation to generate heat in the reaction zone during use;
a first conduit configured to be placed in the opening, wherein the first conduit is configured to provide the oxidizing fluid from the oxidizing fluid source to the reaction zone in the formation during use; and
wherein the system is configured to allow the generated heat to transfer from the reaction zone to the formation during use.

31. A system that provides heat to a hydrocarbon containing formation according to one or more of claims 1 to 29, comprising:

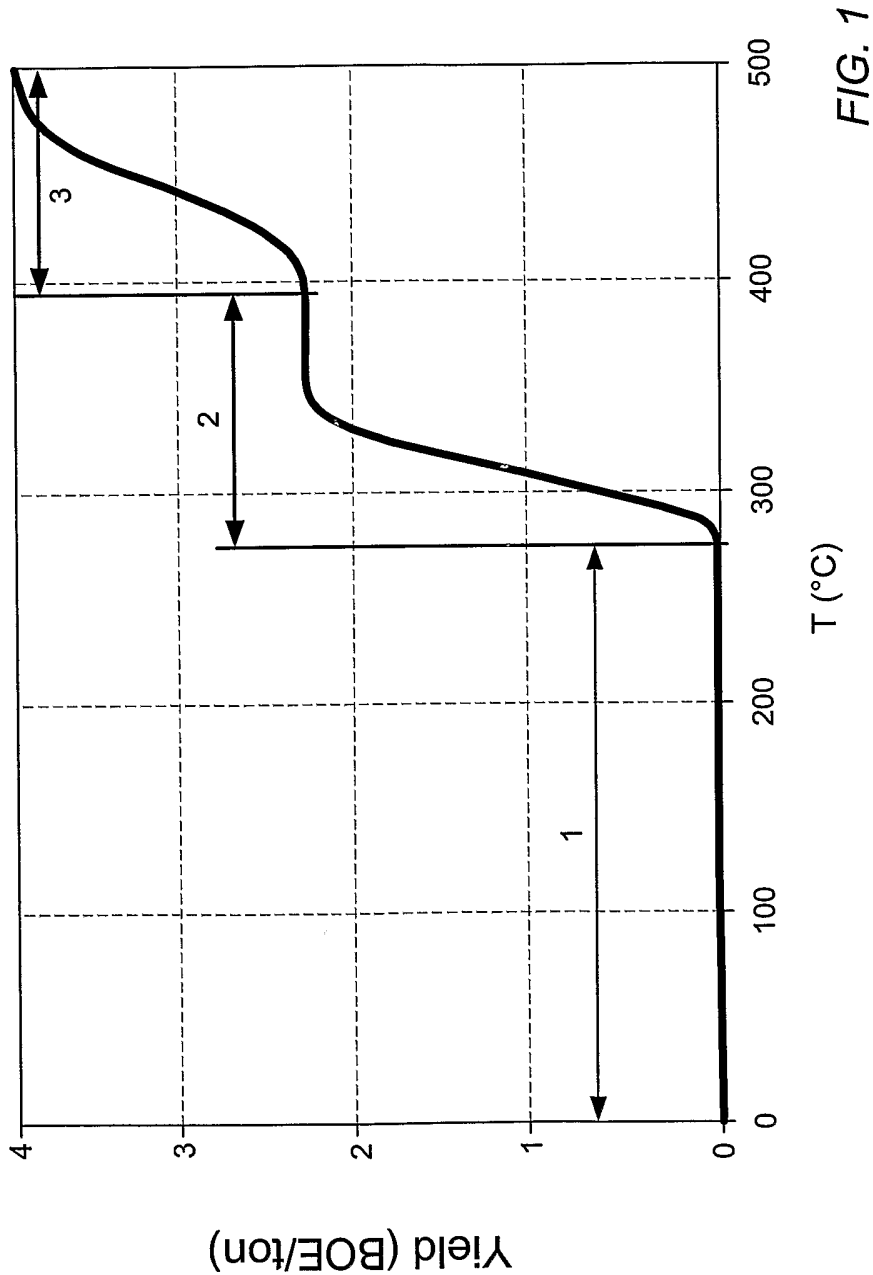
a heater placed in an opening in the formation, wherein the heater provides heat to at least a portion of the formation during use;

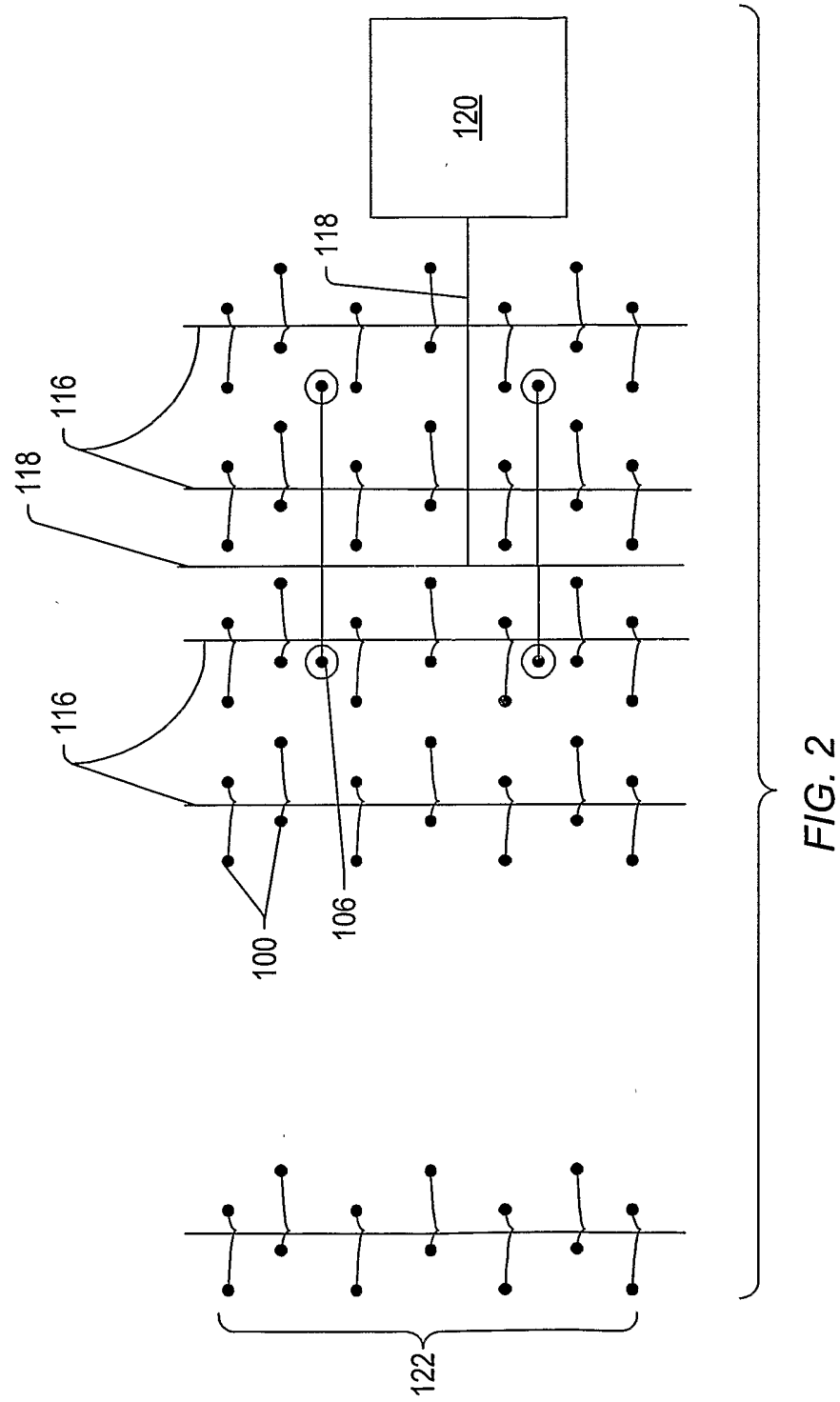
5 an oxidizing fluid source to provide an oxidizing fluid to a reaction zone of the formation to generate heat in the reaction zone during use;

a first conduit placed in the opening, wherein the first conduit provides the oxidizing fluid from the oxidizing fluid source to the reaction zone in the formation during use; and

10 wherein the system allows the generated heat to transfer from the reaction zone to the formation during use.

32. The system according to one or more of claims 1 to 31, wherein a first end of the opening contacts an earth surface at a first location, and wherein a second end of the opening contacts the earth surface at a second location.





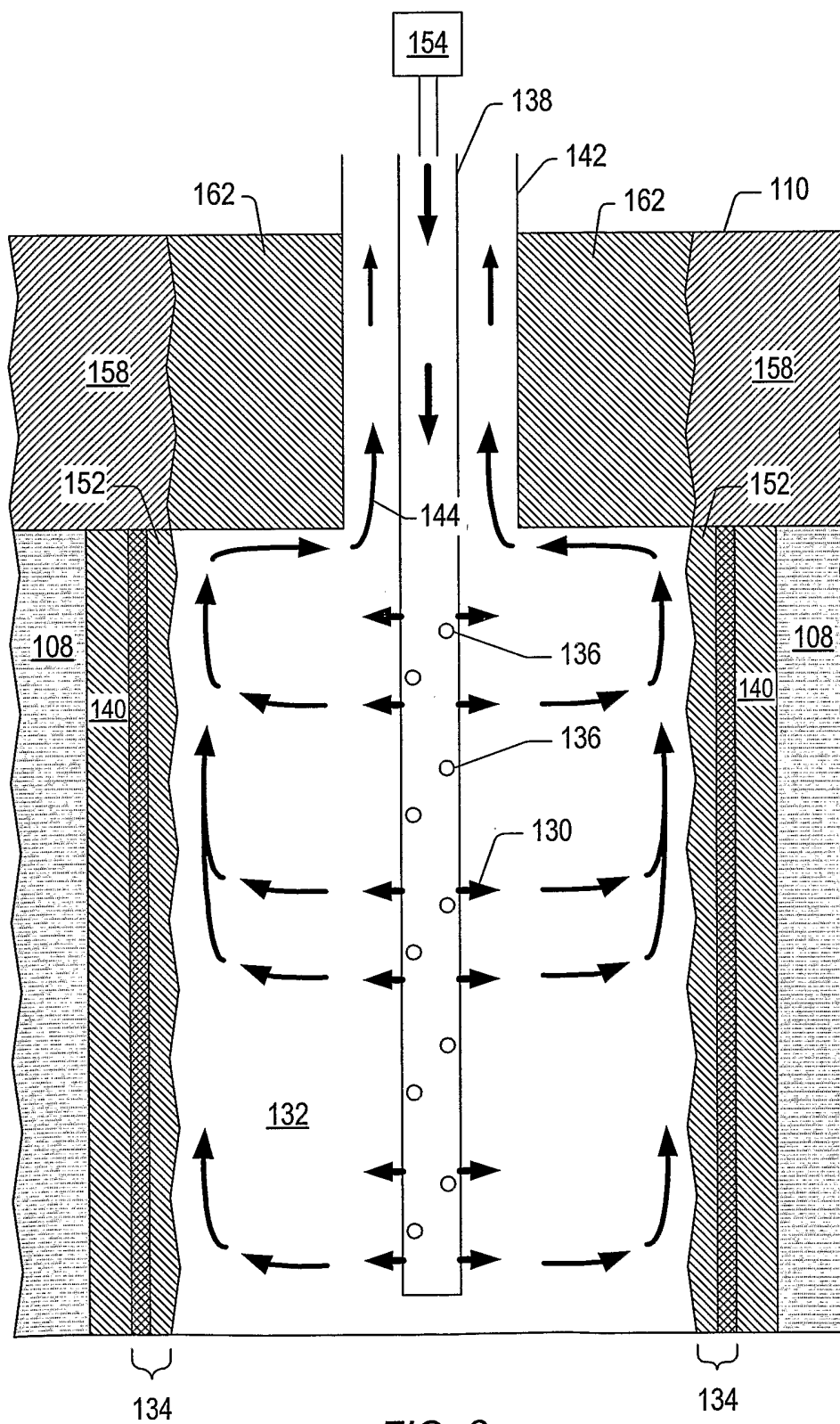


FIG. 3

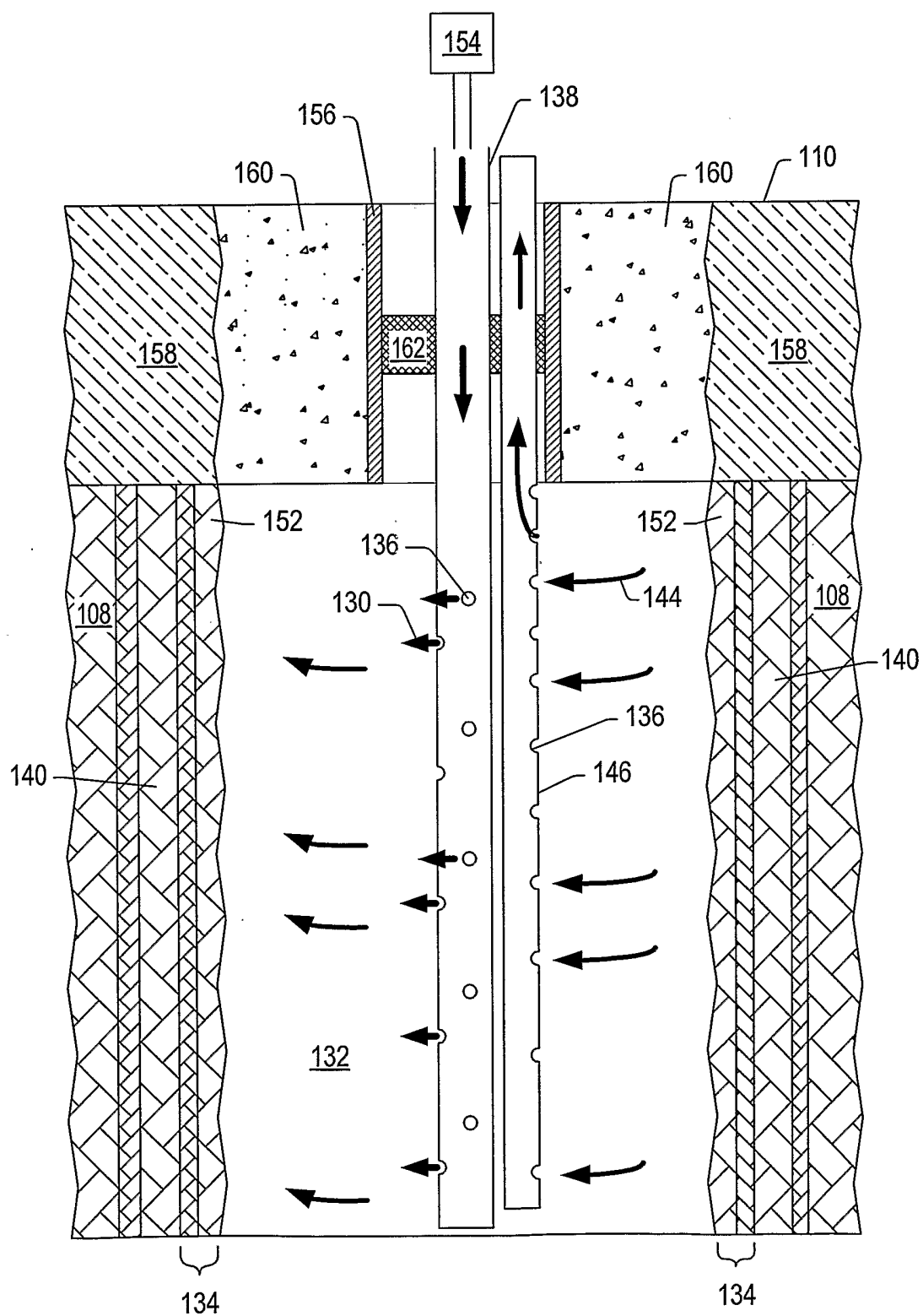


FIG. 4

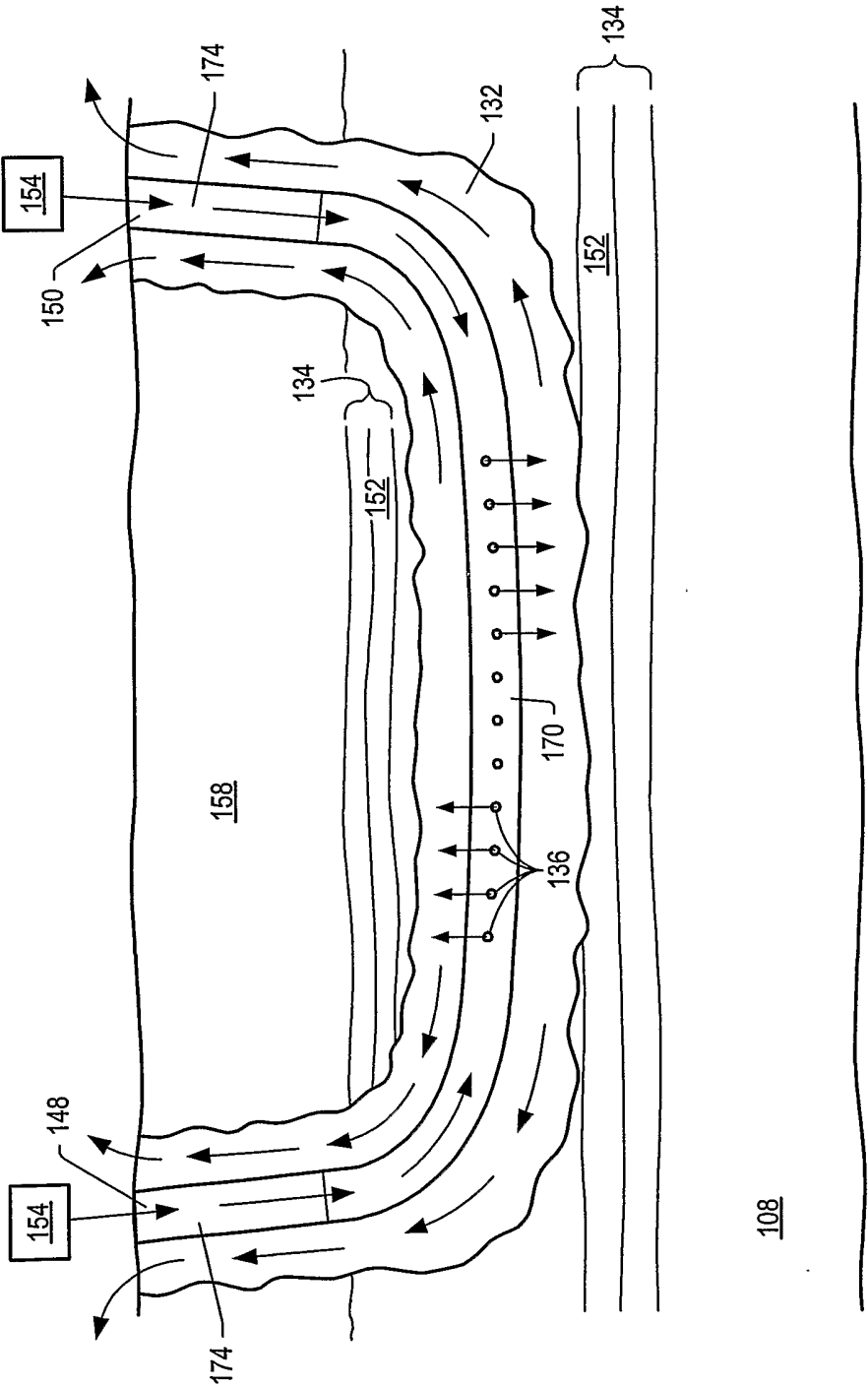


FIG. 5

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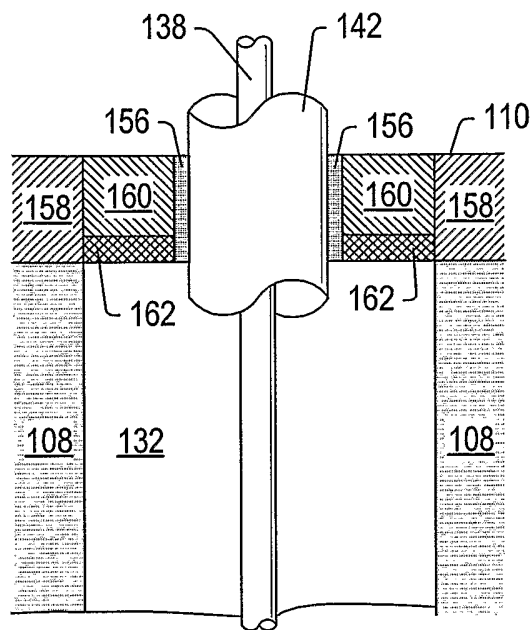


FIG. 6

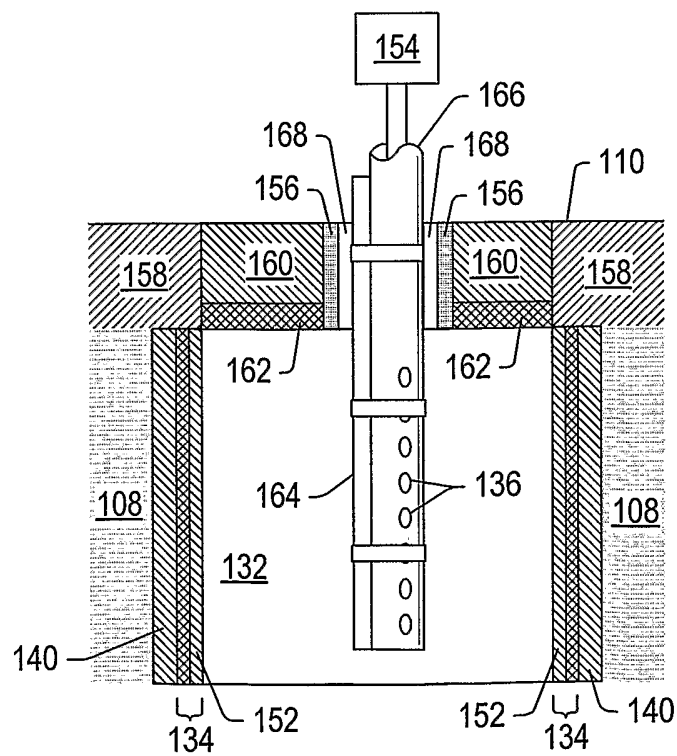


FIG. 7

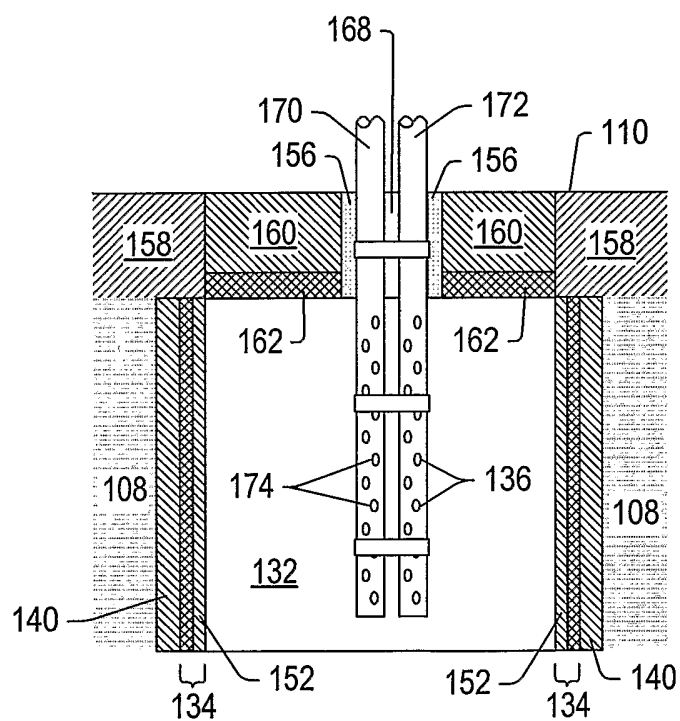


FIG. 8

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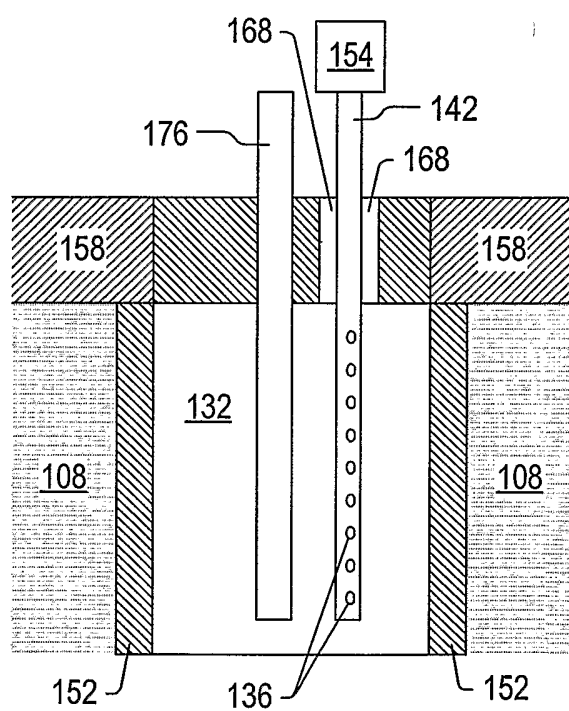


FIG. 9

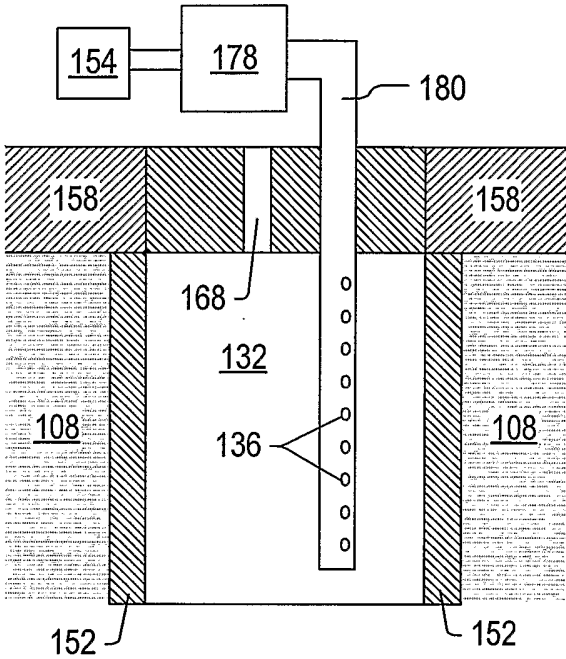


FIG. 10