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(54) Title: CONDUCTOR-IN-CONDUIT HEAT SOURCES WITH AN ELECTRICALLY CONDUCTIVE MATERIAL IN THE OVERBURDEN

(57) Abstract: A system to heat a hydrocarbon-containing formation includes a conduit placed within an opening in the formation. A conductor is placed within the conduit. The conductor provides heat to a portion of the formation. An electrically conductive material is coupled to a portion of the conductor in the overburden. The electrically conductive material lowers the electrical resistance of the portion of the conductor in the overburden. Lowering the electrical resistance of the portion of the conductor in the overburden reduces the heat output of the portion in the overburden. The system allows heat to transfer from the conductor to a portion of the formation. The reduction of the electrical resistance is achieved with cladding sections, which inhibit the temperature rise in the overburden.

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CONDUCTOR-IN-CONDUIT HEAT SOURCES WITH AN ELECTRICALLY CONDUCTIVE MATERIAL IN THE OVERBURDEN

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 heating a portion of a formation with a conductor-in-conduit heat source with an electrically conductive material coupled to a portion of the heat source in the overburden.

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 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.

A heat source may be used to heat a subterranean formation. Electric heaters may be used to heat the subterranean formation by radiation and/or conduction. An electric heater may resistively heat an element. U.S. Patent No. 2,548,360 to Germain describes an electric heating element placed within a viscous oil within a wellbore. The heater element heats and thins the oil to allow the oil to be pumped from the wellbore. U.S. Patent No. 4,716,960 to Eastlund et al. describes electrically heating tubing of a petroleum well by passing a relatively low voltage current through the tubing to prevent formation of solids. U.S. Patent No. 5,065,818 to Van Egmond describes an electric heating element that is cemented into a well borehole without a casing surrounding the heating element.

The efficiency of a heat source in providing heat to a hydrocarbon containing formation may be reduced by excessive heat losses to the overburden of the formation. Heat losses to the overburden are typically unwanted and reduce the amount of energy that may be transferred to more desirable portions of the formation. To increase the amount of energy actually transferred to desired portions of the formation (e.g., hydrocarbon layers), heating losses to the overburden may need to be reduced. For electrical heaters, heating losses in the overburden are typically associated with using resistive elements in the overburden to transfer power to lower portions of the formation. Thus, lowering the electrical resistances of these resistive elements in the overburden may reduce heat losses to the overburden. Reducing heat losses to the overburden may increase the available power for heating desirable portions of the formation.
As outlined above, there has been a significant amount of effort to develop methods and systems to economically produce hydrocarbons, hydrogen, and/or other products from hydrocarbon containing formations. At present, however, there are still many hydrocarbon containing formations from which hydrocarbons, hydrogen, and/or other products cannot be economically produced. Thus, there is still a need for improved methods and systems for production of hydrocarbons, hydrogen, and/or other products from various hydrocarbon containing formations. There is also a need for heaters than can heat formations from wellbores without excessive energy losses in the overburden. Thus, there is a need for heater supports with relatively high mechanical strength and relatively low electrical resistance in the overburden.

**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.

An embodiment of a system and method for heating a hydrocarbon containing formation may include a conductor placed within a conduit (e.g., a conductor-in-conduit heat source). The conduit may be disposed within the opening. An electric current may be applied to the conductor to provide heat to a portion of the formation. The system may allow heat to transfer from the conductor to a section of the formation during use.

In certain embodiments, an electrically conductive material may be coupled to at least a portion of a conductor and/or a conduit. Use of the electrically conductive material on a portion (e.g., in the overburden portion) of the conductor and/or conduit may lower an electrical resistance of the conductor and/or the conduit.

**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 shows 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 conductor-in-conduit heat source in a formation.

FIG. 4 depicts an embodiment of a centralizer.

FIG. 5 depicts an embodiment of a centralizer.

FIG. 6 depicts a cross-sectional representation of an embodiment of a removable conductor-in-conduit heat source.

FIG. 7 illustrates a schematic of an embodiment of a conductor-in-conduit heater, wherein a portion of the heater is placed substantially horizontally within a formation.
FIG. 8 illustrates an enlarged view of an embodiment of a junction of a conductor-in-conduit heater.

FIG. 9 illustrates a schematic of an embodiment of a conductor-in-conduit heater, wherein a portion of the heater is placed substantially horizontally within a formation.

FIG. 10 illustrates a schematic of an embodiment of a conductor-in-conduit heater, wherein a portion of the heater is placed substantially horizontally within a formation.

FIG. 11 illustrates a schematic of an embodiment of a conductor-in-conduit heater, wherein a portion of the heater is placed substantially horizontally within a formation.

FIG. 12 depicts a cross-sectional view of a portion of an embodiment of a cladding section coupled to a heater support and a conduit.

FIG. 13 depicts a cross-sectional representation of an embodiment of a cladding section coupled to a low resistance conductor.

FIG. 14 depicts a representation of two conductor portions and two conduit portions with cladding sections before forge welding.

FIG. 15 depicts an embodiment of a conductor-in-conduit heat source with lead-in and lead-out conductors in the overburden.

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, asphalites, 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. Hydrocarbons may be, but are not limited to, kerogen, bitumen, pyrobitumen, oils, natural mineral waxes, and asphalites. Hydrocarbons may be located within or adjacent to mineral matrices within the earth. Matrices may include, but are not limited to, sedimentary rock, sands, silicilites, carbonates, diatomites, and other porous media. "Hydrocarbon fluids" are fluids that include hydrocarbons. Hydrocarbon fluids may include, entrain, or be entrained in non-hydrocarbon fluids (e.g., hydrogen ("H₂"), nitrogen ("N₂"), carbon monoxide, carbon dioxide, hydrogen sulfide, water, and ammonia).

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.

The terms “formation fluids” and “produced fluids” refer to fluids removed from a hydrocarbon containing formation and may include pyrolyzation fluid, synthesis gas, mobilized hydrocarbon, and water (steam). The term “mobilized fluid” refers to fluids within the formation that are able to flow because of thermal treatment of the formation. Formation fluids may include hydrocarbon fluids as well as non-hydrocarbon fluids.

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 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.

The term “wellbore” refers to a hole in a formation made by drilling or insertion of a conduit into the formation. A wellbore may have a substantially circular cross section, or other cross-sectional shapes (e.g., circles, ovals, squares, rectangles, triangles, slits, or other regular or irregular shapes). As used herein, the terms “well” and “opening,” when referring to an opening in the formation, may be used interchangeably with the term “wellbore.”

“Pyrolyzation fluids” or “pyrolysis products” refers to fluid produced substantially during pyrolysis of hydrocarbons. Fluid produced by pyrolysis reactions may mix with other fluids in a formation. The mixture would be considered pyrolyzation fluid or pyrolyzation product. As used herein, “pyrolysis zone” refers to a volume of a formation (e.g., a relatively permeable formation such as a tar sands formation) that is reacted or reacting to form a pyrolyzation fluid.

“Condensable hydrocarbons” are hydrocarbons that condense at 25 °C at one atmosphere absolute pressure. Condensable hydrocarbons may include a mixture of hydrocarbons having carbon numbers greater than 4. “Non-condensable hydrocarbons” are hydrocarbons that do not condense at 25 °C and one atmosphere absolute pressure. Non-condensable hydrocarbons may include hydrocarbons having carbon numbers less than 5.

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 (as the formation is heated at a relatively low rate).

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% and 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 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. Superposition of heat from heat sources may allow the desired temperature to be relatively quickly and efficiently established in the formation. 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.

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.

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 124 may be placed within at least a portion of the hydrocarbon containing formation. Heat sources 124 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 124 may also include other types of heaters. Heat sources 124 may provide heat to at least a portion of a hydrocarbon containing formation. Energy may be supplied to the heat sources 124 through supply lines 126. 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 128 may be used to remove formation fluid from the formation. Formation fluid produced from production wells 128 may be transported through collection piping 130 to treatment facilities 132. Formation fluids may also be produced from heat sources 124. For example, fluid may be produced from heat sources 124 to control pressure within the formation adjacent to the heat sources. Fluid produced from heat sources 124 may be transported through tubing or piping to collection piping 130 or the produced fluid may be transported through tubing or piping directly to treatment facilities 132. Treatment facilities 132 may include separation units, reaction units, upgrading units, fuel cells, turbines, storage vessels, and other systems and units for processing produced formation fluids.

An in situ conversion system for treating hydrocarbons may include barrier wells 134. In certain embodiments, barrier wells 134 may include freeze wells. 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, 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.
As shown in FIG. 2, in addition to heat sources 124, one or more production wells 128 will typically be placed within a portion of the hydrocarbon containing formation. Formation fluids may be produced through production well 128. In some embodiments, production well 128 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.

FIG. 3 illustrates an embodiment of a conductor-in-conduit heater that may heat a hydrocarbon containing formation. Conductor 142 may be disposed in conduit 150. Conductor 142 may be a rod or conduit of electrically conductive material. Low resistance sections 148 may be present at both ends of conductor 142 to generate less heating in these sections. Low resistance section 148 may be formed by having a greater cross-sectional area of conductor 142 in that section, or the sections may be made of material having less resistance. In certain embodiments, low resistance section 148 includes a low resistance conductor coupled to conductor 142. In some heat source embodiments, conductors 142 may be 316, 304, or 310 stainless steel rods with diameters of approximately 2.8 cm. In some heat source embodiments, conductors are 316, 304, or 310 stainless steel pipes with diameters of approximately 2.5 cm. Larger or smaller diameters of rods or pipes may be used to achieve desired heating of a formation. The diameter and/or wall thickness of conductor 142 may be varied along a length of the conductor to establish different heating rates at various portions of the conductor.

Conduit 150 may be made of an electrically conductive material. For example, conduit 150 may be a 7.6 cm, schedule 40 pipe made of 316, 304, or 310 stainless steel. Conduit 150 may be disposed in opening 140 in hydrocarbon layer 136. Opening 140 has a diameter able to accommodate conduit 150. A diameter of the opening may be from about 10 cm to about 13 cm. Larger or smaller diameter openings may be used to accommodate particular conduits or designs.

Conductor 142 may be centered in conduit 150 by centralizers 144. Centralizers 144 may electrically isolate conductor 142 from conduit 150. Centralizers 144 may inhibit movement and properly locate conductor 142 within conduit 150. Centralizers 144 may be made of a ceramic material or a combination of ceramic and metallic materials. Centralizers 144 may inhibit deformation of conductor 142 in conduit 150. Centralizers 144 may be spaced at intervals between approximately 0.5 m and approximately 3 m along conductor 142. FIGS. 4 and 5 depict an embodiment of centralizer 144.

A second low resistance section 148 of conductor 142 may couple conductor 142 to wellhead 166, as depicted in FIG. 3. Electrical current may be applied to conductor 142 from power cable 164 through low resistance section 148 of conductor 142. Electrical current may pass from conductor 142 through sliding connector 146 to conduit 150. Conduit 150 may be electrically insulated from overburden casing 154 and from wellhead 166 to return electrical current to power cable 164. Heat may be generated in conductor 142 and conduit 150. The generated heat may radiate within conduit 150 and opening 140 to heat at least a portion of hydrocarbon layer 136. As an example, a voltage of about 330 volts and a current of about 795 amps may be supplied to conductor 142 and
conduit 150 in a 229 m (750 ft) heated section to generate about 1150 watts/meter of conductor 142 and conduit 150.

Overburden casing 154 may be disposed in overburden 138. Overburden casing 154 may, in some embodiments, be surrounded by materials that inhibit heating of overburden 138. Low resistance section 148 of conductor 142 may be placed in overburden casing 154. Low resistance section 148 of conductor 142 may be made of, for example, carbon steel. Low resistance section 148 may have a diameter between about 2 cm and about 5 cm or, for example, a diameter of about 4 cm. Low resistance section 148 of conductor 142 may be centralised within overburden casing 154 using centralisers 144. Centralizers 144 may be spaced at intervals of approximately 6 m to approximately 12 m or, for example, approximately 9 m along low resistance section 148 of conductor 142. In a heat source embodiment, low resistance section 148 of conductor 142 is coupled to the conductor by a weld or welds. In other heat source embodiments, low resistance sections may be threaded, threaded and welded, or otherwise coupled to the conductor. Low resistance section 148 may generate little and/or no heat in overburden casing 154. Packing material 152 may be placed between overburden casing 154 and opening 140. Packing material 152 may inhibit fluid from flowing from opening 140 to surface 162.

In a heat source embodiment, overburden casing is a 7.6 cm schedule 40 carbon steel pipe. In some embodiments, the overburden casing may be cemented in the overburden. Reinforcing material 156 may be slag or silica flour or a mixture thereof (e.g., about 1.58 grams per cubic centimeter slag/silica flour). Reinforcing material 156 may extend radially a width of about 5 cm to about 25 cm. Reinforcing material 156 may also be made of material designed to inhibit flow of heat into overburden 138. In other heat source embodiments, overburden casing 154 may not be cemented into the formation. Having an uncemented overburden casing may facilitate removal of conduit 150 if the need for removal should arise.

Surface conductor 158 may couple to wellhead 166. Surface conductor 158 may have a diameter of about 10 cm to about 30 cm or, in certain embodiments, a diameter of about 22 cm. Electrically insulating sealing flanges may mechanically couple low resistance section 148 of conductor 142 to wellhead 166 and to electrically couple low resistance section 148 to power cable 164. The electrically insulating sealing flanges may couple power cable 164 to wellhead 166. Power cable 164 may be a copper cable, wire, or other elongated member. Power cable 164 may include any material having a substantially low resistance. The power cable may be clamped to the bottom of the low resistance conductor to make electrical contact.

In an embodiment, heat may be generated in or by conduit 150. About 10% to about 30%, or, for example, about 20%, of the total heat generated by the heater may be generated in or by conduit 150. Both conductor 142 and conduit 150 may be made of stainless steel. Dimensions of conductor 142 and conduit 150 may be chosen such that the conductor will dissipate heat in a range from approximately 650 watts per meter to approximately 1650 watts per meter. A temperature in conduit 150 may be approximately 480 °C to approximately 815 °C, and a temperature in conductor 142 may be approximately 500 °C to approximately 840 °C. Substantially uniform heating of a hydrocarbon containing formation may be provided along a length of conduit 150 greater than about 300 m or, even greater than about 600 m.

Conduit 160 may be provided to add gas from gas source 172, through valve 168, and into opening 140. An opening is provided in reinforcing material 156 to allow gas to pass into opening 140. Conduit 160 and valve 170 may be used at different times to bleed off pressure and/or control pressure approximate opening 140. It is to be understood that any of the heat sources described herein may also be equipped with conduits to supply additional components, bleed off fluids, and/or to control pressure.
FIG. 6 depicts a cross-sectional representation of an embodiment of a removable conductor-in-conduit heat source. Conduit 150 may be placed in opening 140 through overburden 138 such that a gap remains between the conduit and overburden casing 154. Fluids may be removed from opening 140 through the gap between conduit 150 and overburden casing 154. Fluids may be removed from the gap through conduit 160. Conduit 150 and components of the heat source included within the conduit that are coupled to wellhead 166 may be removed from opening 140 as a single unit. The heat source may be removed as a single unit to be repaired, replaced, and/or used in another portion of the formation.

In certain embodiments, portions of a conductor-in-conduit heat source may be moved or removed to adjust a portion of the formation that is heated by the heat source. For example, in a horizontal well the conductor-in-conduit heat source may be initially almost as long as the opening in the formation. As products are produced from the formation, the conductor-in-conduit heat source may be moved so that it is placed at location further from the end of the opening in the formation. Heat may be applied to a different portion of the formation by adjusting the location of the heat source. In certain embodiments, an end of the heater may be coupled to a sealing mechanism (e.g., a packing mechanism, or a plugging mechanism) to seal off perforations in a liner or casing. The sealing mechanism may inhibit undesired fluid production from portions of the heat source wellbore from which the conductor-in-conduit heat source has been removed.

FIG. 7 illustrates an embodiment of a conductor-in-conduit heater placed substantially horizontally within hydrocarbon layer 136. Heated section 192 may be placed substantially horizontally within hydrocarbon layer 136. Heater casing 186 may be placed within hydrocarbon layer 136. Heater casing 186 may be formed of a corrosion resistant, relatively rigid material (e.g., 304 stainless steel). Heater casing 186 may be coupled to overburden casing 154. Overburden casing 154 may include materials such as carbon steel. In an embodiment, overburden casing 154 and heater casing 186 have a diameter of about 15 cm. Expansion mechanism 194 may be placed at an end of heater casing 186 to accommodate thermal expansion of the conduit during heating and/or cooling.

To install heater casing 186 substantially horizontally within hydrocarbon layer 136, overburden casing 154 may bend from a vertical direction in overburden 138 to a horizontal direction within hydrocarbon layer 136. A curved wellbore may be formed during drilling of the wellbore in the formation. Heater casing 186 and overburden casing 154 may be installed in the curved wellbore. A radius of curvature of the curved wellbore may be determined by properties of drilling in the overburden and the formation. For example, the radius of curvature may be about 200 m from point 182 to point 196.

Conduit 150 may be placed within heater casing 186. In some embodiments, conduit 150 may be made of a corrosion resistant metal (e.g., 304 stainless steel). Conduit 150 may be heated to a high temperature. Conduit 150 may also be exposed to hot formation fluids. Conduit 150 may be treated to have a high emissivity. Conduit 150 may have upper section 178. In some embodiments, upper section 178 may be made of a less corrosion resistant metal than other portions of conduit 150 (e.g., carbon steel). A large portion of upper section 178 may be positioned in overburden 138 of the formation. Upper section 178 may not be exposed to temperatures as high as the temperatures of conduit 150. In an embodiment, conduit 150 and upper section 178 have a diameter of about 7.6 cm.

Conductor 142 may be placed in conduit 150. A portion of the conduit placed adjacent to conductor 142 may be made of a metal that has desired electrical properties, emissivity, creep resistance, and corrosion resistance at high temperatures. Conductor 142 may include, but is not limited to, 310 stainless steel, 304 stainless steel, 316 stainless steel, 347 stainless steel, and/or other steel or non-steel alloys. Conductor 142 may have a diameter of
about 3 cm, however, a diameter of conductor 142 may vary depending on, but not limited to, heating requirements and power requirements. Conductor 142 may be located in conduit 150 using one or more centralizers 144. Centralizers 144 may be ceramic or a combination of metal and ceramic. Centralizers 144 may inhibit conductor 142 from contacting conduit 150. In some embodiments, centralizers 144 may be coupled to conductor 142. In other embodiments, centralizers 144 may be coupled to conduit 150. Conductor 142 may be electrically coupled to conduit 150 using sliding connector 146.

Conductor 142 may be coupled to transition conductor 184. Transition conductor 184 may be used as an electrical transition between lead-in conductor 180 and conductor 142. In an embodiment, transition conductor 184 may be carbon steel. Transition conductor 184 may be coupled to lead-in conductor 180 with electrical connector 190. FIG. 8 illustrates an enlarged view of an embodiment of a junction of transition conductor 184, electrical connector 190, insulator 188, and lead-in conductor 180. Lead-in conductor 180 may include one or more conductors (e.g., three conductors). In certain embodiments, the one or more conductors may be insulated copper conductors (e.g., rubber-insulated copper cable). In some embodiments, the one or more conductors may be insulated or un-insulated stranded copper cable. As shown in FIG. 8, insulator 188 may be placed inside lead-in conductor 180. Insulator 188 may include electrically insulating materials such as fiberglass. Insulator 188 may couple electrical connector 190 to heater support 176 as depicted in FIG. 7. In an embodiment, electrical current may flow from a power supply through lead-in conductor 180, through transition conductor 184, into conductor 142, and return through conduit 150 and upper section 178.

Referring to FIG. 7, heater support 176 may include a support that is used to install heated section 192 in hydrocarbon layer 136. For example, heater support 176 may be a sucker rod that is inserted through overburden 138 from a ground surface. The sucker rod may include one or more portions that can be coupled to each other at the surface as the rod is inserted into the formation. In some embodiments, heater support 176 is a single piece assembled in an assembly facility. Inserting heater support 176 into the formation may push heated section 192 into the formation.

Overburden casing 154 may be supported within overburden 138 using reinforcing material 156. Reinforcing material may include cement (e.g., Portland cement). Surface conductor 158 may enclose reinforcing material 156 and overburden casing 154 in a portion of overburden 138 proximate the ground surface. Surface conductor 158 may include a surface casing.

FIG. 9 illustrates a schematic of an alternative embodiment of a conductor-in-conduit heater placed substantially horizontally within a formation. In an embodiment, heater support 176 may be a low resistance conductor (e.g., low resistance section 148 as shown in FIG. 3). Heater support 176 may include carbon steel or other electrically conducting materials. Heater support 176 may be electrically coupled to transition conductor 184 and conductor 142.

In some embodiments, a heat source may be placed within an uncased wellbore in a hydrocarbon containing formation. FIG. 10 illustrates a schematic of an embodiment of a conductor-in-conduit heater placed substantially horizontally within an uncased wellbore in a formation. Heated section 192 may be placed within opening 140 in hydrocarbon layer 136. In certain embodiments, heater support 176 may be a low resistance conductor (e.g., low resistance section 148 as shown in FIG. 3). Heater support 176 may be electrically coupled to transition conductor 184 and conductor 142. FIG. 11 depicts an alternative embodiment of the conductor-in-conduit
heater shown in FIG. 10. In certain embodiments, perforated casing 198 may be placed in opening 140 as shown in FIG. 11. In some embodiments, centralizers 144 may be used to support perforated casing 198 within opening 140.

In certain heat source embodiments, a cladding section may be coupled to heater support 176 and/or upper section 178. FIG. 12 depicts an embodiment of cladding section 200 coupled to heater support 176. Cladding may also be coupled to an upper section of conduit 150. Cladding section 200 may reduce the electrical resistance of heater support 176 and/or the upper section of conduit 150. In an embodiment, cladding section 200 is copper tubing coupled to the heater support and the conduit.

In other heat source embodiments, heated section 192, as shown in FIGS. 7 and 9-11, may be placed in a wellbore with an orientation other than substantially horizontally in hydrocarbon layer 136. For example, heated section 192 may be placed in hydrocarbon layer 136 at an angle of about 45° or substantially vertically in the formation. In addition, elements of the heat source placed in overburden 138 (e.g., heater support 176, overburden casing 154, upper section 178, etc.) may have an orientation other than substantially vertical within the overburden.

In certain heat source embodiments, the heat source may be removably installed in a formation. Heater support 176 may be used to install and/or remove the heat source, including heated section 192, from the formation. The heat source may be removed to repair, replace, and/or use the heat source in a different wellbore. The heat source may be reused in the same formation or in a different formation. In some embodiments, a heat source or a portion of a heat source may be spooled on a coiled tubing rig and moved to another well location.

FIG. 4 depicts a representation of an embodiment of centralizer 144 disposed on conductor 142. Discs 174 may maintain positions of centralizer 144 relative to conductor 142. Discs 174 may be metal discs welded to conductor 142. Discs 174 may be tack-welded to conductor 142. FIG. 5 depicts a top view representation of a centralizer embodiment. Centralizer 144 may be made of any suitable electrically insulating material able to withstand high voltage at high temperatures. Examples of such materials include, but are not limited to, aluminum oxide and/or Macor. Centralizer 144 may electrically insulate conductor 142 from conduit 150.

In an embodiment of a conductor-in-conduit heat source, a conduit may be pressurized with a fluid to inhibit a large pressure difference between pressure in the conduit and pressure in the formation. Balanced pressure or a small pressure difference may inhibit deformation of the conduit during use. The fluid may increase conductive heat transfer from the conductor to the conduit. The fluid may include, but is not limited to, a gas such as helium, nitrogen, air, or mixtures thereof. The fluid may inhibit arcing between the conductor and the conduit. If air and/or air mixtures are used to pressurize the conduit, the air and/or air mixtures may react with materials of the conductor and the conduit to form an oxide layer on a surface of the conductor and/or an oxide layer on an inner surface of the conduit. The oxide layer may inhibit arcing. The oxide layer may make the conductor and/or the conduit more resistant to corrosion.

Reducing the amount of heat losses to an overburden of a formation may increase an efficiency of a heat source. The efficiency of the heat source may be determined by the energy transferred into the formation through the heat source as a fraction of the energy input into the heat source. In other words, the efficiency of the heat source may be a function of energy that actually heats a desired portion of the formation divided by the electrical power (or other input power) provided to the heat source. To increase the amount of energy actually transferred to the formation, heat losses to the overburden may be reduced. Heat losses in the overburden may be reduced for electrical heat sources by the use of relatively low resistance conductors in the overburden that couple a power supply to the heat source. Alternating electrical current flowing through certain conductors (e.g., carbon steel
conductors) tends to flow along the skin of the conductors. This skin depth effect may increase the resistance heating at the outer surface of the conductor (i.e., the current flows through only a small portion of the available metal) and thus increase heating of the overburden. Electrically conductive casings, coatings, wiring, and/or claddings may be used to reduce the electrical resistance of a conductor used in the overburden. Reducing the electrical resistance of the conductor in the overburden may reduce electricity losses to heating the conduit in the overburden portion and thereby increase the available electricity for resistive heating in portions of the conductor below the overburden.

As shown in FIG. 3, low resistance section 148 may be coupled to conductor 142. Low resistance section 148 may be placed in overburden 138. Low resistance section 148 may be, for example, a carbon steel conductor. Carbon steel may be used to provide mechanical strength for the heat source in overburden 138. In an embodiment, an electrically conductive coating may be coated on low resistance section 148 to further reduce an electrical resistance of the low resistance section. In some embodiments, the electrically conductive coating may be coated on low resistance section 148 during assembly of the heat source. In other embodiments, the electrically conductive coating may be coated on low resistance section 148 after installation of the heat source in opening 140.

In some embodiments, the electrically conductive coating may be sprayed on low resistance section 148. For example, the electrically conductive coating may be sprayed on thermal plasma coating. The electrically conductive coating may include conductive materials such as, but not limited to, aluminum or copper. The electrically conductive coating may include other conductive materials that can be thermal plasma sprayed. In certain embodiments, the electrically conductive coating may be coated on low resistance section 148 such that the resistance of the low resistance conductor is reduced by a factor of greater than about 2. In some embodiments, the resistance is lowered by a factor of greater than about 4 or about 5. The electrically conductive coating may have a thickness of between about 0.1 mm and about 0.8 mm. In an embodiment, the electrically conductive coating may have a thickness of about 0.25 mm. The electrically conductive coating may be coated on low resistance conductors used with other types of heat sources such as, for example, insulated conductor heat sources, elongated member heat sources, etc.

In another embodiment, a cladding may be coupled to low resistance section 148 to reduce the electrical resistance in overburden 138. FIG. 13 depicts a cross-sectional view of a portion of cladding sections 200 of a conductor-in-conduit heater. Cladding section 200 may be coupled to the outer surface of low resistance section 148. Cladding section 200 may also be coupled to an inner surface of conduit 150. In certain embodiments, cladding sections may be coupled to an inner surface of low resistance section 148 and/or an outer surface of conduit 150. In some embodiments, low resistance section 148 may include one or more sections of individual low resistance sections 148 coupled together. Conduit 150 may include one or more sections of individual conduits 150 coupled together.

Individual cladding sections 200 may be coupled to each individual low resistance section 148 and/or conduit 150, as shown in FIG. 13. A gap may remain between each cladding section 200. The gap may be at a location of a coupling between low resistance sections 148 and/or conduits 150. For example, the gap may be at a thread or weld junction between low resistance sections 148 and/or conduits 150. The gap may be less than about 4 cm in length. In certain embodiments, the gap may be less than about 5 cm in length or less than about 6 cm in length. In some embodiments, there may be substantially no gap between cladding sections 200.

Cladding section 200 may be a conduit (or tubing) of relatively electrically conductive material. Cladding section 200 may be a conduit that fits tightly against a surface of low resistance section 148 and/or conduit 150.
Cladding section 200 may include non-ferromagnetic metals that have a relatively high electrical conductivity. For example, cladding section 200 may include copper, aluminum, brass, bronze, or combinations thereof. Cladding section 200 may have a thickness between about 0.2 cm and about 1 cm. In some embodiments, low resistance section 148 has an outside diameter of about 2.5 cm and conduit 150 has an inside diameter of about 7.3 cm. In an embodiment, cladding section 200 coupled to low resistance section 148 is copper tubing with a thickness of about 0.32 cm (about 1/8 inch) and an inside diameter of about 2.5 cm. In an embodiment, cladding section 200 coupled to conduit 150 is copper tubing with a thickness of about 0.32 cm (about 1/8 inch) and an outside diameter of about 7.3 cm. In certain embodiments, cladding section 200 has a thickness between about 0.20 cm and about 1.2 cm.

In certain embodiments, cladding section 200 is brazed to low resistance section 148 and/or conduit 150. In other embodiments, cladding section 200 may be welded to low resistance section 148 and/or conduit 150. In one embodiment, cladding section 200 is Everdur® (silicon bronze) welded to low resistance section 148 and/or conduit 150. Cladding section 200 may be brazed or welded to low resistance section 148 and/or conduit 150 depending on the types of materials used in the cladding section, the low resistance conductor, and the conduit. For example, cladding section 200 may include copper that is Everdur® welded to low resistance section 148, which includes carbon steel. In some embodiments, cladding section 200 may be pre-oxidized to inhibit corrosion of the cladding section during use.

Using cladding section 200 coupled to low resistance section 148 and/or conduit 150 may inhibit a significant temperature rise in the overburden of a formation during use of the heat source (i.e., reduce heat losses to the overburden). For example, using a copper cladding section of about 0.3 cm thickness may decrease the electrical resistance of a carbon steel low resistance conductor by a factor of about 20. The lowered resistance in the overburden section of the heat source may provide a relatively small temperature increase adjacent to the wellbore in the overburden of the formation. For example, supplying a current of about 500 A into an approximately 1.9 cm diameter low resistance conductor (schedule 40 carbon steel pipe) with a copper cladding of about 0.3 cm thickness produces a maximum temperature of about 93 °C at the low resistance conductor. This relatively low temperature in the low resistance conductor may transfer relatively little heat to the formation. For a fixed voltage at the power source, lowering the resistance of the low resistance conductor may increase the transfer of power into the heated section of the heat source (e.g., conductor 142 in heated section 192). For example, a 600 volt power supply may be used to supply power to a heat source through about a 300 m overburden and into about a 260 m heated section. This configuration may supply about 980 watts per meter to the heated section. Using a copper cladding section of about 0.3 cm thickness with a carbon steel low resistance conductor may increase the transfer of power into the heated section by up to about 15% compared to using the carbon steel low resistance conductor only.

In another embodiment, cladding section 200 may be arc welded to a conductor or conduit. For example, copper may be arc deposited and/or welded to a stainless steel pipe or tube.

In some embodiments, cladding section 200 may be formed with plasma powder welding (PPW). PPW formed material may be obtained from Daido Steel Co. (Japan). In PPW, copper powder is heated to form a plasma. The hot plasma may be moved along the length of a tube (e.g., a stainless steel tube) to deposit the copper and form the copper cladding.

In certain embodiments, forge welding (e.g., shielded active gas welding) may be used to form cladding section 200 on a low resistance section and/or conduit. Forge welding may be used to form a uniform weld through the cladding section and the low resistance section or conduit. In some embodiments, forge welding may be used to
couple portions of low resistance sections and/or conduits with cladding sections 200. FIG. 14 depicts an embodiment of portions of low resistance sections 148, conduits 150, and cladding sections 200 aligned for a forge welding process. Portions of low resistance sections 148 and/or conduits 150 with cladding sections 200 to be coupled may be held at a certain spacing before welding, as shown in FIG. 14. Spacers and/or robotic control may be used to maintain the certain spacing between the portions of low resistance sections and/or conduits. The portions of low resistance sections 148 and/or conduits 150 along with cladding sections 200 may be forge welded. Portions of cladding sections 200 may extend beyond the edges of portions of low resistance sections 148 or conduits 150 such that cladding sections 200 are joined together (or touch) before low resistance sections 148 or conduits 150 are joined. Touching the cladding sections first may ensure an electrical connection between each of the joined cladding sections. If the cladding sections are not joined first, the cladding sections may be disconnected by outward bulging of the low resistance sections or conduits as they are joined. The portions of low resistance sections 148, conduits 150, and/or cladding sections 200 to be joined may also have tapered profiles on each end of the portions. The tapered profiles may produce a more cylindrical profile at the weld joint after welding by allowing for thermal expansion of the ends of the welded portions during the welding process.

Another method is to start with strips of copper and carbon steel that are bonded together by tack welding or another suitable method. The composite strip is drawn through a shaping unit to form a cylindrically shaped tube. The cylindrically shaped tube is seam welded longitudinally. The resulting tube may be coiled onto a spool.

Another possible embodiment for reducing the electrical resistance of the conductor in the overburden is to form low resistance section 148 from low resistance metals (e.g., metals that are used in cladding section 200). A polymer coating may be placed on some of these metals to inhibit corrosion of the metals (e.g., to inhibit corrosion of copper or aluminum by hydrogen sulfide).

In some embodiments, a cladding section may be coupled to a conductor or a conduit within a heated section of a heat source (e.g., conductor 142 or conduit 150 in heated section 192 as shown in FIG. 7). The cladding section may be coupled to a conductor or a conduit in a heated section to reduce the cost of materials within the heated section. For example, the conductor and/or the conduit may be made of carbon steel while the cladding section is made of stainless steel. Since alternating electrical current flowing through certain conductors (e.g., steel conductors) tends to flow along the skin of the conductors, a majority of the electricity may propagate through the stainless steel cladding section. Heat may be generated by the electrical current flowing through the stainless steel cladding section, which has a higher electrical resistance. Carbon steel (which is typically cheaper than stainless steel) may be used to provide mechanical support for the stainless steel cladding sections.

In some embodiments, lead-in and lead-out conductors may be used to couple conductors and/or conduits to a power source. Lead-in and lead-out conductors may be less expensive than using coating and/or cladding of conductors or conduits in the overburden. Especially for relatively large overburden depths (e.g., overburdens greater than about 300 m in depth), lead-in and lead-out conductors may be more economically viable than using coating or cladding to reduce heat losses in the overburden. FIG. 15 depicts an embodiment of a conductor-in-conduit heat source with lead-in and lead-out conductors in the overburden. Conductor 142 may be coupled to heater support 176 with transition conductor 184 at or near the junction of overburden 138 and hydrocarbon layer 136. Seal 202 may be placed on conduit 150 at the junction of overburden 138 and hydrocarbon layer 136 to enclose conductor 142 within the conduit. Seal 202 may include electrically insulating material to inhibit electrical conduction between conduit 150 and conductor 142 through the seal.
Lead-in conductor 180 may be electrically coupled to conductor 142. Lead-in conductor 180 may be used to supply electrical power to conductor 142 from wellhead 166. In an embodiment, lead-in conductor 180 may be coupled to conductor 142 within conduit 150. A pressure seal may be used to allow lead-in conductor 180 to pass through seal 202. In one embodiment, lead-in conductor 180 is a copper cable.

Lead-out conductor 204 may be electrically coupled to conduit 150. Lead-out conductor 204 may return electrical power from conductor 142 and conduit 150 to wellhead 166. In an embodiment, lead-out conductor 204 is a copper cable. The electrical resistances of lead-in conductor 180 and lead-out conductor 204 may be relatively low to minimize heat losses in the overburden.

In a heat source embodiment, a conductor may be formed of sections of various metals that are welded or otherwise joined together. The cross-sectional area of the various metals may be selected to allow the resulting conductor to be long, to be creep resistant at high operating temperatures, and/or to dissipate desired amounts of heat per unit length along the entire length of the conductor. For example, a first section may be made of a creep resistant metal (such as, but not limited to, Inconel 617 or HR120), and a second section of the conductor may be made of 304 stainless steel. The creep resistant first section may help to support the second section. The cross-sectional area of the first section may be larger than the cross-sectional area of the second section. The larger cross-sectional area of the first section may allow for greater strength of the first section. Higher resistivity properties of the first section may allow the first section to dissipate the same amount of heat per unit length as the smaller cross-sectional area second section.

In some embodiments, the cross-sectional area and/or the metal used for a particular conduit section may be chosen so that a particular section provides greater (or lesser) heat dissipation per unit length than an adjacent section. More heat may be provided near an interface between a hydrocarbon layer and a non-hydrocarbon layer (e.g., the overburden and the hydrocarbon layer and/or an underburden and the hydrocarbon layer) to counteract end effects and allow for more uniform heat dissipation into the hydrocarbon containing formation.

In a heat source embodiment, a conduit may have a variable wall thickness. Wall thickness may be thickest adjacent to portions of the formation that do not need to be fully heated. Portions of a formation that do not need to be fully heated may include layers of the formation that have low grade, little, or no hydrocarbon material.

Heat may be generated by the conductor-in-conduit heater within an open wellbore. Generated heat may radiatively heat a portion of a hydrocarbon containing formation adjacent to the conductor-in-conduit heater. To a lesser extent, gas conduction adjacent to the conductor-in-conduit heater may heat a portion of the formation. Using an open wellbore completion may reduce casing and packing costs associated with filling the opening with a material to provide conductive heat transfer between the insulated conductor and the formation. In addition, heat transfer by radiation may be more efficient than heat transfer by conduction in a formation, so the heaters may be operated at lower temperatures using radiative heat transfer. Operating at a lower temperature may extend the life of the heat source and/or reduce the cost of material needed to form the heat source.

Subsurface pressure in a hydrocarbon containing formation may correspond to the fluid pressure generated within the formation. Heating hydrocarbons within a hydrocarbon containing formation may generate fluids by pyrolysis. The generated fluids may be vaporized within the formation. Vaporization and pyrolysis reactions may increase the pressure within the formation. Fluids that contribute to the increase in pressure may include, but are not limited to, fluids produced during pyrolysis and water vaporized during heating. As temperature within a selected section of a heated portion of the formation increases, a pressure within the selected section may increase.
as a result of increased fluid generation and vaporization of water. Controlling a rate of fluid removal from the formation may allow for control of pressure in the formation.

In some embodiments, pressure within a selected section of a heated portion of a hydrocarbon containing formation may vary depending on factors such as depth, distance from a heat source, a richness of the hydrocarbons within the hydrocarbon containing formation, and/or a distance from a producer well. Pressure within a formation may be determined at a number of different locations (e.g., near or at production wells, near or at heat sources, or at monitor wells).

Heating of a hydrocarbon containing formation to a pyrolysis temperature range may occur before substantial permeability has been generated within the hydrocarbon containing formation. An initial lack of permeability may inhibit the transport of generated fluids from a pyrolysis zone within the formation to a production well. As heat is initially transferred from a heat source to a hydrocarbon containing formation, a fluid pressure within the hydrocarbon containing formation may increase proximate a heat source. Such an increase in fluid pressure may be caused by generation of fluids during pyrolysis of at least some hydrocarbons in the formation. The increased fluid pressure may be released, monitored, altered, and/or controlled through the heat source. For example, the heat source may include a valve that allows for removal of some fluid from the formation. In some heat source embodiments, the heat source may include an open wellbore configuration that inhibits pressure damage to the heat source.

In an in situ conversion process embodiment, pressure may be increased within a selected section of a portion of a hydrocarbon containing formation to a selected pressure during pyrolysis. A selected pressure may be within a range from about 2 bars absolute to about 72 bars absolute or, in some embodiments, 2 bars absolute to 36 bars absolute. Alternatively, a selected pressure may be within a range from about 2 bars absolute to about 18 bars absolute. In some in situ conversion process embodiments, a majority of hydrocarbon fluids may be produced from a formation having a pressure within a range from about 2 bars absolute to about 18 bars absolute. The pressure during pyrolysis may vary or be varied. The pressure may be varied to alter and/or control a composition of a formation fluid produced, to control a percentage of condensable fluid as compared to non-condensable fluid, and/or to control an API gravity of fluid being produced. For example, decreasing pressure may result in production of a larger condensable fluid component. The condensable fluid component may contain a larger percentage of olefins.

In some in situ conversion process embodiments, increased pressure due to fluid generation may be maintained within a heated portion of a formation. Maintaining increased pressure within a formation may inhibit formation subsidence during in situ conversion. Increased formation pressure may promote generation of high quality products during pyrolysis. Increased formation pressure may facilitate vapor phase production of fluids from the formation. Vapor phase production may allow for a reduction in size of collection conduits used to transport fluids produced from the formation. Increased formation pressure may reduce or eliminate the need to compress formation fluids at the surface to transport the fluids in collection conduits to surface facilities. Maintaining increased pressure within a formation may also facilitate generation of electricity from produced non-condensable fluid. For example, the produced non-condensable fluid may be passed through a turbine to generate electricity.

Increased pressure in the formation may also be maintained to produce more and/or improved formation fluids. In certain in situ conversion process embodiments, significant amounts (e.g., a majority) of the hydrocarbon fluids produced from a formation may be non-condensable hydrocarbons. Pressure may be selectively increased
and/or maintained within the formation to promote formation of smaller chain hydrocarbons in the formation. Producing small chain hydrocarbons in the formation may allow more non-condensable hydrocarbons to be produced from the formation. The condensable hydrocarbons produced from the formation at higher pressure may be of a higher quality (e.g., higher API gravity) than condensable hydrocarbons produced from the formation at a lower pressure.

A high pressure may be maintained within a heated portion of a hydrocarbon containing formation to inhibit production of formation fluids having carbon numbers greater than, for example, about 25. Some high carbon number compounds may be entrained in vapor in the formation and may be removed from the formation with the vapor. A high pressure in the formation may inhibit entrainment of high carbon number compounds and/or multi-ring hydrocarbon compounds in the vapor. Increasing pressure within the hydrocarbon containing formation may increase a boiling point of a fluid within the portion. High carbon number compounds and/or multi-ring hydrocarbon compounds may remain in a liquid phase in the formation for significant time periods. The significant time periods may provide sufficient time for the compounds to pyrolyze to form lower carbon number compounds.

Maintaining increased pressure within a heated portion of the formation may surprisingly allow for production of large quantities of hydrocarbons of increased quality. Maintaining increased pressure may promote vapor phase transport of pyrolyzation fluids within the formation. Increasing the pressure often permits production of lower molecular weight hydrocarbons since such lower molecular weight hydrocarbons will more readily transport in the vapor phase in the formation.

Generation of lower molecular weight hydrocarbons (and corresponding increased vapor phase transport) is believed to be due, in part, to autogenous generation and reaction of hydrogen within a portion of the hydrocarbon containing formation. For example, maintaining an increased pressure may force hydrogen generated during pyrolysis into a liquid phase (e.g., by dissolving). Heating the portion to a temperature within a pyrolysis temperature range may pyrolyze hydrocarbons within the formation to generate pyrolyzation fluids in a liquid phase. The generated components may include double bonds and/or radicals. H₂ in the liquid phase may reduce double bonds of the generated pyrolyzation fluids, thereby reducing a potential for polymerization or formation of long chain compounds from the generated pyrolyzation fluids. In addition, hydrogen may also neutralize radicals in the generated pyrolyzation fluids. Therefore, H₂ in the liquid phase may inhibit the generated pyrolyzation fluids from reacting with each other and/or with other compounds in the formation. Shorter chain hydrocarbons may enter the vapor phase and may be produced from the formation.

Operating an in situ conversion process at increased pressure may allow for vapor phase production of formation fluid from the formation. Vapor phase production may permit increased recovery of lighter (and relatively high quality) pyrolyzation fluids. Vapor phase production may result in less formation fluid being left in the formation after the fluid is produced by pyrolysis. Vapor phase production may allow for fewer production wells in the formation than are present using liquid phase or liquid/vapor phase production. Fewer production wells may significantly reduce equipment costs associated with an in situ conversion process.

In an embodiment, a portion of a hydrocarbon containing formation may be heated to increase a partial pressure of H₂. In some embodiments, an increased H₂ partial pressure may include H₂ partial pressures in a range from about 0.5 bars to about 7 bars. Alternatively, an increased H₂ partial pressure range may include H₂ 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 H₂ partial pressure is within a range of about 5 bars to about 7 bars. A range of H₂ partial
pressures within the pyrolysis H₂ partial pressure range may vary depending on, for example, temperature and pressure of the heated portion of the formation.

Maintaining a H₂ partial pressure within the formation of greater than atmospheric pressure may increase an API value of produced condensable hydrocarbon fluids. Maintaining an increased H₂ 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 H₂ partial pressure within a heated portion of a hydrocarbon containing formation may increase a concentration of H₂ within the heated portion. The H₂ may be available to react with pyrolyzed components of the hydrocarbons. Reaction of H₂ 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.

Controlling pressure and temperature within a hydrocarbon containing formation may allow properties of the produced formation fluids to be controlled. For example, composition and quality of formation fluids produced from the formation may be altered by altering an average pressure and/or an average temperature in a selected section of a heated portion of the formation. The quality of the produced fluids may be evaluated based on characteristics of the fluid such as, but not limited to, API gravity, percent olefins in the produced formation fluids, ethene to ethane ratio, atomic hydrogen to carbon ratio, percent of hydrocarbons within produced formation fluids having carbon numbers greater than 25, total equivalent production (gas and liquid), total liquids production, and/or liquid yield as a percent of Fischer Assay.

Further modifications and alternative embodiments of various aspects of the invention may be apparent to 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 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. In addition, it is to be understood that features described herein independently may, in certain embodiments, be combined.
WHAT IS CLAIMED IS:

1. A system configurable to heat a hydrocarbon containing formation, comprising:
   a conductor configurable to be placed within a conduit in the formation or an opening in the formation, wherein the conductor is further configurable to provide heat to at least a part of the formation during use;
   a first electrically conductive material configurable to be coupled to at least a portion of the conductor, wherein the first electrically conductive material is configurable to lower an electrical resistance of at least part of the conductor when such conductor is in formation overburden during use; and
   wherein the system is configurable to allow heat to transfer from the conductor to at least a part of the formation during use.

2. The system of claim 1, wherein the conductor is configured to be placed in a conduit, and the conduit is configurable to be placed in an opening in the formation.

3. The system of claim 2, further comprising a second electrically conductive material configurable to be coupled to at least a portion of an inside surface of the conduit.

4. The system of any of claims 1-3, further comprising a low resistance conductor configurable to be electrically coupled to the conductor during use, wherein the substantially low resistance conductor is further configurable to be placed within the formation overburden.

5. The system of claim 4, wherein the low resistance conductor comprises carbon steel.

6. The system of any of claims 1-5, wherein the electrically conductive material comprises metal tubing or strips configurable to be clad, in whole or in part, to the conductor, an electrically conductive coating configurable to be sprayed or otherwise applied to the conductor, and/or a thermal plasma applied coating.

7. The system of any of claims 1-6, wherein the electrically conductive material comprises aluminum and/or copper.

8. The system of any of claims 1-7, wherein the electrically conductive material is configurable to reduce the electrical resistance of the conductor in the overburden by a factor of greater than about 3, or by a factor greater than about 10, or by a factor greater than about 15.

9. The system of any of claims 1-8, wherein the system is further configurable to pyrolyze at least some hydrocarbons in the heated section of the formation during use.

10. The system of any of claims 1-9, wherein the system is configured to heat a hydrocarbon containing formation, and wherein the system comprises:
   a conduit configured to be placed within an opening in the formation;
   a conductor configured to be placed within a conduit, wherein the conductor is further configured to provide heat to at least a portion of the formation during use;
an electrically conductive material configured to be coupled to the conductor, wherein the electrically conductive material is further configured to lower an electrical resistance of the conductor in the overburden during use; and
wherein the system is configured to allow heat to transfer from the conductor to a section of the formation during use.

11. The system of any of claims 1-9, wherein the system heats a hydrocarbon containing formation, and wherein the system comprises:
   a conduit placed within an opening in the formation;
   a conductor placed within a conduit, wherein the conductor provides heat to at least a portion of the formation during use;
   an electrically conductive material coupled to the conductor, wherein the electrically conductive material lowers an electrical resistance of the conductor in the overburden during use; and
   wherein the system allows heat to transfer from the conductor to a section of the formation during use.

12. An in situ method for heating a hydrocarbon containing formation using the system of any of claims 1-11, comprising:
   applying an electrical current to the conductor to provide heat to at least a portion of the formation; and
   allowing the heat to transfer from the conductor to a part of the formation.

13. The method of claim 12, further comprising pyrolyzing at least some hydrocarbons within the formation.

14. The method of any of claims 12-13, further comprising controlling a pressure and a temperature within at least a majority of the part of the formation, wherein the pressure is controlled as a function of temperature, and/or the temperature is controlled as a function of pressure.

15. The method of any of claims 12-14, further comprising producing a mixture from the formation, wherein the produced mixture comprises condensable hydrocarbons having an API gravity of at least about 25°.

16. The method of any of claims 12-15, further comprising controlling a pressure within at least a majority of the part of the formation, wherein the controlled pressure is at least about 2.0 bars absolute.

17. The method of any of claims 12-16, further comprising controlling formation conditions such that a produced mixture comprises a partial pressure of H₂ within the mixture greater than about 0.5 bars.

18. The method of any of claims 12-17, further comprising altering a pressure within the formation to inhibit production of hydrocarbons from the formation having carbon numbers greater than about 25.

19. The method of any of claims 12-18, wherein at least a portion of the part of the formation is heated to a minimum pyrolysis temperature of about 270 °C.
FIG. 8
**INTERNATIONAL SEARCH REPORT**

**ASSIFICATION OF SUBJECT MATTER**

7 E21B43/24

The following may be International Patent Classification (IPC) or to both national classification and IPC.

**FIELDS SEARCHED**

C 7 E21B

**DOCUMENTATION SEARCHED OTHER THAN MINIMUM DOCUMENTATION TO THE EXTENT THAT SUCH DOCUMENTS ARE INCLUDED IN THE FIELDS SEARCHED**

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**Date of the actual completion of the international search**

5 February 2003

**Date of mailing of the international search report**

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