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(54) **Title:** SYSTEMS AND METHODS FOR DECREASING COMPACTION WITHIN A PYROLYZED ZONE

(57) **Abstract:** Systems and methods for decreasing compaction within a pyrolyzed zone are disclosed herein. The methods include injecting a sealing fluid into the pyrolyzed zone and flowing the sealing fluid to a peripheral region of the pyrolyzed zone. The methods further include fluidly sealing the peripheral region of the pyrolyzed zone with a sealing fluid where fluidly sealing limits a fluid leakage from the pyrolyzed zone. Subsequent to the fluidly sealing, the methods further include pressurizing the pyrolyzed zone to a zone pressure. The systems include hydrocarbon production systems and/or components thereof that are formed using the methods.



SYSTEMS AND METHODS FOR DECREASING COMPACTION WITHIN A PYROLYZED ZONE

Cross-Reference To Related Application

[0001] This application claims the priority benefit of U.S. Provisional Patent Application 61/840,297 filed 27 June 2013 entitled SYSTEMS AND METHODS FOR DECREASING COMPACTION WITHIN A PYROLYZED ZONE, the entirety of which is incorporated by reference herein.

Field of the Disclosure

[0002] The present disclosure is directed generally to systems and methods for decreasing compaction within a pyrolyzed zone of a subterranean formation, and more particularly to systems and methods that fluidly seal the pyrolyzed zone with a sealing fluid and subsequently pressurize the pyrolyzed zone to decrease compaction within the pyrolyzed zone.

Background

[0003] Certain subterranean formations may include organic compounds, such as shale oil and/or kerogen, that may not flow within the reservoir at a rate that is sufficient for production thereof, that may not define desired material properties, and/or that may not define desired chemical compositions. Thus, these organic compounds may be heated *in situ* to generate more desired hydrocarbon fluids that may more readily be produced from the subterranean formation. This heating process also may be referred to herein as *in situ* pyrolysis and/or simply as pyrolysis. The heating decomposes the organic compounds and also may decompose and/or vaporize evaporite minerals that may be present within the subterranean formation. This decomposition and/or subsequent production of the hydrocarbon fluid from the subterranean formation reduces a volume of the materials that comprise (and/or are present in) the subterranean formation. As an illustrative, non-exclusive example, complete pyrolysis of oil shale that includes 35 gallons of shale oil per ton of oil shale and subsequent producing of the shale oil from the subterranean formation may decrease the volume of oil shale by 22%.

[0004] This volume decrease may permit and/or produce settling within the subterranean formation. This settling may decrease a porosity of the subterranean formation, thereby

decreasing a production rate of the hydrocarbon fluids from the subterranean formation. Additionally or alternatively, this settling also may propagate to a surface region that is associated with the subterranean formation, thereby producing subsidence of the surface region and/or changes in surface topography.

5 [0005] Historically, this compaction and/or subsidence have been mitigated by leaving regions of the subterranean formation unpyrolyzed. These unpyrolyzed regions also may be referred to herein as cold pillars and may support the overlying strata and decrease compaction within the pyrolyzed zone. However, these cold pillars decrease overall hydrocarbon recovery from the subterranean formation and/or may not be effective in all
10 subterranean formations. Thus, there exists a need for improved systems and methods for decreasing compaction within a pyrolyzed zone.

Summary

[0006] Systems and methods for decreasing compaction within a pyrolyzed zone are disclosed herein. The methods include injecting a sealing fluid into the pyrolyzed zone and
15 flowing the sealing fluid to a peripheral region of the pyrolyzed zone. The methods further include fluidly sealing the peripheral region of the pyrolyzed zone with a sealing fluid to limit a fluid leakage from the pyrolyzed zone. Subsequent to the fluidly sealing, the methods further include pressurizing the pyrolyzed zone to a zone pressure.

[0007] The methods may include sweeping at least a portion of a hydrocarbon fluid that
20 may be present within the pyrolyzed zone from the pyrolyzed zone. The fluidly sweeping may include injecting a sweep fluid into the pyrolyzed zone and flowing the sweep fluid to the peripheral region to sweep the pyrolyzed zone. The sweep fluid may be the sealing fluid. The sweep fluid may be different from the sealing fluid.

[0008] The zone pressure may be greater than a hydrostatic pressure that was present
25 within a portion of the subterranean formation that defines the pyrolyzed zone prior to formation of the pyrolyzed zone. The zone pressure may be less than a lithostatic pressure that was present within the portion of the subterranean formation. The zone pressure may be closer to the lithostatic pressure than to the hydrostatic pressure.

[0009] The pressurizing may include pressurizing with the sealing fluid. The
30 pressurizing may include pressurizing with a pressurizing fluid that is different from the sealing fluid. The sealing fluid may be a solidification- initiating material that is selected to solidify the sealing fluid within the peripheral region of the pyrolyzed zone.

[0010] The methods may include pyrolyzing a portion of the subterranean formation to generate the pyrolyzed zone. The methods may include repressurizing the pyrolyzed zone. The repressurizing may be based upon and/or responsive to a status of the pyrolyzed zone.

[0011] The systems include hydrocarbon production sites and/or components thereof that are formed using the methods. The hydrocarbon production site includes a pyrolyzed zone that is present within a subterranean formation and defines an interior region and a peripheral region that surrounds the interior region. The hydrocarbon production site further includes an injection well that extends between a surface region and the interior region and a sealing material that is present within the peripheral region. The sealing material forms a fluid seal between the interior region and a remainder of the subterranean formation. The hydrocarbon production site further includes a pressurizing fluid that is present within the interior region.

Brief Description of the Drawings

[0012] Fig. 1 is a schematic representation of illustrative, non-exclusive examples of a hydrocarbon production site that may include and/or be utilized with the systems and methods according to the present disclosure.

[0013] Fig. 2 is a schematic representation of illustrative, non-exclusive examples of a pyrolyzed zone that may be associated with an injection well and one or more production wells, and which may be utilized with the systems and methods according to the present disclosure.

[0014] Fig. 3 is a flowchart depicting methods according to the present disclosure of decreasing compaction within a pyrolyzed zone of a subterranean formation.

Detailed Description and Best Mode of the Disclosure

[0015] Figs. 1-2 provide illustrative, non-exclusive examples of hydrocarbon production sites according to the present disclosure, components thereof, and/or process flows that may be utilized therewith. Elements that serve a similar, or at least substantially similar, purpose are labeled with like numbers in each of Figs. 1-2, and these elements may not be discussed in detail herein with reference to each of Figs. 1-2. Similarly, all elements may not be labeled in each of Figs. 1-2, but reference numerals associated therewith may be utilized herein for consistency. Elements, components, and/or features that are discussed herein with reference to one or more of Figs. 1-2 may be included in and/or utilized with any of Figs. 1-2 without departing from the scope of the present disclosure.

[0016] In general, elements that are likely to be included are illustrated in solid lines, while elements that are optional are illustrated in dashed lines. However, elements that are shown in solid lines may not be essential. An element shown in solid lines may be omitted without departing from the scope of the present disclosure.

5 [0017] Fig. 1 is a schematic representation of illustrative, non-exclusive examples of a hydrocarbon production site 10 that may include and/or be utilized with the systems and methods according to the present disclosure. Hydrocarbon production site 10 includes an injection well 40. The injection well 40 may extend between a surface region 20 and a subterranean formation 32 that is present within a subsurface region 30. Subterranean
10 formation 32 includes an organic compound 34 and a pyrolyzed zone 60, which defines an interior region 70 and a peripheral region 80. Injection well 40 extends to and/or within interior region 70. Injection well 40 may be (relatively) proximal to and/or in direct fluid communication with the peripheral region 80. Peripheral region 80 extends around and/or surrounds interior region 70, is (relatively) distal from and/or spaced apart from injection well
15 40, and/or is in indirect fluid communication with injection well 40 via interior region 70.

[0018] Peripheral region 80 includes a sealing material 82. The sealing material 82 may form a fluid seal between interior region 70 and a remainder of subterranean formation 32 and/or subsurface region 30. Sealing material 82 is located within a pore space 86. Pore space 86 is defined by a formation material 84 that is present within peripheral region 80.
20 Pore space 86 defines, or has, a chemical composition that is different from a chemical composition of formation material 84.

[0019] Pyrolyzed zone 60 may include an interior region 70 and a peripheral region 80. Interior region 70 may be proximal to and/or in direct fluid communication with injection well 40. Peripheral region 80 may surround interior region 70 and/or be in indirect fluid
25 communication with injection well 40 via interior region 70. Interior region 70 may include any suitable portion, or fraction, of pyrolyzed zone 60 that does not form a boundary and/or interface between the pyrolyzed zone and a remainder of the subterranean formation. Interior region 70 also may be referred to as, may include, and/or may be an interior portion 70 of pyrolyzed zone 60, an internal region 70 of pyrolyzed zone 60, and/or as a central region, or
30 portion, 70 of pyrolyzed zone 60.

[0020] Peripheral region 80 may include any suitable portion, or fraction, of pyrolyzed zone 60 that (at least partially or completely) surrounds interior region 70 and/or forms (or includes) at least a portion (or all) of the boundary and/or interface between the pyrolyzed zone and the remainder of the subterranean formation. Peripheral region 80 may be referred to as, may include, and/or may be a boundary region, or portion, 80 of pyrolyzed zone 60, an interfacial region, or portion, 80 of pyrolyzed zone 60, an outer surface, or portion, 80 of pyrolyzed zone 60, and/or a sealing portion, or region, 80 of pyrolyzed zone 60.

[0021] Interior region 70 may define any suitable portion of a total volume of pyrolyzed zone 60. As illustrative, non-exclusive examples, interior region 70 may define at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, at least 90%, at least 95%, or at least 99% of the total volume of pyrolyzed zone 60, with peripheral region 80 defining a remainder of the total volume of pyrolyzed zone 60. Additionally or alternatively, interior region 70 also may define less than 100%, less than 99%, less than 95%, less than 90%, less than 85%, or less than 80% of the total volume of pyrolyzed zone 60, with peripheral region 80 defining a remainder of the total volume of pyrolyzed zone 60.

[0022] As illustrated in dashed lines in Fig. 1, hydrocarbon production site 10 may include a pressurizing fluid 72. Pressurizing fluid 72 may be present within interior region 70. Pressurizing fluid 72 may be utilized to pressurize interior region 70, such as to decrease and/or prevent compaction within pyrolyzed zone 60 and/or to decrease and/or prevent subsidence of a ground surface 22 that is supported by pyrolyzed zone 60.

[0023] As also illustrated in dashed lines in Fig. 1, hydrocarbon production site 10 may include one or more production wells 50. Production wells 50 may extend between surface region 20 and subterranean formation 32, pyrolyzed zone 60, and/or peripheral region 80. Production wells 50 may permit production of a hydrocarbon fluid from pyrolyzed zone 60 prior to sealing material 82 being located within peripheral region 80.

[0024] Fig. 1 illustrates that subterranean formation 32 may include a plurality of pyrolyzed zones 60 that may be spaced apart from one another, such as via one or more support pillars 62. Support pillars 62 may prevent compaction of pyrolyzed zones 60 and/or subsidence of ground surface 22. However, the hydrocarbon production sites 10 may include fewer support pillars 62 than traditional hydrocarbon production sites that do not include sealing material 82 and/or pressurizing fluid 72 within pyrolyzed zone 60. Alternatively,

the pyrolyzed zones 60 may not be spaced apart from one another and/or the subterranean formation 32 may not include support pillars 62.

[0025] Fig. 2 is a schematic representation of illustrative, non-exclusive examples of a pyrolyzed zone 60 that may be associated with an injection well 40 and one or more production wells 50 and which may be utilized with the systems and methods according to the present disclosure. As discussed in more detail herein with reference to methods 100, pyrolyzed zone 60 may be formed within subterranean formation 32 by heating the subterranean formation and/or by performing an *in situ* combustion reaction therein. This heating may decompose organic compounds 34 that may be present within the subterranean formation to generate a hydrocarbon fluid 36.

[0026] Often, the heating may be performed near and/or proximal to injection well 40, and the generated hydrocarbon fluid 36 may flow to production wells 50 and then may be produced from the subterranean formation. As discussed, heating of subterranean formation 32 to generate hydrocarbon fluid 36 may decrease a volume of formation material 84 and/or may generate (additional) pore space 86 within the pyrolyzed zone. While this volume decrease and/or additional pore space initially may be beneficial to production of hydrocarbon fluid 36 from the subterranean formation, such as by increasing a fluid permeability of the subterranean formation, the volume decrease and/or additional pore space also may increase a potential for compaction within pyrolyzed zone 60 and/or for subsidence of a ground surface that is supported thereby.

[0027] With this in mind, and as discussed, the systems and methods disclosed herein may be utilized to reduce, decrease a potential for, and/or eliminate compaction within pyrolyzed zone 60 and/or subsidence of the ground surface that is supported by the pyrolyzed zone through generation of sealing material 82 within peripheral region 80 and subsequent pressurization of interior region 70 with pressurizing fluid 72 (as illustrated in Fig. 1). As an illustrative, non-exclusive example, and with reference to Fig. 2, the systems and methods may include producing hydrocarbon fluid 36 from pyrolyzed zone 60 through production wells 50. Subsequently, a sweep fluid 87 optionally may be injected into the pyrolyzed zone, such as into interior region 70, through injection well 40. The sweep fluid may flow through pyrolyzed zone 60 toward peripheral region 80, sweeping, or displacing, hydrocarbon fluid 36 from the pyrolyzed zone, as illustrated in dash-dot lines in Fig. 2 at 90 and 92.

[0028] A sealing fluid 88, which may be a liquid sealing fluid, then may be injected into the pyrolyzed zone, such as into and/or through interior region 70, through injection well 40. Similar to sweep fluid 87, the sealing fluid may flow through pyrolyzed zone 60 toward peripheral region 80. Subsequent to reaching peripheral region 80, and as illustrated in Fig. 1, sealing fluid 88 may transition to, become, and/or be referred to herein as sealing material 82 and may form the fluid seal between interior region 70 and the remainder of subterranean formation 32. Sweep fluid 87, when present and/or utilized, may be different from, or formed from a different material than, sealing fluid 88. However, sealing fluid 88 may function as and/or may be sweep fluid 87.

[0029] As illustrated in Fig. 2, pressurizing fluid 72 then may be injected into interior region 70 through injection well 40. The pressurizing fluid may increase a pressure within, or pressurize, pyrolyzed zone 60 to a zone pressure that is sufficient to prevent compaction of the pyrolyzed zone and/or subsidence of the ground surface that is supported thereby.

[0030] Fig. 1 illustrates hydrocarbon production site 10 as including a single injection well 40 and as optionally including two production wells 50, while Fig. 2 illustrates hydrocarbon production site 10 as including a single injection well and two production wells that may be in fluid communication with pyrolyzed zone 60. Hydrocarbon production site 10 may include any suitable number of injection wells 40 and/or production wells 50. Additionally or alternatively, a single well may function as both an injection well and a production well and/or a single well initially may be utilized as one of an injection well and a production well and subsequently may be utilized as the other of the injection well and the production well.

[0031] Sweep fluid 87 may include and/or be any suitable fluid that may displace hydrocarbon fluid 36 from pyrolyzed zone 60, entrain hydrocarbon fluid 36 therewithin, and/or sweep hydrocarbon fluid 36 from the pyrolyzed zone. As illustrative, non-exclusive examples, sweep fluid 87 may include and/or be any suitable liquid and/or gaseous sweep fluid. As additional illustrative, non-exclusive examples, sweep fluid 87 may include and/or be a solvent for hydrocarbon fluid 36, a diluent for hydrocarbon fluid 36, and/or a fluid that forms a lower interfacial energy with formation material 84 than an interfacial energy between hydrocarbon fluid 36 and formation material 84.

[0032] Sealing material 82 may include any suitable structure and/or chemical composition. Sealing material 82 may be located within pyrolyzed zone 60 (and/or peripheral region 80 thereof) in any suitable manner to at least partially fluidly isolate interior region 70 from the remainder of subterranean formation 32. As an illustrative, non-exclusive example, sealing material 82 initially may be sealing fluid 88 that is injected into pyrolyzed zone 60 via injection well 40 and flows from injection well 40, through interior region 70, and into peripheral region 80. Upon reaching peripheral region 80, sealing fluid 88 may transition to, become, and/or be referred to herein as sealing material 82 and may form the fluid seal between interior region 70 and the remainder of subterranean formation 32.

[0033] Illustrative, non-exclusive examples of sealing material 82 and/or sealing fluid 88 include any suitable viscous fluid, fluid with a highly temperature-dependent viscosity, shear thinning fluid, a polymeric material, a concentrated polymeric material, a polymeric fluid, a polymeric solid, a polymer solution (which may include the polymeric material distributed, dissolved, and/or suspended within a carrier fluid), a colloid, and/or a (solid) particulate material. More specific but still illustrative, non-exclusive examples of sealing material 82 and/or sealing fluid 88 include an aqueous material, a non-aqueous material, polybutene, polysiloxane, polystyrene, concentrated polystyrene, bitumen, molten bitumen, clay particles, silica, colloidal silica, a water-clay slurry, sulfur, and/or molten sulfur.

[0034] As illustrative, non-exclusive examples, sealing fluid 88 may be selected to increase in viscosity within peripheral region 80 to form sealing material 82 and/or the fluid seal. As another illustrative, non-exclusive example, sealing fluid 88 may be selected to solidify within peripheral region 80 to form sealing material 82 and/or the fluid seal. As yet another illustrative, non-exclusive example, particulate material within sealing fluid 88 may clog, occlude, and/or block pore space 86 within peripheral region 80, thereby forming sealing material 82 and/or the fluid seal.

[0035] Pressurizing fluid 72, when present, may include any suitable fluid (such as a gas and/or a liquid) that may be selected to pressurize interior region 70. As an illustrative, non-exclusive example, pressurizing fluid 72 may include and/or be sealing material 82 and/or sealing fluid 88. As another illustrative, non-exclusive example, pressurizing fluid 72 may be different from sealing material 82 and/or sealing fluid 88 and/or may define, or have, a different chemical composition than sealing material 82 and/or sealing fluid 88. Illustrative,

non-exclusive examples of pressurizing fluids 72 include a liquid, a gas, carbon dioxide, water, and/or a brine.

[0036] Pressurizing fluid 72 may not be reactive within pyrolyzed zone 60, may not react with sealing material 82 and/or sealing fluid 88, and/or may be selected to be (at least substantially) inert. However, pressurizing fluid 72 may be selected to react, or be reactive, within pyrolyzed zone 60. As an illustrative, non-exclusive example, pressurizing fluid 72 may be selected to react with sealing fluid 88 and/or to initiate formation of the fluid seal subsequent to, or upon, contact with the sealing fluid. As a more specific but still illustrative, non-exclusive example, pressurizing fluid 72 may include and/or be a solidification-initiating material that is selected to solidify sealing fluid 88 within the peripheral region, such as by initiating polymerization of the sealing fluid within the peripheral region.

[0037] Pressurizing fluid 72 may be utilized to pressurize pyrolyzed zone 60 to a zone pressure. The zone pressure may be greater than a hydrostatic pressure that was present within a region of subterranean formation 32 that defines pyrolyzed zone 60 prior to formation of pyrolyzed zone 60 within the subterranean formation 32. Additionally or alternatively, pressurizing fluid 72 also may be utilized to pressurize pyrolyzed zone 60 to a zone pressure that is less than a lithostatic pressure within the region of the subterranean formation prior to formation of the pyrolyzed zone therein. This may include pressurizing to a zone pressure that is at least 50%, at least 60%, at least 70%, at least 75%, at least 80%, at least 85%, at least 90%, at least 92.5%, at least 95%, at least 96%, at least 97%, at least 98%, or at least 99% of the lithostatic pressure but still less than the lithostatic pressure and/or pressurizing to a zone pressure that is closer to the lithostatic pressure than to the hydrostatic pressure.

[0038] As used herein, the phrase “hydrostatic pressure” refers to a pressure that may be generated by a fluid column that is located vertically above a given point within the subterranean formation (i.e., a pressure that is due to the weight of the fluid). As used herein, the phrase “lithostatic pressure” refers to a pressure that may be generated by an overlying rock that is located vertically above the given point (i.e., a pressure that is due to the weight of the rock). Generally, the overlying rock has a greater density than the fluid column. Thus, the lithostatic pressure is generally greater than the hydrostatic pressure at the given point within the subterranean formation.

[0039] Subterranean formation 32 may include any suitable structure and/or material that includes organic compound 34 that may be pyrolyzed to produce hydrocarbon fluid 36 and pyrolyzed zone 60. As illustrative, non-exclusive examples, subterranean formation 32 may include and/or be a hydrocarbon containing formation, a kerogen containing formation, and/or an oil shale formation.

[0040] Fig. 3 is a flowchart depicting methods 100 according to the present disclosure of decreasing compaction within a pyrolyzed zone of a subterranean formation. Methods 100 may include pyrolyzing the subterranean formation at 105 to generate the pyrolyzed zone, producing a hydrocarbon fluid from the pyrolyzed zone at 110, cooling the pyrolyzed zone at 115, and/or sweeping the pyrolyzed zone at 120. Methods 100 include injecting a sealing fluid into an interior region of the pyrolyzed zone at 125 and flowing the sealing fluid from the interior region to a peripheral region of the pyrolyzed zone at 130 and may include producing the sealing fluid from the pyrolyzed zone at 135. Methods 100 may include fluidly sealing the peripheral region of the pyrolyzed zone at 140. Methods may include pressurizing the pyrolyzed zone at 145, determining a status of the pyrolyzed zone at 150, and/or repressurizing the pyrolyzed zone at 155.

[0041] Pyrolyzing the subterranean formation at 105 to generate the pyrolyzed zone may include pyrolyzing any suitable portion of the subterranean formation to produce, or generate, the pyrolyzed zone. This may include heating the subterranean formation, such as via *in situ* combustion within the subterranean formation and/or via steam injection into the subterranean formation. Additionally or alternatively, the pyrolyzing at 105 also may include heating with a heating structure, such as an electric heater, a combustion heater, and/or a granular resistive heater.

[0042] The heating may be performed within a heated region of the pyrolyzed zone, which may include at least a portion of the interior region of the pyrolyzed zone, and the heated zone may be heated to at least a threshold zone temperature. Illustrative, non-exclusive examples of the threshold zone temperature include threshold zone temperatures of at least 400 °C, at least 425 °C, at least 450 °C, at least 475 °C, at least 500 °C, at least 525 °C, at least 550 °C, at least 575 °C, at least 600 °C, at least 625 °C, or at least 650 °C.

[0043] In addition, the heating further may include heating a remainder of the pyrolyzed zone to at least a threshold pyrolysis temperature, with this heating being accomplished by

conduction and/or convection from the heated zone. Illustrative, non-exclusive examples of the threshold pyrolysis temperature include temperatures of at least 200 °C, at least 210 °C, at least 220 °C, at least 230 °C, at least 240 °C, at least 250 °C, at least 260 °C, at least 270 °C, at least 280 °C, at least 290 °C, at least 300 °C, at least 310 °C, at least 320 °C, at least 325 °C, at least 330 °C, at least 340 °C, or at least 350 °C.

[0044] The heating may include providing a fluid, such as a fuel, an oxidant, and/or steam, to the subterranean formation (or to the pyrolyzed zone thereof) through an injection well. Under these conditions, the injecting at 125 may include injecting the sealing fluid through the injection well. Additionally or alternatively, and when the heating includes heating with the heating structure, the injecting at 125 may include injecting proximate to the heating structure.

[0045] The pyrolyzing at 105 may generate the hydrocarbon fluid within the pyrolyzed zone, thereby permitting the producing at 110. The pyrolyzing at 105 may generate a pore space within the pyrolyzed zone and/or decrease a volume of a formation material that is present within the pyrolyzed zone. This may increase a fluid permeability of the pyrolyzed zone, thereby permitting the producing at 110 to be performed at a greater production rate; however, this also may cause the pyrolyzed zone to be susceptible to compaction.

[0046] The pyrolyzing at 105 may include pyrolyzing without creating a support pillar within the subterranean formation. However, the pyrolyzing at 105 may include creating one or more support pillars within the subterranean formation. When the pyrolyzing at 105 includes creating the support pillars, the support pillars may define a support pillar volume, the subterranean formation may define a subterranean formation volume, and the support pillar volume may be substantially less than the subterranean formation volume. As illustrative, non-exclusive examples, the support pillar volume may be less than 50%, less than 45%, less than 40%, less than 35%, less than 30%, less than 25%, less than 20%, less than 15%, less than 10%, or less than 5% of the subterranean formation volume.

[0047] Producing the hydrocarbon fluid from the pyrolyzed zone at 110 may include producing any suitable hydrocarbon fluid from the pyrolyzed zone. As an illustrative, non-exclusive example, the producing at 110 may include producing the hydrocarbon fluid that was generated during the pyrolyzing at 105. As another illustrative, non-exclusive example, the producing at 110 may include producing with, through, and/or via a production well that

is spaced apart from the injection well and that extends between a surface region and the pyrolyzed zone of the subterranean formation.

[0048] Cooling the pyrolyzed zone at 115 may include cooling prior to the injecting at 125. As an illustrative, non-exclusive example, the cooling at 115 may include cooling the pyrolyzed zone to less than a threshold pyrolyzed zone temperature. As another illustrative, non-exclusive example, the cooling at 115 may include waiting at least a threshold cooling time subsequent to the pyrolyzing at 105 and prior to the injecting at 125.

[0049] Illustrative, non-exclusive examples of threshold pyrolyzed zone temperatures include threshold pyrolyzed zone temperatures of less than 400 °C, less than 390 °C, less than 380 °C, less than 370 °C, less than 360 °C, less than 350 °C, less than 340 °C, less than 330 °C, less than 320 °C, less than 310 °C, less than 300 °C, less than 290 °C, less than 280 °C, less than 270 °C, less than 260 °C, less than 250 °C, less than 240 °C, less than 230 °C, less than 220 °C, less than 210 °C, or less than 200 °C. Additionally or alternatively, the threshold pyrolyzed zone temperature also may be greater than 100 °C, greater than 110 °C, greater than 120 °C, greater than 130 °C, greater than 140 °C, greater than 150 °C, greater than 160 °C, greater than 170 °C, greater than 180 °C, greater than 190 °C, greater than 200 °C, greater than 210 °C, greater than 220 °C, greater than 230 °C, greater than 240 °C, greater than 250 °C, greater than 260 °C, greater than 270 °C, greater than 280 °C, greater than 290 °C, or greater than 300 °C.

[0050] Illustrative, non-exclusive examples of the threshold cooling time include threshold cooling times of at least 10 days, at least 25 days, at least 50 days, at least 75 days, at least 100 days, at least 150 days, at least 200 days, at least 250 days, at least 300 days, at least 350 days, at least 400 days, at least 450 days, at least 500 days, at least 550 days, at least 600 days, at least 650 days, at least 700 days, at least 750 days, or at least 800 days.

[0051] Sweeping the pyrolyzed zone at 120 may include removing at least a portion of the hydrocarbon fluid that may be present within the pyrolyzed zone subsequent to the producing at 110. As illustrative, non-exclusive examples, the sweeping at 120 may include injecting a sweep fluid into the pyrolyzed zone and displacing the hydrocarbon fluid with a sweep fluid, dissolving the hydrocarbon fluid within the sweep fluid, diluting the hydrocarbon fluid with the sweep fluid, and/or entraining the hydrocarbon fluid in the sweep fluid to sweep the hydrocarbon fluid from the pyrolyzed zone. This may include injecting the

sweep fluid into the interior region of the pyrolyzed zone (such as via a suitable injection well), flowing the sweep fluid through the interior region to the peripheral region of the pyrolyzed zone, and/or producing the sweep fluid from the pyrolyzed zone (such as via a production well). Illustrative, non-exclusive examples of the sweep fluid are disclosed
5 herein.

[0052] The sweep fluid may be different from, or may define a different chemical composition than, the sealing fluid. Under these conditions, the sweeping at 120 may be performed at least partially prior to the injecting at 125. Additionally or alternatively, the sealing fluid may include and/or be the sweep fluid. Under these conditions, the sweeping at
10 120 may be performed at least partially concurrently with the injecting at 125 and/or at least partially concurrently with the flowing at 130.

[0053] Injecting the sealing fluid into the pyrolyzed zone at 125 may include injecting the sealing fluid in any suitable manner and/or utilizing any suitable structure (such as by flowing the sealing fluid through an injection well and into the interior region). The sealing fluid may
15 include and/or be a liquid sealing fluid that may flow through the pyrolyzed zone during the flowing at 130.

[0054] When methods 100 include the pyrolyzing at 105, the injecting at 125 may include injecting subsequent to the pyrolyzing at 105 and/or subsequent to the cooling at 115. Additionally or alternatively, the injecting at 125 may include injecting at least partially
20 concurrently with the pyrolyzing at 105 (and/or concurrently with the heating that may be associated therewith). Under these conditions, the flowing at 130 further may include absorbing thermal energy with the sealing fluid while the sealing fluid is within the interior region and conveying the absorbed thermal energy to the peripheral region with the sealing fluid.

[0055] Flowing the sealing fluid to the peripheral region of the pyrolyzed zone at 130 may include flowing the sealing fluid through the pore space that is present within the pyrolyzed zone. Additionally or alternatively, the flowing at 130 also may include flowing the sealing fluid radially outward and/or away from the interior region (or an injection point that is located therein) and into the peripheral region of the pyrolyzed zone.

[0056] Producing the sealing fluid from the pyrolyzed zone at 135 may include producing a portion of the sealing fluid that is injected during the injecting at 125. This may include producing through, with, and/or via a production well that extends within the pyrolyzed zone and/or that is located within, or near, the peripheral region of the pyrolyzed zone. When
5 methods 100 include the producing at 135, the produced sealing fluid, which also may be referred to herein as a produced sealing fluid stream, may be recycled and/or returned to the subterranean formation, such as during, or via, the injecting at 125.

[0057] Fluidly sealing the peripheral region of the pyrolyzed zone at 140 may include sealing to limit a fluid leakage from the pyrolyzed zone and/or into a remainder of the
10 subterranean formation. The fluidly sealing at 140 may include fluidly sealing in any suitable manner. As an illustrative, non-exclusive example, the fluidly sealing may include creating a flow barrier within the peripheral region, with the flow barrier resisting and/or preventing fluid flow from the pyrolyzed zone into the remainder of the subterranean formation.

[0058] The fluidly sealing may include fluidly sealing for at least a threshold sealing time
15 (and/or the flow barrier may be configured to resist fluid flow for at least the threshold sealing time). Illustrative, non-exclusive examples of the threshold sealing time include threshold sealing times of at least 1 year, at least 10 years, at least 50 years, or at least 250 years.

[0059] The flow barrier may be formed from the sealing fluid, such as by at least partial
20 solidification of the sealing fluid within the peripheral region, gelling of the sealing fluid within the peripheral region, occluding of the pore space within the peripheral region with the sealing fluid, and/or increasing a shear strength of the sealing fluid within the peripheral region. As an illustrative, non-exclusive example, the sealing fluid may define a zero, or nearly zero, shear strength prior to the fluidly sealing at 140 and may define a non-zero shear
25 strength subsequent to the fluidly sealing at 140.

[0060] As an illustrative, non-exclusive example, methods 100 may include increasing a viscosity of the sealing fluid during the flowing at 130. The fluidly sealing at 140 may be responsive, or directly responsive, to the viscosity increase. This may include increasing the viscosity to (or by) at least 10 poise (P), at least 50 P, at least 100 P, at least 250 P, at least
30 500 P, at least 750 P, at least 1000 P, at least 1250 P, at least 1500 P, at least 1750 P, at least 2000 P, at least 2500 P, at least 3000 P, at least 4000 P, at least 5000 P, at least 7500 P, or at

least 10,000 P. Additionally or alternatively, the fluidly sealing at 140 also may include increasing the viscosity of the sealing fluid by at least a threshold proportion, or percentage. As illustrative, non-exclusive examples, the viscosity may be increased by at least 1, at least 2, at least 3, at least 4, at least 5, at least 6, at least 7, at least 8, at least 9, at least 10, at least 11, or at least 12 orders of magnitude when compared to the viscosity of the sealing fluid as injected during the injecting at 125.

[0061] As another illustrative, non-exclusive example, the sealing fluid may define a temperature-dependent viscosity that increases with decreasing temperature. The flowing at 130 may include decreasing the temperature of the sealing fluid (such as by transfer of thermal energy from the sealing fluid to the subterranean formation and/or to the pyrolyzed zone). Under these conditions, the viscosity increase may be responsive, or directly responsive, to the temperature decrease.

[0062] As yet another illustrative, non-exclusive example, the sealing fluid may include and/or be a shear thinning fluid that decreases in viscosity when sheared and/or that defines a viscosity that is inversely related to a shear rate of the sealing fluid. Under these conditions, the flowing at 130 further may include decreasing the shear rate of the sealing fluid, such as by decreasing a flow rate of the sealing fluid through the pore space as the sealing fluid flows away from the injection point. Under these conditions, the viscosity increase may be responsive, or directly responsive, to the decrease in the shear rate.

[0063] As another illustrative, non-exclusive example, the sealing fluid may include a solid particulate material that may be sized to flow through the interior region of the pyrolyzed zone (or the pore space that is located therein) and to collect within the peripheral region of the pyrolyzed zone (or the pore space that is located therein). Under these conditions, the solid particulate material may collect and/or agglomerate within the peripheral region, thereby limiting, blocking, and/or occluding fluid flow therethrough and generating the fluid seal.

[0064] As yet another illustrative, non-exclusive example, the fluidly sealing at 140 may include solidifying at least a portion of the sealing fluid within the peripheral region to generate the sealing material, such as by polymerization of the sealing fluid within the peripheral region. The solidifying may be based upon, a result of, responsive to, and/or directly responsive to a temperature of the sealing fluid during the flowing at 130, a

temperature decrease of the sealing fluid during the flowing at 130, a shear rate of the sealing fluid during the flowing at 130, a shear rate decrease of the sealing fluid during the flowing at 130, and/or fluid contact between the sealing fluid and a solidification-initiating material that may be located within the peripheral region prior to the flowing at 130 and/or may be supplied to the peripheral region subsequent to the flowing at 130.

[0065] Pressurizing the pyrolyzed zone at 145 may include increasing the pressure within the pyrolyzed zone in any suitable manner. As an illustrative, non-exclusive example, the pressurizing at 145 may include pressurizing to a zone pressure, illustrative, non-exclusive examples of which are disclosed herein. As discussed, the pressurizing at 145 may include pressurizing with the sealing fluid (such as by continuing the injecting at 125 subsequent to the fluidly sealing at 140). Additionally or alternatively, and as also discussed, the pressurizing at 145 also may include pressurizing with a pressurizing fluid that is different from, distinct from, and/or defines a different chemical composition than the sealing fluid (such as by injecting the pressurizing fluid into the interior region of the pyrolyzed zone).

[0066] The pressurizing fluid, when utilized, may define any suitable fraction of a total injected volume of fluid. As an illustrative, non-exclusive example, the pyrolyzed zone may define a (total) pore volume, the injecting at 125 may include injecting a (total) sealing fluid volume, and the pressurizing at 145 may include injecting a (total) pressurizing fluid volume, with the sum of the sealing fluid volume and the pressurizing fluid volume defining a (total) injected volume.

[0067] Under these conditions, the sealing fluid volume may be at least 1%, at least 5%, at least 10%, at least 15%, at least 20%, at least 25%, at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, or at least 90% of a total injected volume. Additionally or alternatively, the sealing fluid volume also may be less than 100%, less than 95%, less than 90%, less than 85%, less than 80%, less than 75%, less than 70%, less than 65%, less than 60%, less than 55%, less than 50%, less than 40%, less than 30%, less than 20%, or less than 10% of the total injected volume.

[0068] Similarly, the pressurizing fluid volume may be at least 1%, at least 5%, at least 10%, at least 15%, at least 20%, at least 25%, at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, or at least 90% of the total injected volume. Additionally or alternatively, the pressurizing fluid volume also may be less than 100%, less than 95%, less

than 90%, less than 85%, less than 80%, less than 75%, less than 70%, less than 65%, less than 60%, less than 55%, less than 50%, less than 40%, less than 30%, less than 20%, or less than 10% of the total injected volume.

[0069] Determining a status of the pyrolyzed zone at 150 may include determining and/or detecting any suitable value and/or variable that may be associated with, may predict, and/or may be indicative of compaction within the pyrolyzed zone and/or subsidence of a ground surface that is supported by the pyrolyzed zone. As an illustrative, non-exclusive example, the determining at 150 may include detecting a pressure within the pyrolyzed zone.

[0070] As another illustrative, non-exclusive example, the determining at 150 additionally or alternatively may include detecting subsidence of the ground surface. This may include detecting with a tiltmeter and/or detecting an angle of inclination of the ground surface with the tiltmeter. As yet another illustrative, non-exclusive example, the determining at 150 additionally or alternatively may include thermally modeling the pyrolyzed zone. This may include estimating a temperature of the pyrolyzed zone, such as by modeling heat flow into and/or out of the pyrolyzed zone.

[0071] Repressurizing the pyrolyzed zone at 155 may include injecting any suitable pressurizing fluid, illustrative, non-exclusive examples of which are disclosed herein, into the pyrolyzed zone to increase the pressure within the pyrolyzed zone. This may include injecting until the pressure within the pyrolyzed zone is greater than, less than, and/or equal to the zone pressure that is reached during the pressurizing at 145.

[0072] The repressurizing at 155 may be initiated and/or based, at least in part, on any suitable criteria. As an illustrative, non-exclusive example, the repressurizing at 155 may be initiated responsive to the determining at 150. As an illustrative, non-exclusive example, the repressurizing at 155 may be initiated responsive to detecting that the pressure within the pyrolyzed zone is less than a threshold pyrolyzed zone pressure. As another illustrative, non-exclusive example, the repressurizing at 155 may be initiated responsive to detecting that the subsidence of the ground surface is greater than a threshold subsidence (such as by detecting that the angle of inclination of the ground surface has changed by greater than a threshold angle). As yet another illustrative, non-exclusive example, the repressurizing at 155 may be initiated responsive to the thermal modeling. This may include initiating the repressurizing

responsive to estimating that the temperature of the pyrolyzed zone is less than a threshold temperature.

[0073] In the present disclosure, several of the illustrative, non-exclusive examples have been discussed and/or presented in the context of flow diagrams, or flow charts, in which the methods are shown and described as a series of blocks, or steps. Unless specifically set forth in the accompanying description, the order of the blocks may vary from the illustrated order in the flow diagram, including with two or more of the blocks (or steps) occurring in a different order and/or concurrently.

[0074] As used herein, the term “and/or” placed between a first entity and a second entity means one of (1) the first entity, (2) the second entity, and (3) the first entity and the second entity. Multiple entities listed with “and/or” should be construed in the same manner, i.e., “one or more” of the entities so conjoined. Other entities may optionally be present other than the entities specifically identified by the “and/or” clause, whether related or unrelated to those entities specifically identified. Thus, as a non-limiting example, a reference to “A and/or B,” when used in conjunction with open-ended language such as “comprising” may refer to A only (optionally including entities other than B); to B only (optionally including entities other than A); to both A and B (optionally including other entities). These entities may refer to elements, actions, structures, steps, operations, values, and the like.

[0075] As used herein, the phrase “at least one,” in reference to a list of one or more entities should be understood to mean at least one entity selected from any one or more of the entity in the list of entities, but not necessarily including at least one of each and every entity specifically listed within the list of entities and not excluding any combinations of entities in the list of entities. This definition also allows that entities may optionally be present other than the entities specifically identified within the list of entities to which the phrase “at least one” refers, whether related or unrelated to those entities specifically identified. Thus, as a non-limiting example, “at least one of A and B” (or, equivalently, “at least one of A or B,” or, equivalently “at least one of A and/or B”) may refer, to at least one, optionally including more than one, A, with no B present (and optionally including entities other than B); to at least one, optionally including more than one, B, with no A present (and optionally including entities other than A); to at least one, optionally including more than one, A, and at least one, optionally including more than one, B (and optionally including other entities). In other

words, the phrases “at least one,” “one or more,” and “and/or” are open-ended expressions that are both conjunctive and disjunctive in operation. For example, each of the expressions “at least one of A, B and C,” “at least one of A, B, or C,” “one or more of A, B, and C,” “one or more of A, B, or C” and “A, B, and/or C” may mean A alone, B alone, C alone, A and B
5 together, A and C together, B and C together, A, B and C together, and optionally any of the above in combination with at least one other entity.

[0076] In the event that any patents, patent applications, or other references are incorporated by reference herein and (1) define a term in a manner that is inconsistent with and/or (2) are otherwise inconsistent with, either the non-incorporated portion of the present
10 disclosure or any of the other incorporated references, the non-incorporated portion of the present disclosure shall control, and the term or incorporated disclosure therein shall only control with respect to the reference in which the term is defined and/or the incorporated disclosure was present originally.

[0077] As used herein the terms “adapted” and “configured” mean that the element,
15 component, or other subject matter is designed and/or intended to perform a given function. Thus, the use of the terms “adapted” and “configured” should not be construed to mean that a given element, component, or other subject matter is simply “capable of” performing a given function but that the element, component, and/or other subject matter is specifically selected, created, implemented, utilized, programmed, and/or designed for the purpose of performing
20 the function. It is also within the scope of the present disclosure that elements, components, and/or other recited subject matter that is recited as being adapted to perform a particular function may additionally or alternatively be described as being configured to perform that function, and vice versa.

[0078] Illustrative, non-exclusive examples of systems and methods according to the
25 present disclosure are presented. It is within the scope of the present disclosure that an individual step of a method recited herein, may additionally or alternatively be referred to as a “step for” performing the recited action.

Industrial Applicability

[0079] The systems and methods disclosed herein are applicable to the oil and gas
30 industry.

[0080] The subject matter of the disclosure includes all novel and non-obvious combinations and subcombinations of the various elements, features, functions and/or properties disclosed herein. Similarly, where the claims recite “a” or “a first” element or the equivalent thereof, such claims should be understood to include incorporation of one or more such elements, neither requiring nor excluding two or more such elements.

[0081] It is believed that the following claims particularly point out certain combinations and subcombinations that are novel and non-obvious. Other combinations and subcombinations of features, functions, elements and/or properties may be claimed through amendment of the present claims or presentation of new claims in this or a related application. Such amended or new claims, whether different, broader, narrower, or equal in scope to the original claims, are also regarded as included within the subject matter of the present disclosure.

CLAIMS

1. A method of decreasing compaction within a pyrolyzed zone of a subterranean formation, wherein the pyrolyzed zone includes a hydrocarbon fluid, the method comprising:
injecting a sealing fluid into an interior region of the pyrolyzed zone;
5 flowing the sealing fluid from the interior region of the pyrolyzed zone to a peripheral region of the pyrolyzed zone;
fluidly sealing the peripheral region of the pyrolyzed zone with the sealing fluid, wherein fluidly sealing limits a fluid leakage from the pyrolyzed zone; and
subsequent to the fluidly sealing, pressurizing the pyrolyzed zone to a zone pressure
10 with a pressurizing fluid.
2. The method of claim 1, wherein the method further includes sweeping at least a portion of the hydrocarbon fluid from the pyrolyzed zone prior to the fluidly sealing.
- 15 3. The method of claim 2, wherein, prior to the injecting the sealing fluid, the method further includes injecting a sweep fluid into the interior region and flowing the sweep fluid from the interior region to the peripheral region to sweep the portion of the hydrocarbon fluid from the pyrolyzed zone.
- 20 4. The method of claim 3, wherein the sweep fluid at least one of (i) is the sealing fluid, and (ii) is different from the sealing fluid.
5. The method of any of claims 1-4, wherein the zone pressure is greater than a hydrostatic pressure within a region of the subterranean formation that defines the pyrolyzed
25 zone prior to formation of the pyrolyzed zone.
6. The method of any of claims 1-5, wherein the zone pressure is less than a lithostatic pressure within a region of the subterranean formation that defines the pyrolyzed zone prior to formation of the pyrolyzed zone.
30
7. The method of claim 6, wherein the zone pressure is closer to the lithostatic pressure than to a hydrostatic pressure within the region of the subterranean formation that defines the pyrolyzed zone prior to formation of the pyrolyzed zone.

8. The method of any of claims 1-7, wherein the pressurizing fluid is at least one of (i) the sealing fluid; and (ii) different from the sealing fluid.
- 5 9. The method of any of claims 1-8, wherein the pressurizing fluid is a solidification-initiating material that is selected to solidify the sealing fluid within the peripheral region of the pyrolyzed zone.
10. The method of any of claims 1-9, wherein the method further includes pyrolyzing a
10 portion of the subterranean formation to generate the pyrolyzed zone.
11. The method of any of claims 1-10, wherein the fluidly sealing includes creating a flow barrier within the peripheral region, wherein the flow barrier resists fluid flow from the pyrolyzed zone into a remainder of the subterranean formation.
- 15 12. The method of claim 11, wherein the fluidly sealing includes at least one of:
(i) at least partially solidifying the sealing fluid to form the flow barrier; and
(ii) gelling the sealing fluid to form the flow barrier.
- 20 13. The method of any of claims 1-12, wherein the flowing includes flowing radially outward from the interior region to the peripheral region.

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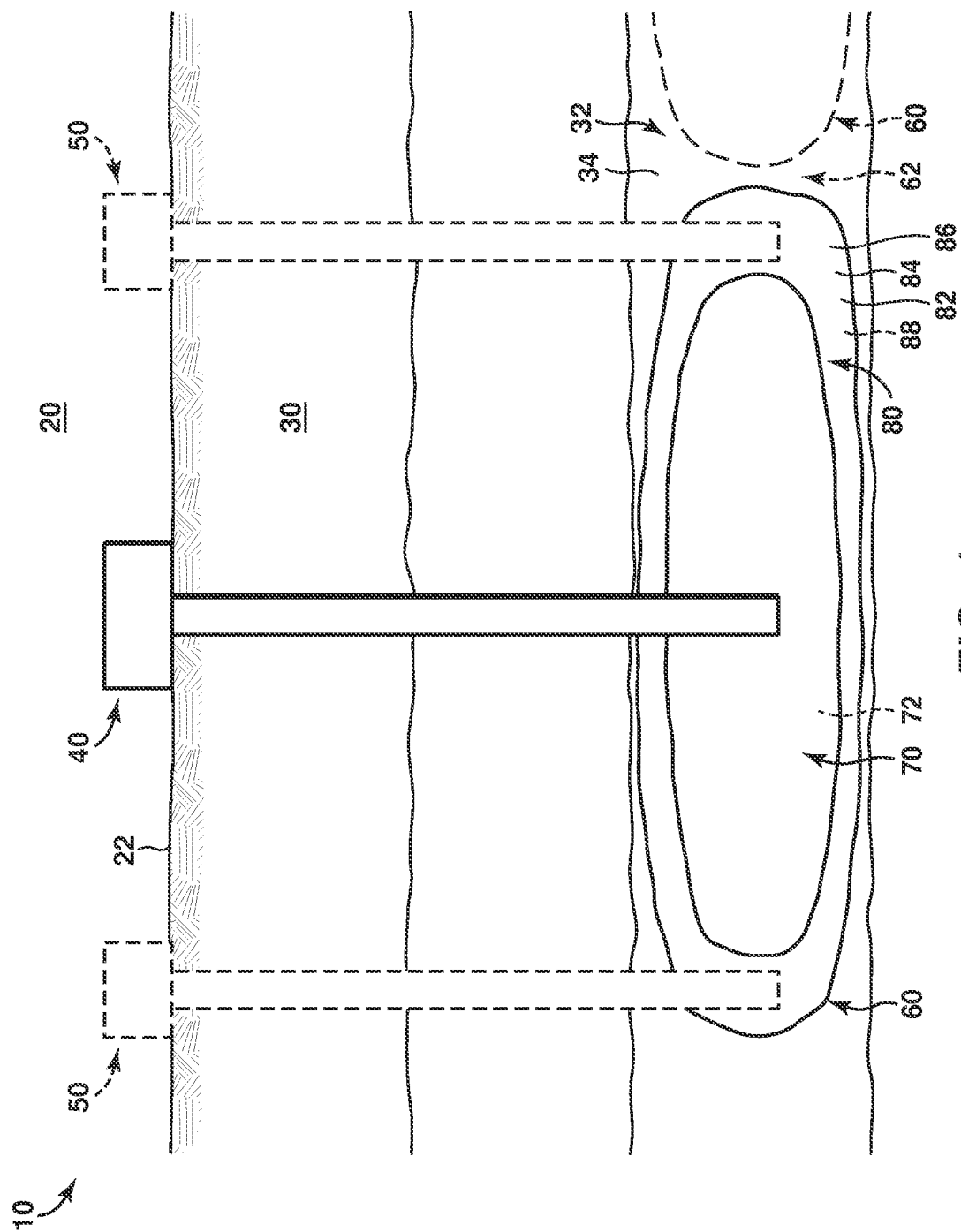


FIG. 1

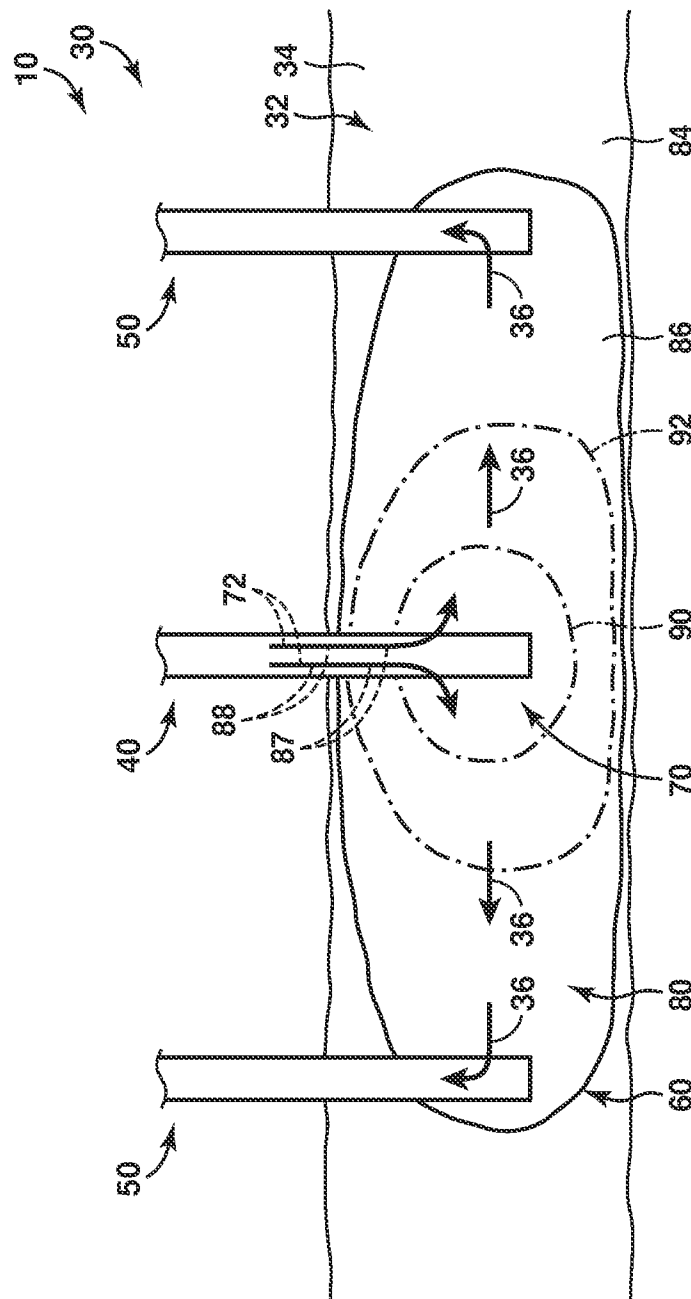
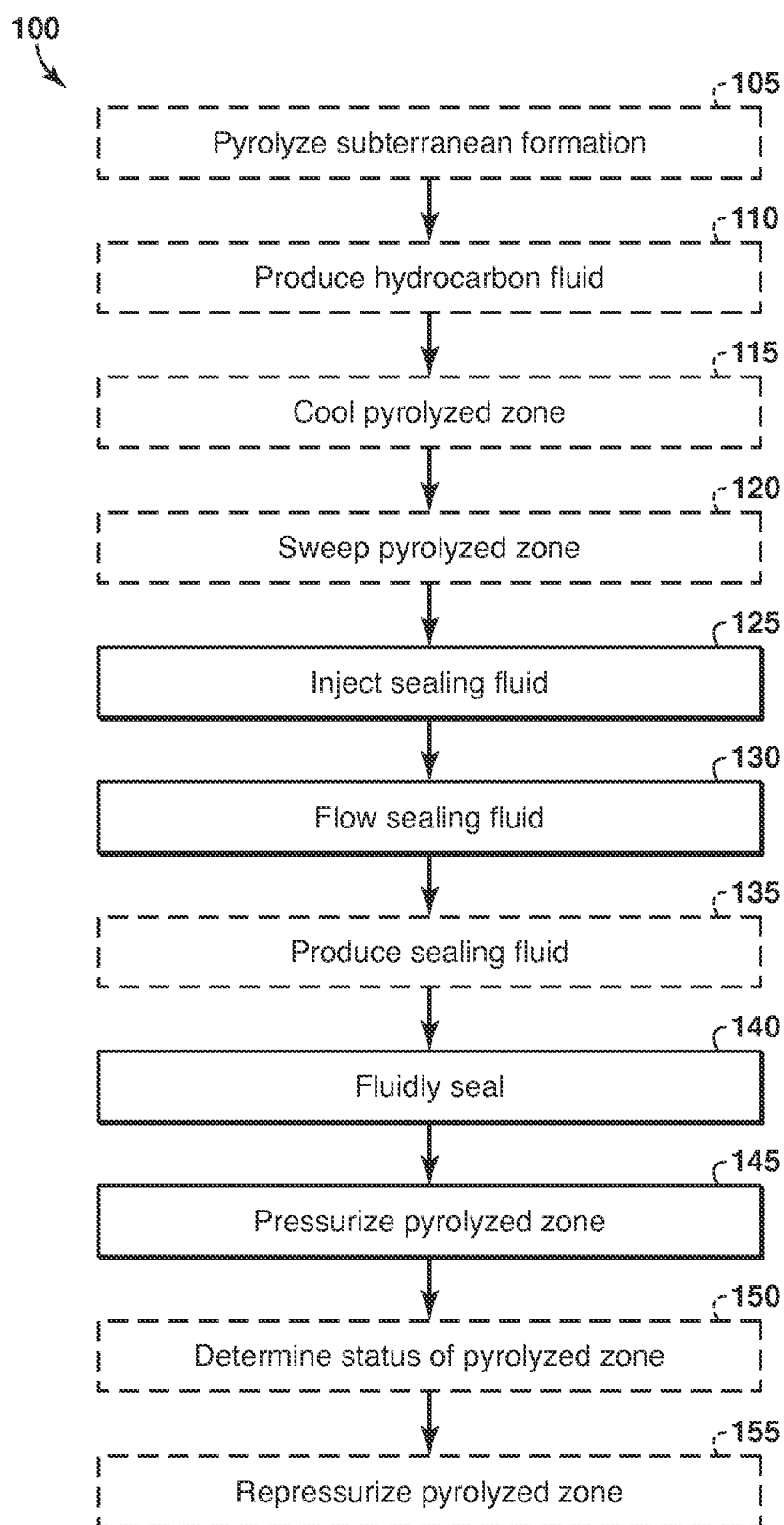


FIG. 2

3/3**FIG. 3**