

GEOHERMAL REACTOR WELL

Technical Field

[0001] This disclosure relates to production of chemical products from reactants circulated in a well, and in particular in a closed-loop well in a geothermal subterranean zone.

Background

[0002] Valuable important products, such as fuels, can be produced from chemical reactions between reactive feedstocks occurring over time under certain temperature and pressure ranges. In addition, some such processes may require catalysts and other substances to increase the rate or amount of produced product. Conventional reactor systems residing on the terranean surface can be limited by cost, size, and other factors.

Summary

[0003] The concepts herein encompass production of chemical products from reactants circulated in a well, and in particular in a closed-loop well in a geothermal subterranean zone.

[0004] In certain aspects, a geothermal reactor well system includes a closed-loop well coupled to one or more sources of reactants. The closed-loop well includes a first surface wellbore extending from a terranean surface to a geothermal subterranean zone and a second surface wellbore extending from the surface to the zone. A plurality of connecting wellbores connect the first surface wellbore to the second surface wellbore. A carrier fluid is disposed within the closed-loop well. The closed-loop well is configured so heat energy from the geothermal subterranean zone and/or reaction of reactants in the closed-loop well drives the fluids in the closed-loop well to circulate by thermosiphon and to thereby carry the reactants through the closed-loop well for the reaction and carry a product of the reaction through the closed-loop well for collection.

[0005] In certain aspects, a method includes disposing reactants in a closed-loop well from one or more sources of reactants coupled thereto. The closed-loop well includes a first surface wellbore extending from a terranean surface to a geothermal subterranean zone and a second surface wellbore extending from a terranean surface to the geothermal subterranean zone. A plurality of connecting wellbores connect the first surface wellbore to the second surface wellbore. The carrier fluid is circulated to carry the reactants through the closed wellbore loop by thermosiphon from heat energy from the geothermal subterranean zone and/or reaction of reactants in the closed-loop well. The product of reaction is then collected from the closed-loop well.

[0006] The aspects above can include some, none or all of the following features. For example, in certain instances, the reaction is driven in part by heat energy from the geothermal subterranean zone. The closed wellbore loop can be configured such that a pressure and temperature within the closed wellbore loop are within a specified pressure and temperature range for the reaction. At least a portion of the connecting wellbores can be sealed against communication of fluids with the surrounding geothermal subterranean zone. The closed-loop well can include a catalyst bed disposed therein. The catalyst bed can include a slurry. The geothermal subterranean zone, in certain instances, has an inherent temperature of at least 200 degrees Celsius

surrounding at least a portion of the connecting wellbores. The product, in certain instances, includes a fuel product, ammonia, and/or methanol. The reaction, in certain instances, includes a Fischer Tropsch synthesis.

[0007] Other aspects will be apparent from the drawings, detailed description and claims that follow.

Brief Description of Drawings

[0008] FIGS. 1A - 1C are schematic side cross-sectional views of example closed-loop reactor well systems in accordance with the concepts herein.

[0009] FIG. 2 is a schematic side cross-sectional view of a portion of a closed-loop reactor well in accordance with the concepts herein.

[0010] Like reference numbers used in the figures identify like elements.

DETAILED DESCRIPTION

[0011] In geothermal reactor well systems, a fluid comprising one or more chemical components (a “carrier fluid” or “working fluid”) is circulated within a subsurface closed-loop well. The carrier fluid and reactants are supplied into the closed-loop well, heated by the Earth (e.g., rock) surrounding the well and then circulated to the surface. As the well is closed-loop, and does not substantively exchange fluids with the surrounding Earth, the primary heat transfer from the Earth surrounding the wellbores is conductive. In some instances, the well has two wellbores at the surface, an inlet wellbore and an outlet wellbore, and the inlet wellbore and outlet wellbore are connected by one or more connecting wellbores in a subterranean zone in the Earth. The wellbores can be sealed to prevent (entirely or substantially) contact or flow between the fluid within the wellbores and the natural fluids in the formation (for example, groundwater). In some instances casing is installed in all or part of the wellbores of the well to provide the sealing. In some instances a sealant is circulated through the wellbore to seal the wellbores and the wellbore is provided without casing for all or a portion of the lengths of the wellbores.

[0012] In certain instances of the present disclosure, a closed loop geothermal well system is used as a subsurface reactor such that products can be generated by chemical reaction between reactive components carried by the carrier fluid. Reactants can be injected into one of the surface wellbores, e.g., the inlet wellbore. The reaction products, byproducts, and unreacted feedstock can be produced up the other surface wellbore. In certain instances, the carrier fluid can be inert as to the reaction or it can be a reactant introduced into the reactor in excess quantity (*i.e.*, more than is needed for the reaction producing the product). A thermosiphon driven by geothermal heat energy and/or exothermic heat from the reaction can drive the circulation of the carrier fluid, reactants and product without the need for pumping. In certain instances, the geothermal heat can additionally or alternatively be an instigator and/or catalyst for the reaction. The reactor well can provide a high-pressure and high-temperature environment for the reaction.

[0013] FIG. 1A shows an example geothermal reactor well system 100A in schematic, side cross-sectional view in accordance with the concepts herein. System 100A includes a well 102 drilled into the Earth through a geothermal subterranean

zone of interest 104. In certain instances, the geothermal subterranean zone has an inherent temperature of 200 degrees Celsius or higher surrounding at least a portion of the well 102. In certain instances, the subterranean zone is a formation, a portion of a formation or multiple formations. In certain instances, the subterranean zone 104 is dry, having little to no naturally occurring fluids. In certain instances, the subterranean zone 104 is impermeable (having a bulk permeability 0.1 millidarcy or less), or has a low permeability, having a bulk permeability of 100 millidarcy or less, 50 millidarcy or less, or 1 millidarcy or less. In certain instances, the subterranean zone is in or is in a basement formation. In certain instances, the rock of the subterranean zone is granite. In the illustrated instance, well 102 includes an inlet surface wellbore 120 and an outlet surface wellbore 130 in close proximity, each extending between the terranean surface and the subterranean zone 104. The inlet surface wellbore 120 and outlet surface wellbore 130 are connected within the subterranean zone 104 by one or more connecting wellbores 140. In the illustrated instance, connecting wellbores 140 define a multilateral pattern of wellbores, including a plurality of pairs of lateral wellbores 150, a subset of which are kicked off from the inlet wellbore 120 and a subset of which are kicked off from the outlet wellbore 130. The pairs of lateral wellbores 150 each intersect at a respective junction 154 at or near their respective toes. Thus, the inlet wellbore 120, outlet wellbore 130 and connecting wellbores 140 define a closed loop.

[0014] The inlet wellbore 120 and the outlet wellbore 130 can be drilled from the same drilling pad and/or reside on the same well site. In certain instances, the wellbores 120, 130 are drilled within 10, 25, 50 or 100 meters of one another. In other instances, the inlet surface wellbore 120 and the outlet surface wellbore 130 can be separated by a longer distance. For example, FIG. 1B, discussed in more detail below, shows a configuration where the surface wellbores 120, 130 and the connecting wellbores 140 define a U-shape configuration. In certain instances, the inlet surface wellbore 120 and the outlet surface wellbore 130, when the geothermal well 102 is configured as a U-shape, are drilled 3,000 meters or more apart.

[0015] In the illustrated instance, inlet surface wellbore 120 and outlet surface wellbore 130 are vertical wellbores, drilled substantially straight (i.e., without the use of directional drilling methods or equipment). In other instances, one or both of the surface wellbores are other than vertical (e.g., slanted) and/or may be drilled with the

use of directional drilling techniques. The connecting wellbores 140 are drilled using directional drilling techniques through the surface wellbores 120, 130, and include a curve in their trajectory beginning at a kickoff 148 at surface wellbores 120, 130.

[0016] FIG. 1A shows each pair of lateral wellbores 150 parallel to one another extending in the same direction (azimuth) from their respective surface wellbore 120, 130. The lateral wellbores 150 extending from the inlet surface wellbore 120 are shown above the lateral wellbores 150 extending from the outlet surface wellbore 130. In some instances, the upper lateral wellbores 150 are directly above their (and are, in some instances, directly above a respective one of the lower lateral wellbores 150. In FIG. 1A the upper lateral wellbores 150 each turn to intersect its adjacent lower lateral wellbore 150 pair at the junction 154 to connect the surface wellbores 120, 130. In other instances, one or more of the lower lateral wellbores 150 could intersect the upper lateral wellbores 150. Regardless, the configuration of connecting wellbores 140, one set atop the other defines a stacked wellbore pattern, with one sub-pattern of wellbores above and one sub-pattern of wellbores below. In certain instances, one or more additional sets of stacked patterns can be drilled from the surface wellbores 120, 130 at different depths (i.e., with different kickoffs 148). In FIG. 1A, the lower lateral wellbores 150 extend past and below the junction 154 to define a sump 152.

[0017] The connecting wellbores 140 of FIG. 1A slant downward; i.e., they have an inclination 160 from vertical. In some instances, some or all of the connecting wellbores can be horizontal (i.e., having an inclination 160 of about ninety degrees) or substantially horizontal. In some instances, as shown in FIG. 1B, connecting wellbores 140 can have a steeper slant; i.e., inclination 160 can be less than that shown in FIG. 1B, or vertical (inclination 160 is zero) or substantially vertical. In some instances, connecting wellbores 140 follow the geological dip of the formation in the subterranean zone. In some instances, lateral wellbores 150 can have a length of 2,000 meters to 10,000 meters or more and can reach a depth of 1,000 meters to 8,000 meters or more.

[0018] FIG. 1C illustrates another embodiment of a geothermal reactor well system - 100C - having lateral wellbores 150 extending, respectively, from the inlet and outlet surface wellbores 120, 130 toward one another. The pairs of lateral wellbores 150, once intersected, together with the inlet and outlet wellbores 120, 130, define a generally U-shape. The configuration of connecting wellbores 140 defines a

pattern of wellbores, in certain instances, in the same plane. In certain instances, one or more additional patterns of connecting wellbores can be drilled between the surface wellbores 120, 130 at different depths (i.e., with different kickoffs 148).

[0019] Referring to FIGS. 1A - 1C, collectively, in some instances, the surface wellbores 120, 130 are cased (at least partially or entirely), and the connecting wellbores 140, including the junctures at the kickoffs 148 are open hole (i.e., without casing or liner or a junction liner). In some instances, the connecting wellbores 140 can be at least partially lined (e.g., include a liner or casing in those portions where the subterranean zone 104 is fractured, susceptible to collapse, unconsolidated or otherwise needing a liner).

[0020] Some or a portion of connecting wellbores 140, including the junctures to the inlet and outlet surface wellbores 120, 130 can be sealed (entirely or substantially) with a sealant against exchange of fluids with the surrounding subterranean zone 104, without requiring casing or liners in those wellbores or wellbore portions. In some instances, the sealant can be in the form of a fluid sealant (such as an alkali-silicate fluid) flowed through the wellbores. The sealant is designed such that all or substantially all of the carrier fluid circulated through the well 102 during operation is recovered to the surface, and no or little naturally occurring fluids from the subterranean zone 104 are recovered and no or little fluids from the wellbores flow into the subterranean zone. In other words, the resulting well 102 is closed loop. In certain instances, the sealant can be applied to the wellbores during drilling the connecting wellbores 140, e.g., included in the drilling fluid and/or supplied in fluid slugs distinct from the drilling fluid. Alternatively or additionally, the sealant can be applied after drilling and/or during operation of the well. In certain instances, the sealant can be included in the carrier fluid and/or supplied in fluid slugs, distinct from the carrier fluid. In certain instances, the multilateral wellbores are lined with casing and cemented and/or lined with a liner to isolate the carrier fluid, reaction fluids and catalysts from the formation and formation fluids. The casing and/or liner can be steel, another metal alloy and/or another type of casing material.

[0021] In the illustrated instance, a facility 110 is connected to inlet surface wellbore 120 and/or outlet surface wellbore 130. In certain instances, facility 110 includes one or more sources of reactants (such as tanks or pipelines) and sources of carrier fluids which can be connected to the wellbores with valves or pumps for

injecting the reactants and carrier fluid into the well 102. In some instances, facility 110 is disposed at or near the Earth's surface; in other instances, facility 110 may be disposed partially or fully within a subsurface location. The facility 110 need not be housed in one location, and, for example as shown in FIG. 1C, it can be split between one or more discrete locations (shown as facility 110a, 110b) connected by piping. The facility 110 is configured to allow offtake of products from the reaction and collection, separation and reuse of the carrier fluid.

[0022] FIG. 2 is a schematic illustration of an example subsurface reactor well 200 according to the concepts herein. The subsurface reactor well 200 is a closed loop well similar to that in well system 100A, 100B, or 100C, having an inlet and outlet surface wellbores 120, 130 connected by one or more connecting wellbores 140, in a subterranean zone 104. FIG. 2 shows a relatively simple configuration of reactor well 200 for convenience of description, but the configuration of reactor well 200 can differ and be more complex and/or U-shaped, such as described above in connection with well systems 100A, 100B, or 100C.

[0023] Geothermal heat from subterranean zone 104 can provide the heat necessary to drive, act as a catalyst, and/or initiate the chemical reactant to produce the desired products. In addition, a thermosiphon effect results when the fluid flowing down the inlet surface wellbore 120 is denser than the hot fluids, heated by the geothermal subterranean zone 104, flowing up through the outlet surface wellbore 130. In certain instances, when the reaction is exothermic, the heat of reaction is transferred to the carrier fluid, reactants and product mixture, further increasing the temperature of the mixture, contributing to a higher thermosiphon. In certain instances, due to this effect, the maximum temperature of the carrier fluid, reactant and product mixture can exceed the maximum rock temperature of the subterranean zone 104. The difference in density creates a pressure differential between the fluids in the inlet surface wellbore 120 and the fluids in the outlet surface wellbore 130 tending to drive the fluids through the well 200 to the surface. The pressures at the outlet surface wellbore 130 can be controlled (e.g., with a valve or valves in the surface facility 110 and/or elsewhere) to control the pressures of the reacting fluids in the connecting wellbores 140. In certain instances, the thermosiphon can drive the fluids through the reactor well 200 without further assistance. In certain instances, the thermosiphon can be initiated and/or boosted by one or more pumps (e.g., a pump in the surface facility 110 or elsewhere).

[0024] In certain instances, the reactor well 200 is purpose built to be a reactor well 200. However, in certain instances, the reactor well 200 is an existing closed loop geothermal well that is repurposed, permanently or temporarily, to serve as a subsurface reactor. For example, at a geothermal well site having one or multiple geothermal wells, one or multiple of the wells can be repurposed to operate as a reactor well 200. The remaining wells can continue to operate producing heat and/or electricity, and some or all of the wells on the same site can be operated to generate electricity aid in production from reactor well 200. The reactor well 200, even when purpose built, can be on the same well site as geothermal well(s), and in certain instances, the site can include geothermal wells used in generating heat or electricity. The electricity can be used to, for example, drive pumps, compressors and other components of the reactor well systems.

[0025] As shown in FIG. 2, carrier fluid 202 flows down surface inlet wellbore 120, carrying reactants 204. Carrier fluid 202 and reactants 204 can be in the form of a homogenous or heterogeneous mixture of the carrier fluid and reactants, or as slugs alternating with each other. Carrier fluid 202 can also carry products 206 of the reaction (along with byproducts and unreacted reactants up the outlet surface wellbore 130 for collection (at, for example, a valve at the surface facility). In certain instances, it is desirable that carrier fluid 202 be inert, or inert as to the reaction between the reactants 204. In some instances, carrier fluid 202 may contain impurities or other substances that themselves are not inert but that are present in small enough quantities such that the carrier fluid remains materially inert (non-reactive) to the desired degree. In some instances, an inert phase change material (“PCM”) carrier fluid can be used that absorbs the heat of reaction as latent heat, and this can improve the thermosiphon drive as the PCM carrier fluid would be heavier in the inlet wellbore 120 where the reactants are lightest and lighter in the outlet wellbore 130, where the products of the reaction are heaviest. In some instances, the carrier fluid is a reactant in the desired chemical reaction and introduced into the system in excess quantities, i.e., more than is needed for the reaction. Whether a reactant, inert to the reaction, or generally inert, the carrier fluid can be selected based on a density to achieve a desired pressure in the multilateral section of the wellbore system and/or based on geomechanical considerations to maintain wellbore stability. In some instances, the average density of the carrier fluid in the wellbore system is $>500\text{kg/m}^3$, $>1000\text{ kg/m}^3$, or $>1250\text{ kg/m}^3$.

In some instances, a weighted solid (such as barite) is introduced into the carrier fluid to maintain this density. In some instances the carrier fluids include one or more of n-pentane, isopentane, cyclopentane, R1234zEe, R1233zdE, R227ea, dimethyl ether, R1234yf, R1234zeZ, isobutane, butane, propane, hexane, toluene, R152a, R1243zf, propylene, R1243zf, naphtha, ethylene glycol, water, carbon dioxide or other solvents, diluents or chemical reactants.

[0026] At surface, products, reactants and carrier fluid are separated, where the remaining reactants and carrier fluid are recycled and re-introduced into the closed loop well reactor. The excess heat energy from the produced mixture can be utilized in an Organic Rankine Cycle, a Steam Rankine Cycle, or as input energy for another process, which in turn cools the mixture. It is beneficial if reactants (and recycled carrier fluid) enter the well cold (to increase thermosiphon drive and maintain wellbore geomechanics balance), however they need to heat up to sufficient temperature to initialize certain reactions that display commercially viable reaction rates at higher temperatures. In some instances, “cold” refers to inlet temperatures less than 100°C, but can be lower than 50°C. In some instances, the “initialization heat” is provided from the hot rock (geothermal energy). In some instances, other techniques are used to supplement the geothermal energy to initialize the reaction such as electromagnetic heating methods (such as microwave and radio frequency heating), electric resistance heaters etc. Once a threshold temperature is reached for exothermic reactions, the reaction can be self-sustaining as the heat of formation increases the temperature of the carrier fluid, reactant and product mixture, further increasing reaction rate as conversion increases. In certain cases, the chemical reaction is endothermic, and the required input energy is supplied by geothermal energy and can be supplemented by external heating methods.

[0027] In some instances, the system is designed such that the carrier fluid is cooled to be liquid or supercritical liquid (above critical pressure but below critical temperature). In certain instances, the carrier fluid for the reactants can be a solvent. Use of a supercritical solvent carrier fluid can increase the heat transfer and enable more stable local temperatures within the catalyst bed. Furthermore, the carrier fluid can be maintained in proportions to achieve a specified density within the inlet wellbore 120 that facilitates the thermosiphon, among many other considerations for

this design parameter (other considerations are partial pressure of reactants and heat transfer from exothermic reactions). In certain instances, a molar fraction of at least 50% of carrier fluid is workable. In other instances, a molar fraction of carrier fluid of the total mixture is at least 60%, 70%, 80%, 90% or at least 95%. The system 200 is also designed such that there is sufficient heat generation and operating temperature to generate less dense fluid in the outlet wellbore 130. The reaction products are typically much heavier than the reactants in the inlet wellbore 120, so the density reduction from high temperature is important in creating the thermosiphon. Solvent proportion can also have a significant effect on this value. In certain instances, the system 200 is configured so that the carrier fluid is liquid or supercritical liquid (below critical temperature) at the top of the inlet wellbore 120 and transitions to supercritical fluid within the reaction/catalyst portion of the well, i.e., in the connecting wellbores 140. As described above, in some instances a sump 152 can be formed at the junctions of lateral wellbores 150. Sump 152 can provide a location for debris or precipitant by-products from the reaction to accumulate outside of the flow path of the wellbores.

[0028] In some instances, the reactor well 200 includes a catalyst bed 208 within the well, in the connecting wellbore 140 or wellbores 140 comprising a catalyst or catalysts that can increase the rate of the reaction of the reactants. As the reactants are introduced down the inlet surface wellbore 120 they can react in the catalyst bed 208 as they pass through the connecting wellbores 140 and high temperatures of the subterranean zone 104.

[0029] In certain instances, the catalyst is packed to fully fill to the top of the connecting wellbore 140. To achieve the desired high porosity and permeability (for example, 10s -100s of Darcies), large catalyst particles can be used. Alternatively, the reactor well 200 can use a slurry with small catalyst particles suspended within the fluid. The small catalyst particles have a high surface area and can provide a lower pressure drop across the catalyst bed. In some instances, the effectiveness of the catalyst can be improved by the use of a PCM carrier fluid which can create an isothermal condition within the wellbores. Another approach is to use a high molar percentage of carrier fluid and at a high flowrate to limit runaway temperature changes and maintain the reaction in an optimum temperature window (based on catalyst activity and desired reaction rate).

[0030] In some instances, the catalyst can be placed similar to sand in a fracturing process, so as to “screen out” the wellbore with the catalyst. This can be done by placing gravel sized catalyst at the beginning of the laterals of the connecting wellbores 140 in the outlet wellbore 130, essentially just letting the gravel sized catalyst fall by gravity for form a gravel plug. Then, viscous fluid with entrained sand sized catalyst is pumped from the inlet wellbore 120 to the outlet wellbore 130. The sand sized catalyst will pack-off and screen out at the gravel plug, and the carrying fluid will continue passing through the wellbore until all catalyst is placed. A surface separator can be used to remove particles of catalyst that may flow to the surface. If it is desired that the catalyst be removed, for example to replace the catalyst at the end of its useful life, the catalyst can be removed by drilling through the catalyst bed with a drill string and drill bit.

[0031] Depending on the cost to remove and install new catalyst it may be desirable to instead rejuvenate the catalyst. For example, fouling by carbon of the catalyst can be rejuvenated by reduction with H_2 at a temperature above $350^\circ C$. A system flush with a solvent (supercritical CO_2 , organic fluid) can be performed to remove contaminants on the catalyst surface. The use of a catalyst in the form of a slurry can also support continuous regeneration of the catalyst at surface.

[0032] Using a closed loop well as a reactor well 200 can provide high pressure on the fluids. In certain instances, reactor pressure can be in the range of 40-200 MPa (which is up to approximately two orders of magnitude (100x) higher than standard surface reactors) or higher. Due to Le Chatelier’s principle, increasing the reaction pressure for certain reactions increases the reaction selectivity to counteract the high pressure. The high pressures in the closed loop well may also contribute the autocatalysis of certain chemical reactions, thus reducing the amount of catalyst needed or even eliminating the need for catalyst in the wellbore system. As an example, the synthesis of ammonia from gaseous hydrogen and nitrogen can begin autocatalysis at pressures $>100\text{-}200\text{MPa}$. In certain instances, the volume of the connecting wellbores 140 may be greater than a typical surface reactor volume, such as 2500 m^3 or greater, such that the output per reactor can be higher (for example, an order of magnitude higher). Furthermore, the residence time of the closed loop well reactor operating on thermosiphon can be on the order of several to tens of hours, whereas most surface reactor vessels are operated with a residence time on the order

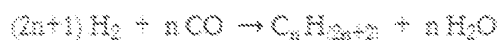
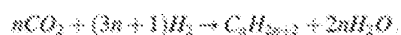
of seconds to minutes. Both high reactor volume (and longer residence time) and high reactor pressure can enable higher single pass conversion for certain chemical reactions, reducing required surface infrastructure (improving capital efficiency), improving energy efficiency and reducing required catalyst activity. Achieving high single-pass conversion is advantageous because it reduces the size of equipment required for recycle streams, such as heat exchangers, compressors, pumps, separators, refrigeration units and other equipment. This leads to lower overall plant capital costs, and a reduced electrical / energy demand on process mechanical equipment which enhances the energy efficiency of the process.

[0033] Chemical plants and processes significantly benefit from economies of scale, which is why most commodity chemical plants are typically large. For example, a 3300-ton/day ammonia plant may achieve a 11% lower specific cost than a conventional 2000-ton/day plant. However, increasing the size of reaction vessels to support higher plant capacities is challenging due to transportation and site limitations, making vessel size a key constraint in scaling up new facilities. A closed loop well reactor can eliminate these logistical constraints, enabling larger scale chemical facilities with improved capital efficiency.

[0034] In some instances, the closed loop well as a reactor well 200 can be operated in a batch manner rather than a continuous manner. This batch method involves circulating a fluid composition with a higher density and a fluid composition with a lower density within a loop. The lower density fluid contains the reactants and/or catalysts necessary for the reaction. The higher density fluid follows, ensuring that the lower density fluid remains in the multilateral reactor. During the reaction phase, the hydrostatic head generated by the denser fluid creates a higher-pressure reactor zone. Circulation can be stopped or slowed, to allow time for the reaction to progress to completion. Pumps can be used to circulate the fluids out of the closed loop well for further processing. This cyclic process can be repeated. This method of operation is most advantageous when very high pressures and/or longer residence times are necessary.

[0035] The well systems described herein could be used to produce many different products, and optimized to maximize yield of a certain product or a certain mix of products. In some instances, reactor well 200 can be used for the production of fuels such as jet fuel, gasoline, or diesel. For example, in some instances, reactor well 200

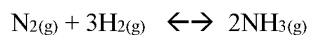
can be used for Fischer Tropsch synthesis either the direct CO₂ pathway or the CO pathway shown below:



For purposes of Fischer Tropsch synthesis, catalyst bed 208 can include, for example Fe, Co, Cu, ZnO, and/or Al₂O₃ based catalyst materials. The Fischer–Tropsch process can be operated in the temperature range of 150–300° C. Higher temperatures lead to faster reactions and higher conversion rates, but also tend to favor methane production. For this reason, in lower pressure applications, the temperature can be maintained at the low to middle part of the range. Increasing the pressure leads to higher conversion rates and also favors formation of long-chained alkanes, both of which may be desirable. Typical pressures can range from one to several tens of atmospheres. In certain instances, the reaction well 200 can enable increasing pressure to ~400-2000 atmospheres and at high temperature, which can result in high conversion rates and high yield of longer-chain alkanes than feasible with typical surface reactors.

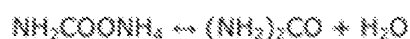
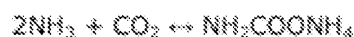
[0036] In certain instances, the reactor well 200 can facilitate a single step conversion from CO₂ and H₂ to fuel. The concepts herein can also be applicable to reactions where the CO and H₂ are the primary reactants, which is a 2-step process – creation of CO from CO₂ with reverse water gas shift (RWGS) reaction followed by Fischer-Tropsch synthesis. Two-step reactions have either low CO₂ conversion and low selectivity of higher chain hydrocarbons, or both. Some catalysts have high CO₂ conversion but low C₅+ selectivity (for example FeNa), or low CO₂ conversion but higher C₅+ selectivity (for example Na-Fe₃O₄/HZSM-5). The single-step reaction shows improvements in reactant conversion and selectivity to jet-fuel range hydrocarbons. For example, the single-step reaction can have yield of ~19% of jet fuel products, which can provide a 50% reduction in unit capital costs.

[0037] In some instances, the well systems and methods described herein could be used to produce other products. For example, reactants nitrogen and hydrogen can be used as reactants 204 for the production of ammonia using the Haber–Bosch process:

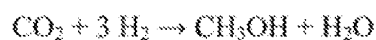
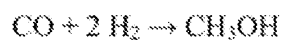


The ammonia synthesis process today typically operates at high temperature $>400^{\circ}\text{C}$, and at pressures of 10-20 MPa. Typical single pass conversion is in the $\sim 20\%$ range at these operating conditions. Higher pressure and low temperature lead to high conversion (both conditions feasible in a closed loop well reactor). Low pressures and high temperatures, although they lead to lower conversion, are used today to optimize the reaction with surface, energy efficiency and material constraints. Using a subsurface wellbore network enables the economical use of higher pressures (400-2000 atmospheres) and much higher single pass conversions. This may involve relying on a different or modified reaction pathway that is similar to the Claude process or the Casale process. The long residence time of the closed loop well reactor allows for the economical use of lower-activity (and less expensive) catalysts without compromising selectivity or yield.

[0038] In some instances, to produce urea as product 206, ammonia and carbon dioxide can be injected as reactants 204 to form ammonium carbamate, which then can decompose to form urea:



[0039] In some instances, product 206 can be methanol produced by reaction of carbon monoxide or carbon monoxide and hydrogen as reactants 204:



In some instances, product 206 can be methanol produced by direct reaction of CH_4 :



[0040] In some instances, the reactions include the conversion of methanol, ethanol, iso-butanol or other alcohols to acetic acids, formaldehyde, methyl tert-butyl ether, gasolines, olefins, kerosene and / or other oligomerization products.

[0041] In some instances, the reactions can include high-pressure polymerization

[0042] In some instances, the reactions include extraction methods of critical minerals and metals including high pressure acid leaching, pressure oxidation and other forms of pressure leaching.

[0043] In some instances, the reactions include conversion of hydrocarbon, biomass or bio waste feedstocks into fuels by processes including hydrothermal liquefaction, hydrothermal carbonization and supercritical fluid extraction.

[0044] In some instances, the reactions involve hydrogenation to upgrade hydrocarbons into more valuable products through processes like supercritical water upgrading.

[0045] The term “uphole” as used herein means in the direction along a wellbore tubing string or the wellbore from its distal end (furthest from the surface) towards the surface, and “downhole” as used herein means the direction along a tubing string or the wellbore from the surface towards its distal end. A downhole location means a location along the tubing string or wellbore downhole of the surface.

[0046] While this disclosure contains many specific implementation details, these should not be construed as limitations on the subject matter or on what may be claimed, but rather as descriptions of features that may be specific to particular implementations. Certain features that are described in this disclosure in the context of separate implementations can also be implemented, in combination, or in a single implementation. Conversely, various features that are described in the context of a single implementation can also be implemented in multiple implementations, separately, or in any suitable sub-combination. Moreover, although previously described features may be described as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can, in some cases, be excised from the combination, and the claimed combination may be directed to a sub-combination or variation of a sub-combination.

[0047] Particular implementations of the subject matter have been described. Nevertheless, it will be understood that various modifications, substitutions, and alterations may be made. While operations are depicted in the drawings or claims in

a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed (some operations may be considered optional), to achieve desirable results. Accordingly, the previously described example implementations do not define or constrain this disclosure.

WHAT IS CLAIMED IS:

1. A geothermal reactor well system comprising:
 - a closed-loop well coupled to one or more sources of reactants, the closed-loop well comprising:
 - a first surface wellbore extending from a terranean surface to a geothermal subterranean zone;
 - a second surface wellbore extending from the terranean surface to the geothermal subterranean zone; and
 - plurality of connecting wellbores connecting the first surface wellbore to the second surface wellbore; and
 - a carrier fluid disposed within the closed-loop well, the closed-loop well configured such that heat energy from the geothermal subterranean zone and/or reaction of reactants in the closed-loop well drives the fluids in the closed-loop well to circulate by thermosiphon and to thereby carry the reactants through the closed-loop well for the reaction and carry a product of the reaction through the closed-loop well for collection.
2. The geothermal reactor well system of claim 1, wherein the reaction is driven in part by heat energy from the geothermal subterranean zone.
3. The geothermal reactor well system of claims 1 or 2, wherein the closed wellbore loop is configured such that a pressure and temperature within the closed wellbore loop are within a specified pressure and temperature range for the reaction.
4. The geothermal reactor well system of any of claims 1 to 3, wherein the closed-loop well further comprises a catalyst bed disposed therein.
5. The geothermal reactor well system of claim 4, where the catalyst bed comprises a slurry.

6. The geothermal reactor well system of any of claims 1 to 5, wherein the geothermal subterranean zone has an inherent temperature of at least 200 degrees Celsius surrounding at least a portion of the connecting wellbores.
7. The geothermal reactor well system of any of claims 1 to 6, wherein the product is a fuel product.
8. The geothermal reactor well system of any of claims 1 to 6, wherein the reaction comprises Fischer Tropsch synthesis.
9. The geothermal reactor well system of any of claims 1 to 6, wherein the product comprises ammonia.
10. The geothermal reactor well system of any of claims 1 to 6, wherein the product comprises methanol.
11. The geothermal reactor well system of any of claims 1 to 10, wherein at least a portion of the plurality of connecting wellbores are sealed against communication of fluids between the connecting wellbores and the surrounding geothermal subterranean zone.
12. A method comprising:
 - disposing reactants in a closed-loop well from one or more sources of reactants coupled thereto, the closed-loop well comprising:
 - a first surface wellbore extending from a terranean surface to a geothermal subterranean zone;
 - a second surface wellbore extending from a terranean surface to the geothermal subterranean zone; and
 - plurality of connecting wellbores connecting the first surface wellbore to the second surface wellbore; and
 - disposing a carrier fluid within the closed-loop well;
 - circulating the carrier fluid to carry the reactants through the closed wellbore loop, the circulation driven by thermosiphon from heat energy from the geothermal

subterranean zone and/or reaction of reactants in the closed-loop well; and
collecting from the closed-loop well a product from a reaction of the
reactants.

13. The method of claim 12, wherein the reaction is driven in part by heat energy from the geothermal subterranean zone.
14. The method of claims 13 or 14, further comprising configuring the closed wellbore loop such that a pressure and temperature within the closed wellbore loop are within a specified pressure and temperature range for the reaction.
15. The method of any of claims 12 to 14, wherein the closed-loop well further comprises a catalyst bed disposed therein, and wherein the circulating comprises circulating the carrier fluid and the reactants through the catalyst bed.
16. The method of claim 15, where the catalyst bed comprises a slurry.
17. The method of any of claims 12 to 16, wherein the geothermal subterranean zone has an inherent temperature of at least 200 degrees Celsius surrounding at least a portion of the connecting wellbores.
18. The method of any of claims 12 to 17, wherein the product is a fuel product.
19. The method of any of claims 12 to 17, wherein the reaction comprises Fischer Tropsch synthesis.
20. The method of any of claims 12 to 17, wherein the product comprises ammonia.
21. The method of any of claims 12 to 17, wherein the product comprises methanol.