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METHOD FOR PRODUCING HYDROCARBONS IN AN IN SITU COMBUSTION OPERATION

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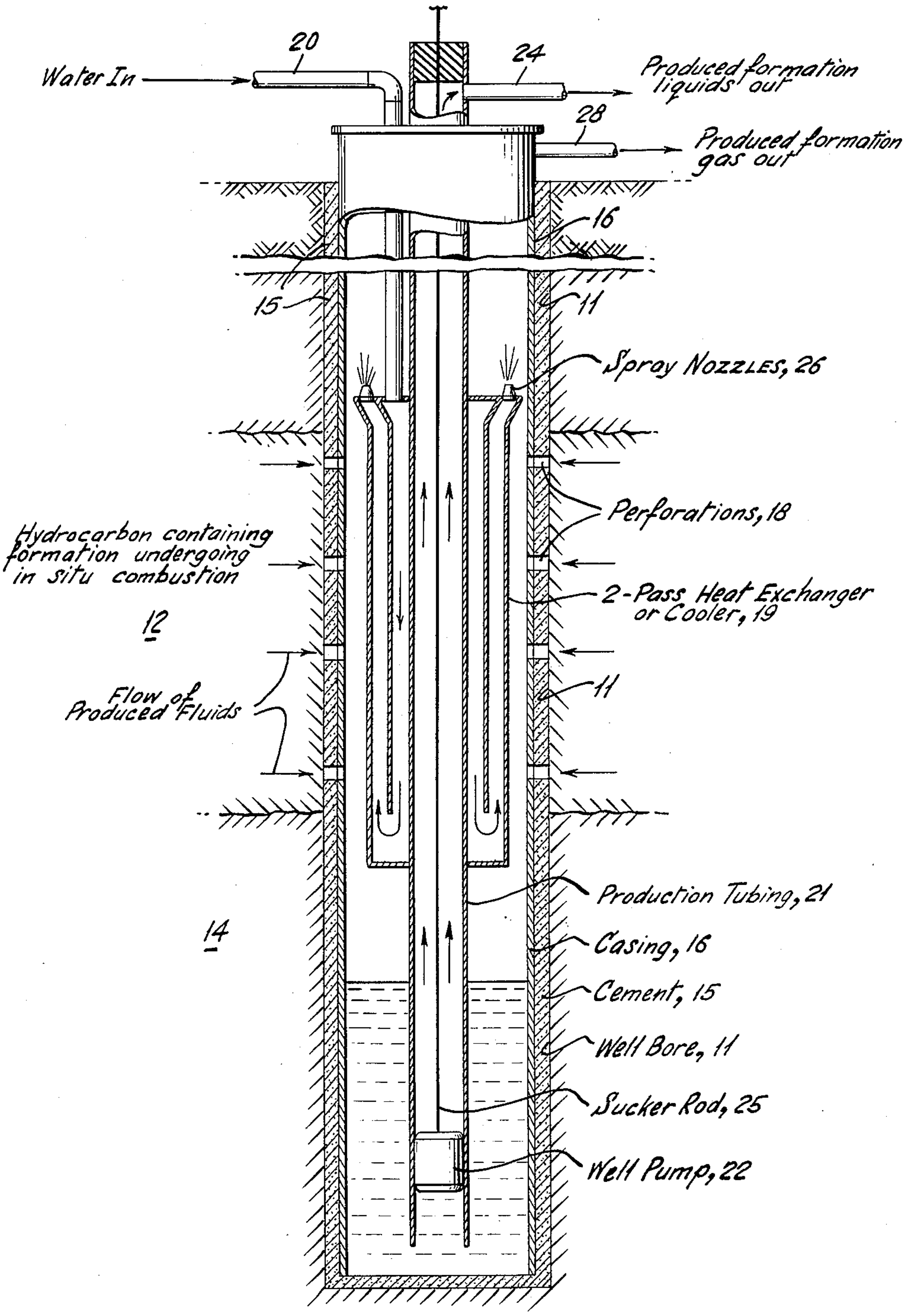

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METHOD FOR PRODUCING HYDROCARBONS IN AN IN SITU COMBUSTION OPERATION

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This invention relates to the production of hydrocarbons from hydrocarbon-containing formations. More particularly, this invention relates to a method of carrying out an in situ combustion operation for the production and recovery of hydrocarbons from a hydrocarbon-containing formation, such as a petroleum producing formation, tar sands, oil shales and the like. In accordance with one specific embodiment this invention is directed to a well completion assembly particularly useful in the production of hydrocarbons from underground formations by a method involving in situ combustion.

Various techniques have been proposed for the recovery of hydrocarbons from underground formations and for the treatment of hydrocarbon-containing formations. For example, for the recovery of petroleum from petroleum producing formations secondary recovery operations which involve water flooding or thermal recovery methods such as in situ combustion, employing at least one injection well and at least one production well, have been proposed. As indicated hereinabove, the practice of this invention is particularly directed to thermal recovery methods such as methods involving in situ combustion for the production of petroleum and the like from underground formations.

Explanatory of an in situ combustion operation and indicative as to how an in situ combustion operation may be carried out, a high temperature zone is established in an underground hydrocarbon or petroleum-containing formation in the vicinity of a wellbore penetrating the same. Suitable means for establishing or creating a high temperature zone within the wellbore penetrating a hydrocarbon-containing formation may comprise an electric heating device or a gas fired bottom hole igniter or heater. A suitable device for initiating in situ combustion and for establishing a high temperature zone within a wellbore is described in U.S. 2,722,278. Upon introducing a combustion-supporting gas, such as air, into the thus-heated wellbore adjacent the petroleum-containing formation a resulting high temperature combustion zone is generated therein by the reaction between the oxygen and the combustible petroleum hydrocarbons or residues within the formation, such as combustible residues resulting from the distillation and/or thermal cracking of the petroleum hydrocarbons originally in place or introduced thereinto. This high temperature combustion zone (temperature in the range 700–2000° F., more or less) will commence to move into the formation outwardly from the wellbore upon continued introduction of air into the wellbore. Leaving this high temperature zone is a relatively high temperature gas stream which, as it moves outwardly into the formation, loses heat to the formation. By this method the high temperature combustion zone or flame front is moved for a considerable distance, for example a distance in the range 3–25′, more or less, outwardly from the wellbore into the formation without further direct application of heat to the zone of the formation adjacent the wellbore. Continued direct application of heat to this zone, however, may sometimes be desirable. The distance which the high temperature combustion zone moves radially outwardly, and as a result the volume of the petroleum-containing formation swept by or comprised within the high temperature in situ combustion zone, is determined by the relative magnitude of the rate of heat generation (combustion of combustible residues) and the rate of heat loss to the surrounding formation.

It has been postulated that the following mechanisms are important in the movement of the high temperature combustion zone outwardly from a wellbore into the petroleum producing formation during an in situ combustion operation therein. Although the exact mechanism of an in situ combustion is not definitely and completely known, the following sequence of events are postulated and are presented herein for the purpose of enabling one skilled in the art to better understand this invention.

As the high temperature combustion zone approaches any given volume of the hydrocarbon or petroleum-containing formation the temperature of this volume of formation rises. This results, first, in a reduction in the viscosity of the formation fluids therein (oil, water) due to temperature increase. These fluids may then be moved more readily under the influence of the hot combustion gas stream continuously emanating from the high temperature combustion zone. As the temperature continues to rise, distillations of the formation fluids begin. The products of these distillations condense in cooler regions of the formation removed from the high temperature combustion zone in the direction of flow of the hot combustion gases therein. The distillations continue as the temperature rises within the given portion of the formation until the heavier components remaining from the hydrocarbons or petroleum originally in place within the formation or introduced thereinto prior to initiating in situ combustion therein begin to crack and yield hydrocarbon gases, oxygenated hydrocarbons, oxides of carbon, other combustion products, as well as coke and similar solid carbonaceous residues. As the temperature continues to rise and the oxygen content of the incoming combustion-supporting gas increases due to depletion of combustible residues in the preceding regions of the formation, a point will be reached at which the coke or other combustible residues will begin to react with the oxygen with the resulting release of heat to the formation and the combustion gas stream emanating therefrom. This heat is carried away by the on-moving combustion gas stream and also to some extent by thermal conduction to adjoining regions of the formation. When the coke or combustible residue has been burned away there remains a volume of liquid-free formation.

Another method of carrying out an in situ combustion operation involving operations as disclosed hereinabove, i.e., initiation of a high temperature zone within a wellbore and then causing an in situ combustion zone to move outwardly therefrom into the formation toward a production well, is known. In this method after the high temperature combustion zone has moved a sufficient distance outwardly from the wellbore, such as a distance in the range 5–50′, air or other combustion-supporting gas is injected into another well removed from the well wherein in situ combustion was initiated. When these operations are carried out the in situ combustion zone or flame front moves countercurrently with respect to the flow of the combustion-supporting gas (air) within the formation undergoing treatment, i.e., the in situ combustion zone moves toward the other well into which the combustion-supporting gas is injected while the combustion-supporting gas as well as the resulting hot combustion gases and displaced hydrocarbons, partially oxygenated hydrocarbons, etc., move from this other well toward the well wherein in situ combustion was initiated. The mechanisms and technique for carrying out an in situ combustion operation in accordance with this method are completely disclosed in U.S. 2,793,696. The disclosures of this patent are herein incorporated and made part of this disclosure.

In an in situ combustion operation many difficulties arise in the production well, i.e., the well wherein the formation fluids displaced in the in situ combustion operation are recovered and produced. These wells in an in situ combustion operation are subjected to rather high temperature, above about 800° F. Under the high temperature conditions experienced in an in situ combustion operation these wells are subject to failure due to tubing, liner or casing collapse brought on by the high temperatures in the wells. Additionally well fires sometimes occur therein. These well fires arise due to the intermingling within the well of the produced hydrocarbons or partially oxygenated hydrocarbons with an oxidizing or oxygen-containing gas such as air. Further, in some instances the high temperatures experienced in an in situ combustion operation sometimes cause collapse of the wellbore itself, if the wellbore is unsupported, due to the well fires or explosions within the wellbore.

Accordingly, it is an object of this invention to provide an improved in situ combustion operation for the production of hydrocarbons or partially oxygenated hydrocarbons from hydrocarbon-containing formations such as petroleum formations, tar sands, oil shales and the like.

Another object of this invention is to provide a method for carrying out an in situ combustion operation wherein the production well, i.e., the well wherein the resulting displaced formation fluids are produced, is protected against the high temperatures experienced in an in situ combustion operation.

Yet another object of this invention is to provide a method for the elimination of well fires in a production well involved in an in situ combustion operation.

Yet another object of this invention is to provide a method for the protection of the well and/or equipment of a production well involved in an in situ combustion operation.

Still another object of this invention is to provide a method for the creation of a substantially non-oxidizing environment in the wellbore of a production well involved in an in situ combustion operation.

How these and other objects of this invention are accomplished will become apparent in the light of the accompanying disclosure and drawing which schematically illustrates one embodiment of the practice of this invention particularly directed to a method of operating a production well involved in an in situ combustion operation. In at least one embodiment of the practice of this invention at least one of the foregoing objects will be achieved.

In an in situ combustion operation wherein a well bore penetrates a hydrocarbon-containing formation which is undergoing in situ combustion and wherein formation fluids are displaced during the in situ combustion operation and are produced via the well bore, improved operation is obtained by cooling the wellbore adjacent the formation undergoing in situ combustion. The resulting produced formation fluids, gaseous hydrocarbons, liquid hydrocarbons, partially oxygenated hydrocarbons and combustion gases are cooled as they enter the well bore. Within the well bore the thus-produced liquids are collected at a location or sump therein relatively remote from that portion of the wellbore adjacent the formation undergoing in situ combustion and are recovered therefrom at the surface. Desirably suitable pumping means are located within the wellbore wherein the thus-produced liquids are collected as means for moving these liquids to the surface.

In the practice of this invention, particularly with respect to one embodiment thereof as illustrated in the accompanying drawing, a wellbore **11** is shown penetrating a hydrocarbon-containing formation **12**. As illustrated in the drawing the wellbore **11** extends through the hydrocarbon-containing formation **12** into an underlying formation **14**, which may be the lower portion of formation **12**, wherein the wellbore is bottomed. The wellbore **11**, particularly that portion penetrating hydrocarbon-containing formation **12**, is shown lined with cement **15**. Also, as illustrated the wellbore is provided with a casing **16** extending through the hydrocarbon-containing formation **12** into the underlying formation **14**. The casing, cement and formation are perforated at **18** to provide for the entry of the formation fluids displaced during the in situ combustion operation from the hydrocarbon-containing formation **12** into the interior of casing **16**.

Within casing **16** is positioned a heat exchanger or cooler **19**, such as a two-pass heat exchanger, which is provided with a conduit **20** for the supply of liquid coolant such as water or formation brine and the like. The heat exchanger or cooler **19** is positioned within wellbore **11** adjacent the hydrocarbon-containing formation which is undergoing in situ combustion and located therein so as to cool or maintain the wellbore temperature at a relatively low level during the in situ combustion operation. Extending through well bore **11**, and preferably through heat exchanger **19**, as shown, is production tubing **21**. Production tubing **21** is shown concentrically positioned within wellbore **11** and with rerespect to heat exchanger **19**. As illustrated production tubing **21** extends below heat exchanger **19** into the lower end of wellbore **11**. This lower end of wellbore **11** serves as a sump for the collection of the formation liquids, such as liquid hydrocarbons, partially oxygenated hydrocarbons, water, etc., displaced into wellbore **11** during the in situ combustion operation.

Associated with production tubing **21** is a well pump **22** adapted to withdraw formation liquids which collect in the lower end of wellbore **11** and to pump the same via production tubing **21** for recovery at the surface through conduit **24**. As illustrated, pump **22** is actuated by means of sucker rod **25** operatively connected at the upper end thereof to a suitable lifting or pumping means, not illustrated. As illustrated in the drawing, heat exchanger **19** is provided with spray nozzles **26** for spraying into the wellbore **11** the liquid coolant which is supplied via conduit **20** into heat exchanger **19** which is employed to cool the wellbore and the resulting produced formation fluids by indirect heat exchange.

In the practice of this invention as illustrated in the accompanying drawing formation fluids, including liquid hydrocarbons, partially oxygenated hydrocarbons as well as gaseous hydrocarbons and gaseous products of combustion such as carbon dioxide, carbon monoxide, steam in varying amounts, are produced or displaced from the hydrocarbon-containing formation **12** during the in situ combustion operation as these formation fluids enter wellbore **11** via perforations **18**. As the relatively hot formation fluids enter wellbore **11** they are cooled by indirect heat exchange with the liquid coolant flowing within heat exchanger **19** positioned within wellbore **11** immediately adjacent the formation **12** undergoing in situ combustion. Due to the close proximity of the heat exchanger **19** to the wellbore **11** and casing **16** and production tubing **21** these elements are effectively protected against unduly high temperatures during the in situ combustion operation, particularly as the high temperature combustion zone approaches wellbore **11**. Accordingly, equipment failure such as casing collapse and tubing collapse and wellbore disruption is inhibited or avoided. As the formation fluids enter the wellbore **11** via perforations **18** they are cooled by cooler **19**. Certain of the components will condense and collect in the lower end of wellbore **11** together with the produced formation liquids. The produced gases and vaporous formation fluids within wellbore **11** are withdrawn from wellbore **11** at the surface through suitable means such as conduit **28**. The formation liquids which accumulate in the bottom of wellbore **11** are pumped therefrom by means of well pump **22** which is operated through sucker rod **25** and recovered at the surface via conduit **24**.

In accordance with a specific feature of this invention in addition to the cooling of the wellbore and associated well equipment adjacent the formation undergoing in situ combustion by indirect heat exchange with cooler **19**, the wellbore and associated equipment therein are effectively cooled by direct contact with the liquid coolant introduced into heat exchanger **19** via line **20**. In accordance with this embodiment instead of returning the coolant, such as water, from cooler **19** back to the surface (by means not shown) the liquid coolant is forced through spray nozzles **26** associated with cooler **19** with the result that a liquid spray of coolant is forced into the wellbore **11** in the vicinity of the formation undergoing in situ combustion. This spray of liquid coolant by direct contact serves very effectively to cool the wellbore and associated equipment therein. Additionally vaporization of the coolant provides a shielding, non-oxidizing atmosphere within the wellbore with the result that wellbore fires and explosions are avoided.

Any suitable coolant, liquid or non-combustible gas, may be effectively employed in the practice of this invention. Suitable coolants, in addition to water, include aqueous brines such as formation brines. Aqueous brines and the like are less desirable, however, since brines tend to deposit salt within the wellbore. In some instances the resulting produced formation fluids such as liquid hydrocarbons and the like might be employed as the liquid coolant. In those instances where formation fluids are employed as coolants it would be more desirable to return the formation fluids to the surface rather than spraying them within the wellbore.

As illustrated in the drawing, the pump **22** is shown positioned in the lower end of wellbore **11**, below formation **12**. By thus positioning the pump **22** at a location in the wellbore relatively remote from that portion of formation **12** undergoing in situ combustion the well pump is less likely to be exposed to unduly high temperatures during the in situ combustion operation. If desired, however, well pump **22** may be positioned within or in close heat exchange relationship with cooler **19** so that cooler **19** effectively protects the well pump from high temperatures.

Although in the practice of this invention, as illustrated in the drawing, the wellbore **11** is shown lined with cement and provided with a casing, and perforated, an uncased or open wellbore might also be employed. In such a situation the produced formation fluids enter directly the wellbore from the formation.

As will be apparent to those skilled in the art many modifications and improvements which do not depart from the spirit or scope of this invention will present themselves to those skilled in the art in the light of this disclosure.

I claim:

1. A method of producing hydrocarbons from a subsurface hydrocarbon-containing formation including the steps: (1) initiating in situ combustion within said formation to heat the formation fluids therein, (2) displacing the resulting heated formation fluids, including liquid hydrocarbons, during the in situ combustion operation from the zone of in situ combustion toward the well bore of a production well penetrating said formation, (3) cooling by indirect heat exchange with a relatively cool liquid the resulting relatively hot formation fluids as they enter said well bore at a location adjacent said formation undergoing in situ combustion and by direct heat exchange by spraying coolant into contact with said well bore adjacent said formation to the extent necessary to avoid equipment failure and wellbore disruption due to high temperature conditions experienced as a result of said in situ combustion, (4) collecting the resulting cooled formation fluids within said wellbore at a location therein remote from said formation, and (5) transferring the resulting cooled formation fluids from the last mentioned location via said wellbore to the surface.

2. A method of producing hydrocarbons from a subsurface hydrocarbon-containing formation which comprises subjecting said formation to an in situ combustion operation to displace said hydrocarbons from said formation toward a production well penetrating said formation, cooling the thus-displaced hydrocarbons leaving said formation as the displaced hydrocarbons enter the well bore of said production well adjacent said formation to cool the thus-displaced hydrocarbons therein to the extent necessary to prevent casing and tubing collapse and wellbore disruption due to fire, explosion and other high temperature conditions as a result of said in situ combustion, collecting the thus-displaced hydrocarbons within said wellbore at a location therein relatively remote from said formation, and producing the resulting cooled hydrocarbons from said location, said cooling of the displaced hydrocarbons being accomplished by passing an aqueous liquid in indirect heat exchange with said displaced hydrocarbons and by spraying said aqueous liquid within said well bore adjacent said formation undergoing in situ combustion for direct heat exchange.

3. A method of producing formation hydrocarbons from a subsurface hydrocarbon-containing formation which comprises subjecting said formation to an in situ combustion operation to displace formation hydrocarbons within said formation toward a production well penetrating said formation, the wellbore of said well adjacent said producing formation being subjected to a relatively high temperature due to the aforesaid in situ combustion operation, cooling said wellbore adjacent said formation to maintain said wellbore relatively cool with respect to the in situ combustion operation being carried out within said formation by indirect heat exchange with a liquid coolant flowing through said well and by direct heat exchange by spraying liquid coolant into contact with said well bore adjacent said formation, and to the extent necessary to inhibit wellbore equipment failure and disruption due to high temperature conditions experienced in said wellbore as a result of said in situ combustion operation within said formation, collecting the displaced cooled hydrocarbons as they enter the wellbore from the formation undergoing in situ combustion, the resulting cooled hydrocarbons being collected within said wellbore at a location therein relatively remote from said formation, and producing the thus-collected hydrocarbons from said location of said wellbore.

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