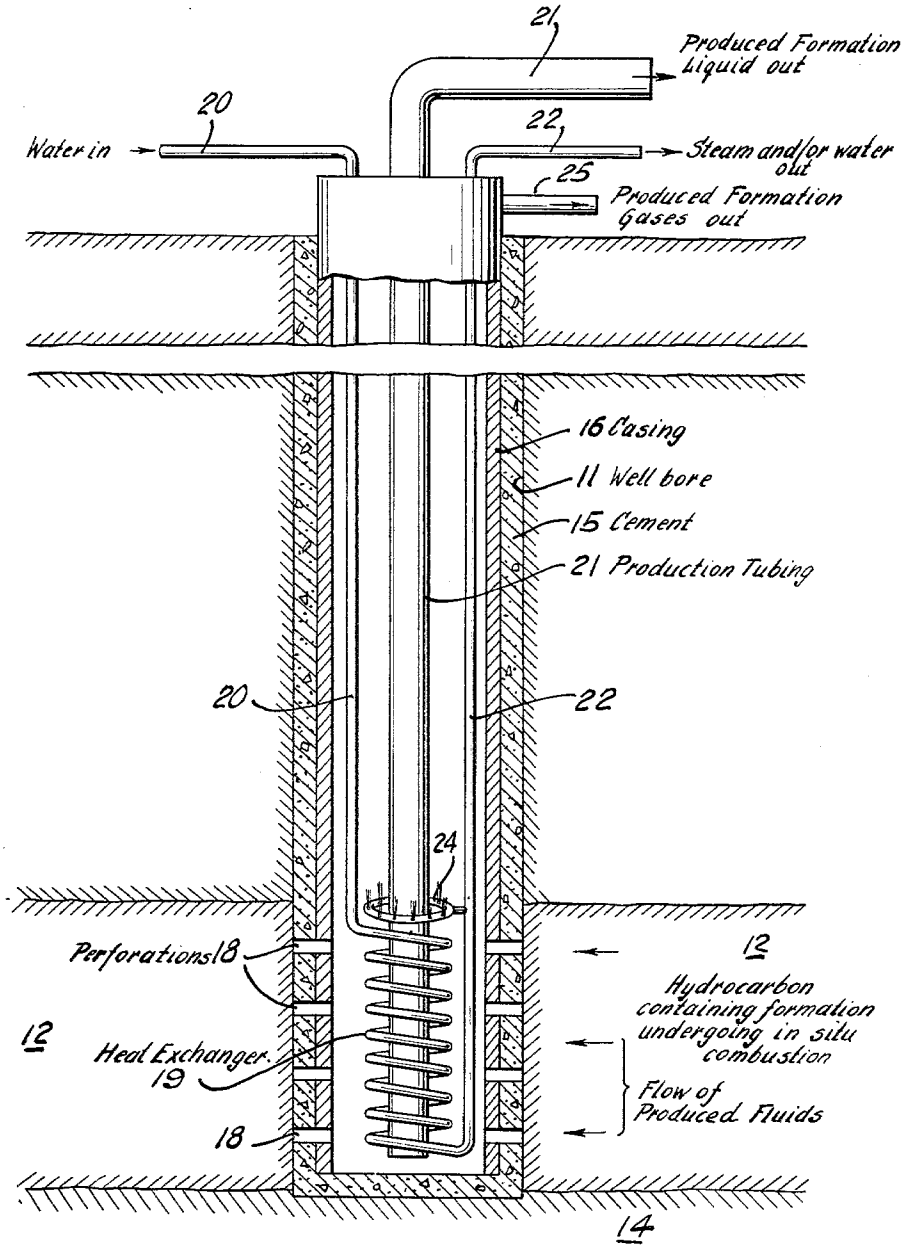
Jan. 11, 1966 A. M. SHOOK 3,228,471

METHOD FOR PRODUCING HYDROCARBONS IN AN IN SITU COMBUSTION OPERATION

Filed June 11, 1958



United States Patent Office 3,228,471 Patented Jan. 11, 1966

3,228,471

METHOD FOR PRODUCING HYDROCARBONS IN AN IN SITU COMBUSTION OPERATION

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Filed June 11, 1958, Ser. No. 741,334
5 Claims. (Cl. 166—39)

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 well bore penetrating the same. Suitable means for establishing or creating a high temperature zone within the well bore 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 well bore is described in U.S. 2,722,278. Upon introducing a combustion-supporting gas, such as air, into the thus-heated well bore 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 well bore upon continued introduction of air into the well bore. 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 well bore into the formation without further direct application of heat to the zone of the formation adjacent the well bore. 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 well bore 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, gas) 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 well bore 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 well bore, 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 well bore itself if the well bore is unsupported, due to the well fires or explosions within the well bore.

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 well bore 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 wellbore penetrates a hydrocarbon-containing formation which is undergding in situ combustion and wherein formation fluids such as hydrocarbons displaced in the in situ combustion operation, as well as partially oxygenated hydrocarbons, are produced, improved operation is obtained by cooling the well-bore adjacent the formation undergding in situ combustion during the in situ combustion operation and while the wellbore is being subjected to the high temperature involved in the in situ combustion operation.

More particularly, in accordance with the practice of this invention the wellbore of a well producing formation fluids from an underground hydrocarbon-containing formation undergoing in situ combustion is maintained relatively cool by positioning within the wellbore of the production well suitable heat exchange means or a cooler so that the resulting produced formation fluids, including oxygenated combustion products, as well as the wellbore adjacent the formation undergoing in situ combustion is cooled.

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 well bore 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 coil or 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 well bore **11** adjacent the hydrocarbon-containing formation which is undergoing in situ combustion and located therein so as to cool or maintain the well bore 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 well bore **11** and with respect to heat exchanger **19**. As illustrated production tubing **21** extends below heat exchanger **19** into the lower end of well bore **11**. This lower end of well bore **11** serves as a sump for the collection of the formation liquids, such as liquid hydrocarbons, partially oxygenated hydrocarbons, water, etc., displaced into well bore **11** during the in situ combustion operation.

Heat exchanger **19** is provided with a conduit **22** for the return of the relatively hot water and/or steam generated within heat exchanger **19**. The relatively hot steam and water is recovered at the surface via conduit **22** and may be recycled to the well bore via conduit **20** and/or employed for the recovery of the heat energy therein. Also, as indicated in the accompanying drawing, heat exchanger **19** has associated therewith a ring sparger **24** in communication with conduit **22**. If desired, all or a portion of the coolant supplied to heat exchanger **19** via line **20** may be sprayed directly into the well bore at a location therein adjacent the formation undergoing in situ combustion through suitable openings in ring sparger **24**. By this means the coolant (water) after having served to cool by indirect heat exchange the produced formation fluids as they enter the well bore now again serves to cool these produced fluids by direct contact or heat exchange therewith. When water is employed as the liquid coolant within heat exchanger **19** the resulting admixture of water and steam introduced or created within the well bore serves to provide a non-oxidizing atmosphere therein to quench any production well fires.

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 and enter well bore **11** via perfora-

tions 18. The entering hot formation fluids are cooled by indirect heat exchange with the liquid coolant flowing within heat exchanger 19 positioned within well bore 11 immediately adjacent the formation 12 undergoing in situ combustion. Due to the close proximity of the heat exchanger 19 to the well bore 11 and casing 16 and production tubing 21 (concentrically located within heat exchanger 19) in that portion of the well bore adjacent the formation undergoing in situ combustion, these elements are effectively protected against unduly high temperatures during the in situ combustion operation, particularly as the high temperature combustion zone approaches well bore 11. Accordingly equipment failure, such as casing collapse, tubing collapse, as well as well bore disruption, is inhibited or avoided. As the hot formation fluids enter the well bore 11 via perforations 18 they are cooled by heat exchanger 19. Certain of the components of the produced formation fluids will condense and collect in the lower portion of well bore 11 together with the produced formation liquids. The produced gases and vaporous formation fluids within well bore 11 are withdrawn therefrom at the surface through suitable means as conduit 25. The produced formation liquids which accumulate in the bottom of well bore 11 are recovered therefrom via production tubing 21.

In accordance with a specific feature of this invention, in addition to the cooling of the well bore and associated well equipment adjacent the formation undergoing in situ combustion by indirect heat exchange with heat exchanger 19, the well bore 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 heat exchanger 19 back to the surface via line 22, all or part of the liquid coolant is forced through ring sparger 24 with the result that a liquid spray of coolant is forced into the well bore 11 in the vicinity of the formation undergoing in situ combustion. This spray of liquid coolant serves very effectively to cool by direct contact the well bore and associated equipment therein. Additionally, vaporization of the coolant provides a shielding, non-oxidizing atmosphere within the well bore with the result that well bore fires and explosions are avoided.

Any suitable coolant, liquid or gas, may be effectively employed in the practice of this invention. Suitable coolants, in addition to water, include aqueous brines such as formation brines. 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, other than formation water or brines, are employed as coolants it would be more desirable to return these formation fluids to the surface rather than spraying them within the well bore. Other fluid coolants such as air might also be employed. When air is employed as the coolant it would be desirable to return the coolant, air, back to the surface rather than forcing it into the well bore into direct contact with the produced formation fluids therein.

Although in the practice of this invention, as illustrated in the drawing, the well bore 11 is shown lined with cement and provided with a casing, and perforated, an uncased or open well bore might also be employed. In such a situation the produced formation fluids enter directly the well bore 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 which comprises subjecting said formation to an in situ combustion operation to displace hydrocarbons within said formation toward a production well penetrating said formation, the wellbore of said well adjacent said producing formation being exposed to a relatively high temperature due to the aforesaid in situ combustion operation, flowing water within said well in indirect heat exchange relationship with said wellbore adjacent said formation undergoing in situ combustion, spraying water within and in contact with said wellbore adjacent said formation, said flowing and spraying of water within said wellbore being to the extent necessary for inhibiting casing and tubing collapse and wellbore disruption by fire and explosion, and producing hydrocarbons from said formation via said well.

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 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 and due to the movement of relatively high temperature formation fluids emanating from said in situ combustion operation and entering said wellbore adjacent said formation, flowing water within said welbore adjacent said formation in indirect heat exchange relationship with the formation fluids entering said wellbore, spraying the resulting heated water or resulting steam wthin and in contact with said wellbore adjacent said formation, and producing the resulting cooled formation fluids, including said hydrocarbons, from said wellbore via said well, said flowing of water and said spraying of heated water or resulting steam within said wellbore being to the extent required for inhibiting the collapse of well casing and tubing as a result of high temperatures therein and wellbore disruption from well fires and explosions within the wellbore.

3. 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, from the zone of the aforesaid in situ combustion operation toward the wellbore of a production well penetrating said formation, (3) cooling the resulting produced formation fluids within said wellbore adjacent said formation by indirect heat exchange with a relatively cool liquid and by direct heat exchange by spraying coolant into contact with said wellbore adjacent said formation, and (4) producing the resulting cooled formation fluids, including hydrocarbons, from said formation via said well.

4. A method of producing liquid hydrocarbons from a subsurface hydrocarbon-containing formation which comprises subjecting said formation to an in situ combustion to displace said hydrocarbons from said formation toward a production well penetrating said formation, cooling the hydrocarbons leaving the zone of in situ combustion within said formation and entering the wellbore of said production well adjacent said formation to condense hydrocarbons therein, and producing the resulting condensed liquid hydrocarbons from said well, said cooling of the hydrocarbon within said wellbore being achieved by passing a relatively cool liquid aqueous medium in indirect heat exchange relationship with said hydrocarbons entering said production well and by direct cooling by spraying said cool liquid aqueous medium into contact with said wellbore adjacent said formation.

5. A method in accordance with claim 4 wherein said liquid aqueous medium is water.

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