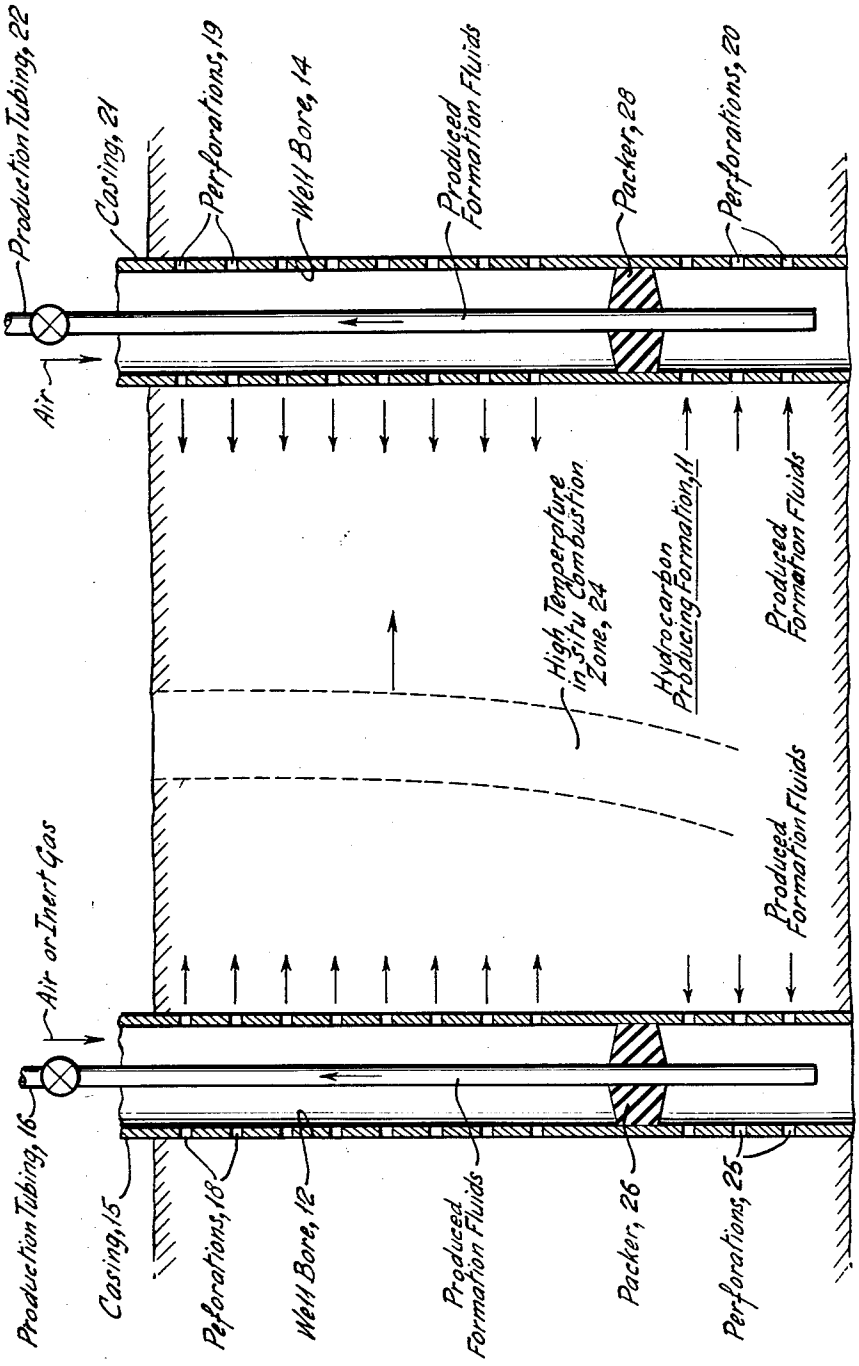
Sept. 19, 1961 R. E. KUNETKA 3,000,441

IN SITU COMBUSTION

Filed July 18, 1958



United States Patent Office 3,000,441 Patented Sept. 19, 1961

3,000,441

IN SITU COMBUSTION

Robert E. Kunetka, Houston, Tex., assignor to Texaco Inc., a corporation of Delaware

Filed July 18, 1958, Ser. No. 749,498
9 Claims. (Cl. 166—11)

This invention relates to the production of hydrocarbons, such as petroleum, from underground hydrocarbon-containing formations.

In situ the combustion has been proposed as a method of improving or enhancing the recovery of oil from underground formations. Explanatory of one type of an in situ combustion operation a high temperature zone is established in an oil-containing formation in the vicinity of a well bore penetrating the same. Suitable heating means for establishing a high temperature zone within the formation may comprise an electrical heating device or a gas fired bottom hole igniter or heater. A suitable device for initiating in situ combustion within a well bore is described in U.S. 2,722,278. Upon introducing a combustion supporting or an oxygen-containing gas, such as air, into the heated formation via the well bore a high temperature combustion zone is created by the reaction between the oxygen and combustible residues within the formation in the high temperature zone, such as combustible residues resulting from the distillation and/or thermal cracking of oil or combustible material originally in place or introduced thereinto. Upon continued introduction of the combustion supporting gas this high temperature zone will commence to move into the formation outwardly from 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 is moved for a considerable distance outwardly from the well bore without further direct application of heat to portions of the formation immediately surrounding the well bore. In some instances, however, continued direct application of heat to the formation immediately surrounding the well bore may be desirable. The distance the high temperature combustion zone moves outwardly into the formation and as a result the volume of formation swept by or comprised within the 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 this type of in situ combustion operation for the movement of the high temperature combustion zone outwardly into the formation. Although the precise mechanism of an in situ combustion operation is not definitely known, the following sequence of events in an in situ combustion operation 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-producing formation the temperature of this volume of formation rises. This results in a reduction in the viscosity of the formation liquids due to temperature increase. These liquids may then be moved more readily under the influence of the stream of gaseous products of combustion continuously emanating from the high temperature combustion zone. As the temperature continues to rise, distillations of the formation liquids therein begin. The products of these distillations condense in cooler regions of the formation removed from the high temperature combustion zone. These distillations continue until the heavier components or hydrocarbons within the formation begin to crack, yielding hydrocarbon gases and coke or similar carbonaceous residues. Also, as the temperature continues to rise and the oxygen content of the incoming combustion supporting gas increases due to depletion of combustible residues in preceding regions of the formation, a point will be reached at which the coke or other combustible residue will begin to react with the oxygen with the resulting release of heat to the formation and the on-moving combustion gas stream comprising gaseous products of combustion. 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 residues have been burned away there remains a volume of liquid-free formation which, unless otherwise treated, is gradually cooled by the relatively cool on-coming combustion supporting gas entering the formation via the well bore. It is mentioned that it is believed that the temperatures reached in the high temperature combustion zone are in the range 600–2000° F., more or less, usually in the range 700–1500° F.

In accordance with yet another type of an in situ combustion operation as completely described in U.S. 2,793,696 issued May 28, 1957, in the name of Richard A. Morse, after initiation of a high temperature combustion zone within a hydrocarbon-containing formation in the immediate vicinity of a well bore penetrating the formation, the supply of combustion supporting gas or air into the formation via this well bore is discontinued. Thereafter air or other suitable combustion supporting gas is introduced into the formation via another well bore spaced from the first mentioned well bore. The air thus-introduced into the formation via this other spaced-apart well bore serves to maintain the in situ combustion operation. However, in this instance the high temperature combustion zone moves in a direction countercurrent to the flow of air or combustion supporting gas through the formation. Moreover, in this type of in situ combustion operation, which may be conveniently called a reverse in situ combustion operation, all the displaced formation fluids pass through the high temperature combustion zone. In the first mentioned type of in situ combustion operation, which might be conveniently referred to as direct in situ combustion operation, the displaced hydrocarbons move ahead of the in situ combustion zone and are not necessarily exposed to the high temperatures prevailing in the high temperature combustion zone.

It has been observed that the above-described reverse in situ combustion operation is useful for the displacement and recovery of relatively high gravity crude oils from formations containing the same, such as crude oils having a gravity above about 20° A.P.I., especially above 30° A.P.I. Relatively low gravity crudes, such as crude oils having a gravity below about 20° A.P.I., are relatively less effectively displaced by the above-described reverse in situ combustion operation.

It is an object of this invention to provide an improved in situ combustion operation for the recovery of hydrocarbons, such as petroleum and the like, from a subsurface formation containing the same.

It is another object of this invention to provide an improved method of carrying out an in situ combustion operation, employing the so-called reverse in situ combustion operation, which is particularly applicable for the recovery of viscous hydrocarbons from subsurface formations.

Still another object of this invention is to provide a method of carrying out an in situ combustion operation generally applicable for the recovery of crude oil from

relatively high gravity or relatively low gravity crude oil-containing formations.

How these and other objects of this invention are accomplished will become apparent in the light of the accompanying disclosure made with reference to the accompanying drawing which schematically illustrates an embodiment of the practice of this invention.

In accordance with this invention a hydrocarbon-producing formation is penetrated by a first well bore and by a second well bore, said second well bore being spaced apart within said formation from said first well bore. A high temperature zone is then created in a zone within said formation adjacent said first well bore. This high temperature zone is then caused to be moved outwardly from said first well bore within said formation in the direction of said second well bore. Movement of this high temperature zone outwardly from the first well bore within the formation in the direction of the second well bore is effected by the introduction of a combustion supporting gas, such as air, from said first well bore into said hydrocarbon-producing formation. While the thus-initiated and maintained in situ combustion operation is carried out within the formation by the injection of a combustion supporting gas thereinto via said first well bore the resulting displaced formation fluids, including formation hydrocarbons, are recovered from said formation via said second well bore. After the resulting high temperature in situ combustion zone has been caused to move from the vicinity of said first well bore toward said second well bore for a substantial distance within said formation, the injection of air or combustion supporting gas into the formation via said first well bore is discontinued.

Thereupon an inert or non-combustion supporting gas is introduced into the formation via said first well bore. As this inert gas moves through the formation the thus-introduced inert gas picks up heat from the high temperature in situ combustion zone previously created within the formation and transfers heat to the adjacent portions of the formation removed from said high temperature combustion zone in the direction of flow of the inert gas through the formation toward the second well bore. When a sufficient amount of heat has been thus transferred to other portions of the formation adjacent said high temperature combustion zone such that formation fluids and/or normally viscous hydrocarbons therein exhibit a substantially reduced viscosity a combustion supporting gas, such as air, is introduced into the formation via said second well bore. Upon the commencement of the injection of the combustion supporting gas into the formation undergoing treatment the above-referred so-called reverse in situ combustion operation takes place. Upon injection of the combustion supporting gas into the formation via said second well bore the high temperature combustion zone still continues to move within the formation in the original direction, that is, from the first well bore toward the second well bore but now countercurrent to the flow of the combustion supporting gas introduced into the formation via said second well bore. During this so-called reverse in situ combustion operation the resulting displaced formation hydrocarbons are recovered from the formation via said first well bore. It is mentioned that the injection of the aforementioned inert or non-combusion supporting gas is continued for a sufficient period of time to heat the adjacent forward portions of the formation sufficiently to reduce substantially the viscosity of the formation fluids (oil) therein. Care, however, should be taken to avoid cooling the formation, particularly the high temperature combustion zone and adjacent regions within the formation below the ignition temperature or combustion temperature of the combustible materials therein, such as a temperature below about 500° F.

By operating in the aforementioned manner, which operations may be carried out alternately, a subsurface formation containing low gravity crudes, such as crude oils having a gravity below 30° A.P.I., especially a gravity below 20° A.P.I., can readily be produced.

Referring now to the accompanying drawing which schematically illustrates an embodiment of the practice of this invention directed to the production of oil from an oil-containing formation, as illustrated in the drawing an oil-containing formation **11** is penetrated by a first well bore **12** and by a second well bore **14**, the second well bore **14** being spaced-apart from said first well bore **12**. In the initial operation of the practice of this invention gas or air permeability is established across formation **11** by the introduction of gas or air via the annular space in well bore **12** between casing **15** and production tubing **16** and through perforations **18** into formation **11** in the direction of or for recovery at said second well bore **14** through perforations **19** and/or perforations **20** therein. If desired, gas permeability may be established within formation **11** by introducing gas or air into formation **11** via perforations **19**, gas or air being supplied thereto via the annular space within well bore **14** between casing **21** and production tubing **22** therein.

Following the establishment of gas or air permeability across formation **11** a high temperature zone is created by suitable means, such as by means of an electrical igniter or gas fired bottom igniter in the vicinity of well bore **12** within formation **11**. Following the establishment of this high temperature zone within formation **11** adjacent well bore **12** a combustion supporting gas, such as air, is introduced into the annular space between casing **15** and production tubing **16** via perforations **18** into formation **11**. This injected combustion supporting gas or air upon entering formation **11** via perforations **18** serves to maintain and/or initiate in situ combustion therein and to move the previously created high temperature zone, wherein in situ combustion now takes place, outwardly from well bore **12** within formation **11** in the direction of well bore **14**. During the injection of air through well bore **14** via perforations **18** into formation **11** to maintain in situ combustion therein, the resulting displaced formation fluids, including formation hydrocarbons, are recovered from formation **11** via perforations **20** located within casing **21** in the lower portion of well bore **14**. These displaced formation fluids are recovered at the surface via production tubing **22** within well bore **14**.

Upon continued injection of combustion supporting gas or air via well bore **12** and perforations **18** into formation **11**, and after the high temperature in situ combustion zone **24** has been moved outwardly from well bore **12** within formation **11** in the direction of well bore **12**, the injection of air into formation **11** via well bore **12** is discontinued. Thereupon an inert or non-combustion supporting gas is introduced into formation **11** via the annular space within well bore **12** between casing **15** and tubing **16** and perforations **18**. The thus-injected inert or non-combustion supporting gas upon passing through formation **11** from well bore **12** in the direction of well bore **14** picks up heat from the previously burned out portion of formation **11** which has already undergone in situ combustion and from the high temperature combustion zone **24** therein and transfers this heat to other portions of formation **11** adjacent and removed from high temperature zone **24** therein in the direction of well bore **14** and the flow of the resulting heated inert gas within formation **11**. As a result those portions of formation **11** not previously subjected to in situ combustion are now heated to a relatively elevated temperature, such as about ignition temperature, for the combustion hydrocarbons and/or the carbonaceous residue therein while at the same that portion of formation **11** previously swept by the in situ combustion zone is cooled. As a result of thus heating the other portions of formation **11** between the high temperature combustion zone **24** and well bore **14** the viscosity of the formation fluids therein, particularly liquid hydrocarbons or crude oil

therein, is substantially reduced. Further, it is mentioned that during the injection of the inert gas into formation **11** via well bore **12** and perforations **18** any resulting displaced formation fluids or hydrocarbons are recovered from formation **11** via perforations **20** of well bore **14** and withdrawn to the surface by means of production tubing **22**.

After a portion of the formation between high temperature zone **24** and well bore **14** has been suitably heated to reduce the viscosity of the formation fluids therein and to bring the temperature of the combustible materials therein to at least ignition temperature or the temperature to which in situ combustion takes place, the supply of inert gas to formation **11** via well bore **12** and perforations **18** is shut off. Thereupon combustion supporting gas or air is introduced into formation **11** via the annular space within well bore **14** between casing **21** and production tubing **22**.

As this injected combustion supporting gas or air moves within formation **11** from well bore **14** in the direction of well bore **12** in situ combustion is initiated and/or again maintained within formation **11**, this time in the manner of the above-described, so-called reverse in situ combustion. As a result of the continued injection of combustion supporting gas into formation **11** via perforations **19** of well bore **14** the high temperature combustion zone **24** wherein in situ combustion is now maintained still continues to move in the direction of well bore **14** as indicated by the arrow in the accompanying drawing and countercurrent to the flow of combustion supporting gas now being introduced into formation **11** via perforations **19** of well bore **14** toward well bore **12**. During this reverse type in situ combustion operation production of formation fluids from formation **11** via well bore **14** and perforations **20** and production tubing **22** is discontinued, the resulting displaced formation fluids now being recovered from formation **11** via perforations **25** in the lower portion of well bore **12**. As indicated in the accompanying drawing a packer **26** and a packer **28** are provided in the annular space within well bore **12** and well bore **14**, respectively, to separate the injected fluids and produced fluids, respectively.

In the practice of this invention any suitable inert or non-combustion supporting gas may be employed. Suitable non-combustion supporting gases include carbon dioxide, nitrogen, natural gas, gaseous products of combustion, particularly gaseous products of combustion produced during the in situ combustion operation and recovered from formation **11** by means not shown and reinjected into formation **11**. The recycle of hot gaseous products of combustion from formation **11**, recovered therefrom via perforations **20** of well bore **14** via tubing **22** and separated at the surface for reinjection, by means not illustrated, into formation **11** via perforations **18** of well bore **12**, is particularly advantageous since these gaseous products of combustion are relatively hot and more readily induce high temperatures within those portions of formation **11** not yet swept by the high temperature combustion zone **24**. By operating in the above-indicated manner as illustrated in the drawing a hydrocarbon-producing formation, such as one containing a low gravity or highly viscous crude, is satisfactorily produced by the so-called reverse in situ combustion.

If desired, and/or if advantageous, the above-described operations employing direct and reverse in situ combustion in sequence may be alternately repeated. By alternately carrying out so-called direct and reverse in situ combustion operations for the recovery of petroleum from formation **11** the temperatures at the producing well can be controlled to avoid creating undue high temperatures therein since in each type of in situ combustion operation a different well bore is employed for producing the resulting displaced formation hydrocarbons. More particularly, when an in situ combustion operation is carried out within formation **11** the injection of combustion supporting gas into formation **11** via perforations **18** of well bore **12**, the resulting displaced formation fluids are recovered from formation **11** via perforations **20** of well bore **14**. In this operation well bore **14** serves as the producing well. When the formation temperature experienced at well bore **14** during this in situ combustion operation tends to become unduly high, reverse in situ combustion is then carried out within formation **11** in the manner in accordance with this invention. When reverse in situ combustion is carried out within formation **11** well bore **12** becomes the producing well since the resulting displaced formation fluids are recovered from formation **11** via perforations **25** of well bore **12**.

As will be apparent to those skilled in the art in the light of the foregoing disclosure many modifications, alterations and changes are possible in the practice of this invention without departing from the spirit or scope thereof.

I claim:

1. A method of producing hydrocarbons from a subsurface hydrocarbon-producing formation containing heavy crude oil which comprises initiating in situ combustion in said formation in a zone adjacent a first well bore penetrating said formation, introducing a combustion supporting gas into said formation via said first well bore to maintain in situ combustion therein to make the more viscous crude oil less viscous, producing the resulting less viscous hydrocarbons from said formation via a second well bore penetrating said formation, discontinuing the injection of said combustion supporting gas into said formation via said first well bore and injecting an inert gas into said formation via said first well bore whereby heat from the high temperature in situ combustion zone within said formation is carried from said high temperature in situ combustion zone to another portion of the formation removed from said high temperature in situ combustion zone in the direction of said second well bore to reduce the viscosity of formation fluids, discontinuing the injection of said inert gas into said formation via said first well bore and introducing a combustion supporting gas into said formation via said second well bore to continue in situ combustion within said formation such that the high temperature in situ combustion zone moves within said formation in the direction of said second well bore counter-current to the flow of said combustion supporting gas introduced thereinto via said second well bore and producing the resulting less viscous hydrocarbons from said formation via said first well bore.

2. A method in accordance with claim 1 wherein said combustion supporting gas alternately introduced into said formation via said first well bore and said second well bore to continue in situ combustion therein is air.

3. A method in accordance with claim 1 wherein said inert gas introduced into said formation via said first well bore has a heat transfer agent therein comprising gaseous products of combustion.

4. A method in accordance with claim 1 wherein the resulting displaced hydrocarbons are produced from said formation only via said first well bore when combustion supporting gas is introduced into said formation via said second well bore.

5. A method in accordance with claim 1 wherein said inert gas introduced into said formation via said well bore is natural gas.

6. A method in accordance with claim 1 wherein said inert gas introduced into said formation via said first well bore comprises methane enriched with normally liquid hydrocarbons.

7. A method of carrying out an in situ combustion operation for the production of hydrocarbons from an underground formation containing viscous crude oil having an API gravity less than 30° which comprises initiating in situ combustion within said formation in a zone adjacent a first well bore penetrating said formation, introduc-

ing air into said formation via said first well bore to maintain in situ combustion therein to reduce the viscosity of said crude oil and to displace hydrocarbons of reduced viscosity from said formation toward a second well bore penetrating said formation at a distance removed from said first well bore, producing the resulting displaced hydrocarbons from said formation via said second well bore, discontinuing the injection of said combustion supporting gas into said formation via said first well bore, introducing into said formation via said first well bore a non-combustion supporting gas as a heat carrier to transfer the heat from the high temperature combustion zone created within said formation to another portion of said formation adjacent said high temperature combustion zone in the direction of said second well bore and in the direction of the flow of said non-combustion supporting gas within said formation whereby the hydrocarbons in said other portion of the formation are heated to a relatively elevated temperature to effect viscosity reduction, discontinuing the injection of said non-combustion supporting gas into said formation via said first well bore, introducing air into said formation via said second well bore to initiate and/or maintain in situ combustion in the presence of hydrocarbons with reduced viscosity within said formation in said other portion of said formation under conditions such that the high temperature combustion zone within said formation resulting from said in situ combustion moves within said formation in the direction of said second well bore and countercurrent to the flow of said combustion supporting gas introduced into said formation via said second well bore and producing the resulting displaced hydrocarbons of reduced viscosity from said formation via said first well bore.

8. A method in accordance with claim 7 wherein said combustion supporting gas and non-combustion supporting gas introduced into said formation via said first well bore are alternately injected into said formation with respect to the combustion supporting gas introduced into said formation via said second well bore.

9. A method of producing hydrocarbons from an underground formation containing viscous crude oil having an API gravity less than about 20° which comprises establishing air permeability within said formation between a first well bore and a second well bore penetrating said formation, said second well bore being removed from said first well bore, creating a high temperature combustion zone within said formation in a zone therein adjacent said first well bore, introducing air via said first well bore into said formation to initiate and/or maintain in situ combustion therein and thereby reduce the viscosity of said viscous crude oil in said formation, producing via said second well bore hydrocarbons of reduced viscosity displaced from said formation during in situ combustion, discontinuing the injection of air into said formation via said first well bore, introducing an inert gas into said formation via said first well bore to transfer heat from the high temperature zone created within said formation during the aforesaid in situ combustion operation therein to heat an adjacent portion of said formation removed from said high temperature combustion zone in the direction of flow of said inert gas therethrough to reduce the viscosity of crude oil in said formation while continuing the production of displaced hydrocarbons and formation fluids via said second well bore, discontinuing the injection of said inert gas into said formation via said first well bore, introducing air into said formation via said second well bore to initiate in situ combustion within said formation in that portion thereof adjacent the aforesaid high temperature combustion zone and heated by the flow of the aforesaid previously injected inert gas for reducing the viscosity of crude oil in said formation therein and producing the resulting displaced hydrocarbons from said formation via said first well bore.

References Cited in the file of this patent

UNITED STATES PATENTS

2,642,943	Smith	June 23, 1953
2,734,579	Elkins	Feb. 14, 1956
2,788,071	Pelzer	Apr. 9, 1957
2,793,696	Morse	May 28, 1957