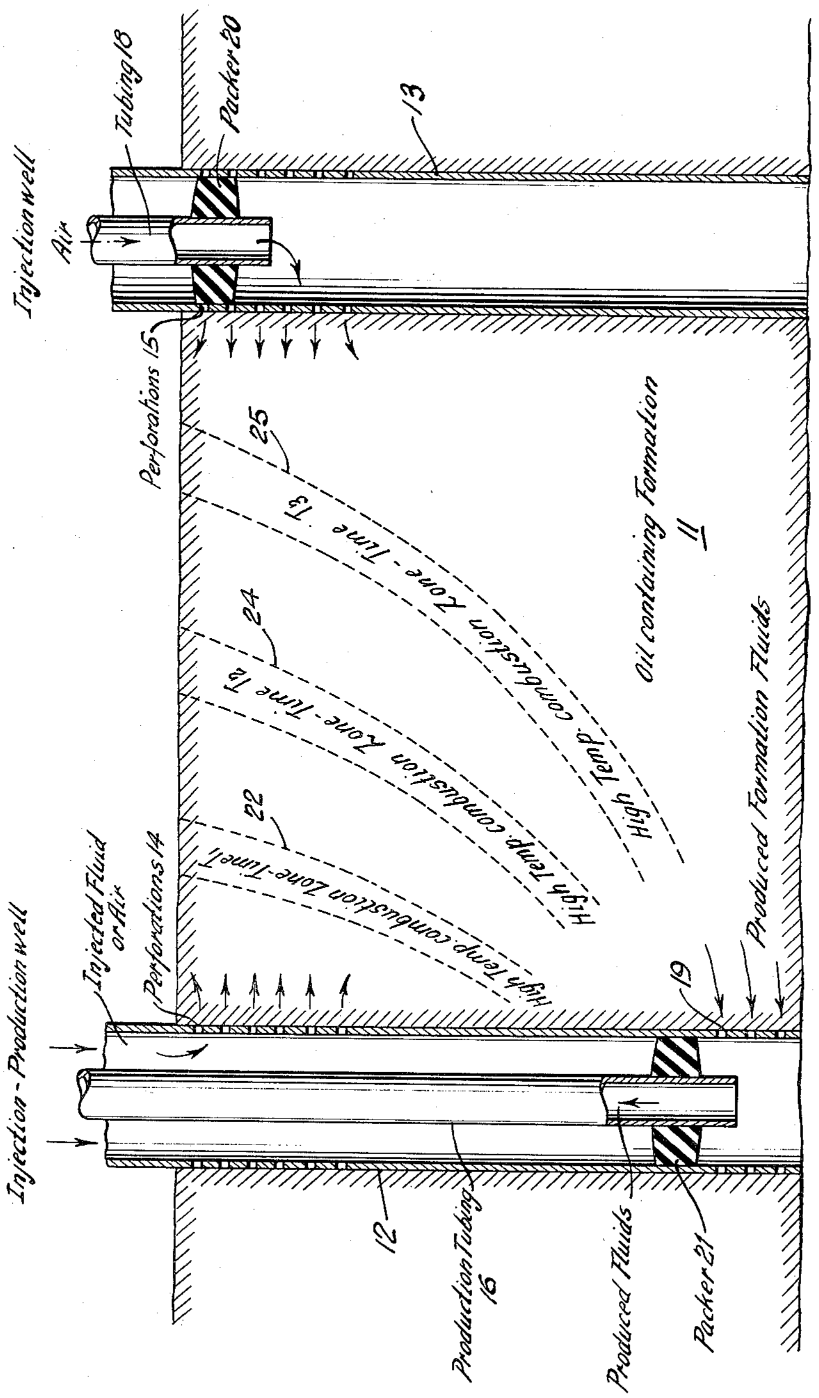
March 27, 1962 J. C. ALLEN ETAL 3,026,935

IN SITU COMBUSTION

Filed July 18, 1958



United States Patent Office 3,026,935
Patented Mar. 27, 1962

1

3,026,935
IN SITU COMBUSTION
Joseph C. Allen, Bellaire, and Robert E. Kunetka, Houston, Tex., assignors to Texaco Inc., a corporation of Delaware
Filed July 18, 1958, Ser. No. 749,497
11 Claims. (Cl. 166—11)

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

In situ 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 the 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 crude oil 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 the area immediately surrounding the well bore. In some instances, however, continued direct application of heat to that portion of 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 combustion gas stream 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 formtaion 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 immedaite 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 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. 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. One disadvantage of the so-called reverse in situ combustion operation appears to be in the fact that the displaced formation fluids must pass through the high temperature combustion zone wherein they are subjected to rather high temperatures and in some instances undergo partial or complete oxidation or thermal cracking with the resultant formation of less desirable normally gaseous hydrocarbons.

In both types of in situ combustion operations, certain problems present themselves. For example, gravity segregation within the formation undergoing in situ combustion is a problem. Gravity segregation is due to the fact that the air or combustion-supporting gas introduced into the formation to maintain the in situ combustion operation is lighter than the formation fluids and, accordingly, tends to move through only the upper portion of the formation resulting in a somewhat irregular or uneven sweeping of the formation by the in situ combustion zone. Another problem associated with in situ combustion operations for the recovery of petroleum and the like is the high temperature experienced in the production well. This high temperature leads to well fires, casing collapse, formation spalling, well failure, and other difficulties.

The efficiency of an in situ combustion operation depends upon the manner in which the heat generated within the high temperature combustion zone is transferred to the bulk of the formation or rock matrix. Ideally, it would appear that the most efficient in situ combustion process would consume the minimum quantity of formation fluids, oil and the like, and all the heat of combustion would be transferred to the rock matrix and to the formation fluids therein. The amount of heat generated within the high temperature combustion zone ideally should be just sufficient to reduce the viscosity and/or crack the remainder of the petroleum or oil therein to effect the maximum displacement and/or volatilization thereof by the injected gas and/or gaseous products of combustion.

Accordingly, 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 wherein substantially all of the formation undergoing in situ combustion is swept by a high temperature combustion zone with the resultant displacement or depletion of substantially all of the hydrocarbons therefrom.

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 one embodiment of the practice of this invention.

In accordance with this invention a hydrocarbon producing formation is penetrated by an in injection-production well and by an injection well spaced apart from said injection-production well. A high temperature zone is then created in a zone within said formation adjacent said injection-production well. This high temperature zone is then caused to be moved outwardly from said injection-production well in the upper portion of said formation in the direction of said injection well. Movement of this high temperature zone outwardly from the injection-production well within the upper portion of the formation in the direction of the injection well is effected by the introduction of a combustion-supporting gas, such as air, from the injection well into the upper portion of the producing formation. Desirably a combustion-supporting gas, such as air, is also simultaneously introduced into the upper portion of the producing formation via the injection-production well. As the high temperature combustion zone is thus caused to move from the injection-production well in the direction of the injection well the resulting displaced formation fluids, such as oil, are produced from the lower portion of the formation via said injection-production well. It is mentioned that as the produced formation fluids are recovered from the lower portion of the formation undergoing in situ combustion these produced and/or displaced fluids are cooled by heat exchange with the on-coming combustion-supporting gas or air as it moves downwardly within the injection-production well for introduction into the upper portion of the producing formation. The practice of this invention is generally applicable to the recovery of all types of petroleum crudes and hydrocarbons, including oil from so-called tar sands, low gravity oil or high gravity oil, etc. from underground formations containing the same.

Referring now to the accompanying drawing which schematically illustrates one 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 well bore such as injection-production well **12** and by another well bore such as injection well **13** which is spaced apart from said injection-production well **12**. In the initial operation of the practice of this invention gas or air permeability is established across the upper portion of formation **11** by the introduction of air via injection-production well **12** into formation **11** through perforations **14** in the direction of or for recovery at injection well **13** through perforations **15**. If desired, gas permeability may be established within the upper portion of oil-containing formation **11** in an opposite direction, i.e., introducing gas or air into formation **11** through perforations **15** of injection well **13** in the direction of or for recovery through perforations **14** at injection-production well **12**.

Following the establishment of gas or air permeability across the upper portion of 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 injection-production well **12** within the upper portion of oil-producing formation **11**. Following the establishment of this high temperature zone a combustion-supporting gas is introduced via the annular space within injection-production well **12** between production tubing **16** and the injection-production well **12**. This combustion-supporting gas or air enters the upper portion of the oil-containing formation **11** via perforations **14** and serves to move the high temperature zone wherein in situ combustion now takes place outwardly from the injection-production well **12** within the upper portion of the formation **11** in the direction of the injection well **13**.

Air or suitable combustion-supporting gas is also introduced into the upper portion of formation **11** via perforations **15** of injection well **13**, the air or combustion-supporting gas being supplied to injection well **13** via tubing **18** positioned within injection well **13**. A packer **20** is provided associated with tubing **18** to occupy a portion of and to seal off the annular space between tubing **18** and injection well **13** to assure that substantially all of the air or combustion-supporting gas supplied to injection well **13** via tubing **18** enters the upper portion of formation **11** via perforations **15**.

While air is being introduced into the upper portion of formation **11** via perforations **15** the resulting displaced formation fluids, including petroleum and gaseous products of combustion, are produced from the lower portion of formation **11** via the lower perforations **19** located in injection-production well **12**. A packer **21** is provided in the annular space between the lower end of tubing **16** and injection-production well **12** to seal off the annular space and to assure that all the produced fluids entering perforations **19** move upwardly within injection-production well **12** via production tubing **16**.

Upon continued injection of combustion-supporting gas or air into the upper portion of producing formation **11** via perforations **14** and perforations **15** the high temperature combustion zone moves outwardly from injection-production well **12** within formation **11** in the direction of injection well **13**. The various stages of movement of this high temperature combustion zone originating in the vicinity of injection-production well **12** as it moves outwardly within the formation in the direction of injection well **13** is illustrated in the dashed lines in the accompanying drawing. As illustrated in the drawing, the location of the high temperature combustion zone is indicated by reference numerals **22**, **24** and **25** at various times T_1, T_2 and T_3, T_3 being later than T_2 and T_2 being later than T_1. In these operations a combination of in situ combustion processes, so-called direct in situ combustion and so-called reverse in situ combustion, occurs and serves to displace the formation hydrocarbons and fluids to the lower portion of formation **11** in the general direction of production perforations 19 of production-injection well 12.

As the produced formation fluids are recovered from the lower portion of formation 11 via perforations 19 and production tubing 16, combustion-supporting gas or other suitable coolant fluid or gas is desirably supplied through the annular space between production tubing 16 and injection-production well 12 for introduction into formation 11. As the combustion-supporting gas such as air moves downwardly within injection-production well 12 it passes in indirect heat exchange relationship with the produced formation fluids, thereby tending to cool the produced formation fluids and at the same time preheating the combustion-supporting gas being introduced into the upper portion of the formation.

When a combustion-supporting gas, such as air, is introduced simultaneously into the upper portion of formation 11 via perforations 14 and 15, as previously indicated, the high temperature combustion front moves from the injection-production well 12 toward the injection well 13. When a relatively high gravity crude is contained within the formation 11 undergoing in situ combination the injection of air into the upper portion of formation 11 via perforations 14 can be discontinued. In this instance the high temperature combustion zone is maintained by the continued injection of air into the upper portion of formation 11 via perforations 15 of injection well 13. Accordingly, when the injection of air into formation 11 via perforations 14 is discontinued the in situ combustion operation is maintained and carried out in the manner of the above-described so-called reverse in situ combustion operation. If desired, however, a combustion-supporting gas or air can be intermittently injected into the upper portion of formation 11 via perforations 14.

In accordance with another embodiment of the practice of this invention a non-combustible fluid, such as water, may be introduced into the upper portion of formation 11 via perforations 14 of injection-production well 12, the thus-introduced fluid serving not only to cool the produced formation fluids leaving injection-production well 12 via tubing 16 but also serving to control the temperature of the in situ combustion operation and the extent and rate at which the in situ combustion operation is carried out within formation 11. Also the injection of a non-combustible fluid serves to further cool the produced formation fluids as they enter injection-production well 12 via perforations 19.

In accordance with yet another embodiment of the practice of this invention normally gaseous hydrocarbons or combustible liquids or fluids may be introduced into the upper portion of formation 11 via perforations 14, continuously or intermittently, as air is being introduced into the upper portion of formation 11 via perforations 15 to aid the combustible reaction taking place within the formation in the high temperature combustion zone therein.

In accordance with yet another embodiment of the practice of this invention, particularly applicable when a low gravity crude is contained within formation 11 undergoing in situ combustion, upon continued injection of air via perforations 15 in the upper portion of formation 11 a combustible fluid, such as normally gaseous hydrocarbons or normally liquid hydrocarbons and the like, are introduced into formation 11 via perforations 14 in order to maintain the in situ combustion operation therein since, as previously indicated, a so-called reverse type in situ combustion operation is difficult to maintain when a low gravity crude oil is present in the formation being subjected to in situ combustion. The combustion of the thus-extraneously introduced combustible fluids serves to maintain the in situ combustion operation by increasing the amount of heat released thereby maintaining a sufficiently high temperature during the in situ combustion operation to render the low gravity crudes more fluid and more readily displaceable by the combustion-supporting gas, air, introduced into the injection well during a reverse type in situ combustion operation. When operating in this manner the introduction of combustion-supporting gas such as air into formation 11 via perforations 14 can be discontinued or carried out intermittently as desirable.

It is mentioned that when the high temperature combustion zone has reached perforations 15 within the upper portion of formation 11 the continued injection of air into the formation via perforations 15 can be discontinued, these perforations sealed off and the producing formation 11 perforated at another location within injection well 13 below perforations 15. The injection of a combustion-supporting gas can then be continued in the manner in accordance with this invention.

Further, it is to be noted that one advantage derivable in accordance with the practice of this invention is that the resulting displaced and produced formation fluids for the most part do not pass through the high temperature combustion zone. Accordingly, crude losses due to thermal cracking with the resultant formation of normally gaseous hydrocarbons are substantially eliminated.

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

We claim:

1. A method of producing hydrocarbons from a subsurface hydrocarbon-producing formation which comprises initiating in situ combustion in the upper portion of said formation in a zone surrounding an injection-production well penetrating said formation, introducing air into the upper portion only of said formation via said injection-production well while simultaneously introducing air into the upper portion only of said formation via an injection well penetrating said formation at a location spaced from said injection-production well and producing resulting displaced formation hydrocarbons; from the lower portion only of said formation via said injection-production well.

2. A method of carrying out an in situ combustion operation for the production of petroleum from a subsurface petroleum-producing formation which comprises penetrating said formation with an injection-production well and an injection well, said injection well being spaced-apart from said injection-production well, establishing air permeability through the upper portion of said formation between said injection-production well and said injection well by introducing air through the formation penetrating wells, initiating in situ combustion in the upper portion of said formation in a heated zone adjacent said injection-production well by providing combustion-supporting gas thereto, introducing air into the upper portion only of said formation via said injection-production well and said injection well, continuing the injection of air into the upper portion only of said formation via said injection-production well to cause a high temperature in situ combustion zone to move outwardly into said formation from said injection-production well toward said injection well and producing petroleum displaced during the aforesaid in situ combustion operation from the lower portion only of said formation via said injection-production well.

3. A method of carrying out an in situ combustion operation for the production of petroleum from a subsurface petroleum-containing formation which comprises penetrating said formation by means of an injection-production well and an injection well, said injection well being spaced-apart from said injection production well, establishing gas permeability across the upper portion of said formation between said injection-production well and said injection well by introducing air through the formation penetrating wells, creating a high temperature combustion zone within the upper portion of said formation adjacent said injection-production well by heating means,

introducing a combustion-supporting gas into the upper portion only of said formation via said injection well and simultaneously therewith, introducing air into the upper portion only of said formation via said injection-production well for in situ combustion in said formation and producing the resulting displaced petroleum from the lower portion only of said formation via said injection-production well.

4. A method in accordance with claim 3 wherein simultaneously with the injection of said combustion-supporting gas into the upper portion only of said formation via said injection well, a non-combustible fluid is introduced into the upper portion only of said formation via said injection-production well.

5. A method in accordance with claim 4 wherein said non-combustible fluid is water.

6. A method of producing a relatively low gravity oil from a subsurface formation containing the same wherein said formation is penetrated by an injection-production well and an injection well spaced from said injection-production well which comprises establishing air permeability through the upper portion of said formation between said injection-production well and said injection well by introducing air through the formation penetrating wells, initiating in situ combustion in the upper portion of said formation in a heated zone adjacent said injection-production well by providing combustion-supporting gas thereto, introducing air via said injection-production well into the upper portion only of said formation to cause the in situ combustion zone to move outwardly from said injection-production well into said formation, introducing air into the upper portion only of said formation via said injection well and producing the resulting oil from the lower portion only of said formation via said injection-production well.

7. A method in accordance with claim 6 wherein air is simultaneously introduced into the upper portion only of said formation via said injection-production well and said injection well.

8. A method of producing a relatively high gravity oil from a subsurface formation containing the same which comprises penetrating said formation with an injection-production well and an injection well spaced-apart from said injection-production well, establishing air permeability across the upper portion of said formation between said injection-production well and said injection well by introducing air through the formation penetrating wells, initiating in situ combustion in the upper portion of said formation in a heated zone therein adjacent said injection-production well by providing combustion-supporting gas thereto, injecting a combustion-supporting gas into the upper portion only of said formation via said injection well so as to cause the zone in said formation wherein in situ combustion takes place to move outwardly from said injection-production well in the direction of said injection well substantially countercurrent to the flow of air introduced into said formation via said injection well and introducing air into the upper portion only of said formation via said injection-production well simultaneously with the injection of air into said formation via said injection well and producing oil displaced during the aforesaid in situ combustion operation from the lower portion only of said formation via said injection-production well.

9. A method in accordance with claim 8 wherein a non-combustible fluid is intermittently introduced into the upper portion only of said formation via said injection-production well while air is introduced into the upper portion only of said formation via said injection well.

10. A method in accordance with claim 8 wherein water is intermittently injected into the upper portion only of said formation via said injection-production well during the introduction of air into said formation via said injection well.

11. A method in accordance with claim 8 wherein a combustion-supporting gas is intermittently introduced into the upper portion only of said formation via said injection-production well simultaneously with the injection of air into said formation via said injection well.

References Cited in the file of this patent

UNITED STATES PATENTS

2,788,071	Pelzer	Mar. 5, 1954
2,754,911	Spearow	July 17, 1956
2,793,696	Morse	May 28, 1957
2,818,118	Dixon	Dec. 31, 1957
2,819,761	Popham	Jan. 14, 1958
2,901,043	Champion et al.	Aug. 25, 1959