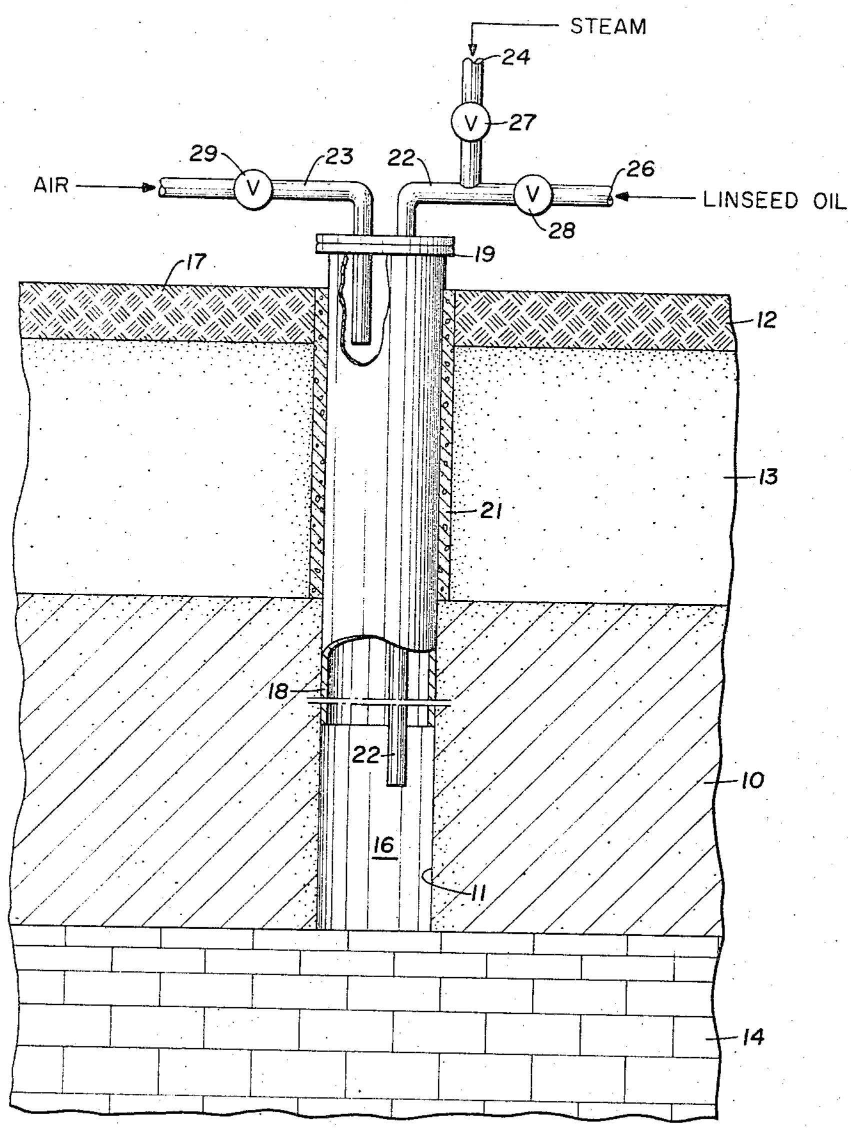
April 23, 1968 B. G. HOLMES 3,379,254

METHOD FOR INITIATING IN SITU COMBUSTION WITHIN A SUBTERRANEAN FORMATION

Filed Aug. 25, 1966



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United States Patent Office

3,379,254

Patented Apr. 23, 1968

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3,379,254

METHOD FOR INITIATING IN SITU COMBUSTION WITHIN A SUBTERRANEAN FORMATION

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Filed Aug. 25, 1966, Ser. No. 574,963

3 Claims. (Cl. 166—38)

This invention relates to recovering petroleum from a subterranean formation with in situ combustion procedures. More particularly, this invention relates to a method for initiating such in situ combustion procedures.

Petroleum recovery from subterranean formations with in situ combustion procedures is well known. Usually these procedures are employed where the petroleum is viscous. The in situ combustion procedures require the initiating of combustion by igniting the carbonaceous material within a formation, usually adjacent a well. It has been proposed to introduce into the formation readily combustible materials and then an oxidizing medium for their auto-oxidation at a rate sufficient to produce spontaneous combustion. Usually, this auto-oxidation begins at formation-temperature and continues until temperatures above about 700° F. are reached before these materials ignite.

Auto-oxidation as a means for initiating in situ combustion within a formation is subject to several difficulties. The flow of the oxidizing medium requires careful regulation for auto-oxidation to generate sufficient heat to raise the temperature sufficiently of the oxidizable material that it will ignite. Experience in the field has shown that this method of ignition is not certain. Too low a rate of flow of the oxidizing medium produces insufficient heat to produce spontaneous ignition. An excessive flow of the oxidizing medium "quenches" the auto-oxidation reaction and prevents spontaneous combustion. Thus, ignition by the known auto-oxidation procedures is uncertain as a method for initiating in situ combustion within a formation.

Another difficulty with employing auto-oxidation is the danger of downhole explosions occurring by contact of the oxidizing medium with the readily oxidized material within the well. For example, it has been proposed to introduce linseed oil into a well and then displace it into the formation with air. Under certain conditions within the well, the linseed oil becomes sufficiently dispersed that upon contact with air spontaneous combustion occurs with explosive violence. The resulting explosion can destroy the well and cause possible injury to field personnel.

Another difficulty with auto-oxidation is the creation of a combustion front in the formation spaced from the well. This front returns to the well and, with its attendant high temperatures, causes thermal destruction of the well. For example, if linseed oil is injected into the formation adjacent a well and air subsequently is introduced from the well into the formation, the linseed oil is forced back away from the face of the formation to be disposed through the formation some distance from the well. The subsequent flow of air through the formation can then raise the temperature of the linseed oil, by auto-oxidation, sufficiently to result in its auto-ignition. The continued flow of air moves the combustion front radially through the formation, back to the well. The combustion front may also expand away from the well, but the expanding combustion front causes the injury to the well apparatus

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by creating high temperatures at the well in the formation.

The present invention has as its principal object to provide a method for initiating in situ combustion within a formation. Another object is to provide such a method without aforementioned difficulties wherein linseed oil is employed as the readily oxidizable material. Another object is to provide a method, in accordance with the foregoing objects, that: (a) produces certain ignition of the linseed oil to initiate in situ combustion within a formation; (b) is safe to employ without danger of explosions in a well; and (c) produces a combustion front upon ignition which moves through the formation only radially outwardly away from the well through which the various fluids are injected into the formation.

In accordance with this invention for achieving the above-stated objects, there is provided a method in which in situ combustion is initiated in a petroleum-bearing subterranean formation penetrated by a well. Various steps are practiced through this well in a certain manner that the formation about the well is heated to a predetermined minimum temperature with steam. Thereafter, linseed oil is introduced into the well to be disposed by a regulated flow of steam along the surface of the formation surrounding the well. Then while steam yet flows, a gaseous stream containing oxygen is injected through the well into the formation to produce immediate, spontaneous ignition of the linseed oil in the formation facing the well. Such ignition is safe and instantaneous, and results in a combustion front supported by carbonaceous materials in the formation moving radially outwardly through the formation in a direction away from the well.

Reference may be taken to the drawing wherein is shown, in a vertical section taken through the earth, a well penetrating a petroleum-containing subterranean formation wherein in situ combustion is to be initiated, and the well embodying suitable apparatus which may be employed in carrying out the steps of this invention.

The drawing shows a permeable and petroleum-containing subterranean formation **10** which resides below an overburden **12** and a superimposed strata **13**. A strata **14** resides below the formation **10**. The strata **13** and **14** for purposes of this invention will be considered not to contain petroleum. A well **16** extends downwardly from the earth's surface **17** and terminates adjacent the strata **14**.

The well **16** may be provided with suitable apparatus for the conveying of fluids between the earth's surface **17** and the formation **10**. For this purpose, the well **16** has a casing **18** extending downwardly from a wellhead **19** to terminate adjacent the formation **10**. The casing **18** is sealed to the overburden **12** and strata **13** by a cement sheath **21**. The well **16** is open-completed at the exposed face **11** of the formation **10**. The well **16** carries conduit means for conveying fluids between the earth's surface **17** and the formation **10**. The conduit means may take the form of conduits **22** and **23**. The conduit **22** extends downwardly through the wellhead **19** to terminate within the well **16** adjacent the formation **10**. The conduit **23** passes through the wellhead **19** into fluid communication with the annulus formed between the casing **18** and the conduit **22** of the well **16**. This arrangement provides for two separate means for conveying fluids into the well **16** from the earth's surface **17**. Other arrangements may be used as will be obvious from this description. The conduit **22** has inlets **24** and **26** through which flow is regulated, respectively, by valves **27** and **28**. The conduit **23** carries a valve **29** by which to regulate the flow of fluids therethrough.

The conduit **24** connects to a source of steam (not shown). Various types of steam boilers and generators presently employed in the oil patch may be used as sources of steam, if desired. The steam source needs to provide a flow of steam at suitable conditions of temperature and pressure to heat the face **11** of the formation **10** to at least 300° F. For example, in one field test, pressurized steam of 80 percent quality, entering the well **16** at 550° F. for a three-hour interval was sufficient to raise the temperature of the face **11** of the formation **10** about the well **16** to this temperature.

The inlet **26** connects to a supply of linseed oil (not shown). This source may be any reservoir from which the linseed oil flows into the conduit **26**. Thus, the adjustment of the valves **27** and **28** regulates the flow of steam and linseed oil via the conduit **22** into the well **16**.

The conduit **23** connects to a source of pressurized air (not shown). The nature of the source is uncritical. A suitable supply of air was provided by an air compressor which delivered air into the conduit **23** at a rate of about 1 million standard cubic feet per day.

An embodiment of the method of this invention will now be described relative to the use of the illustrative apparatus shown in the drawing for initiating in situ combustion within the formation **10**. As one step, steam from a suitable source is passed via the inlet **24** into the well **16** through the conduit **22**. The flow of steam is regulated with the valve **27**. If desired, the steam can be introduced through the conduit **23**, or other conduit means, into the well **16**. The steam is introduced, under suitable conditions of temperature and pressure, that its passage into the formation **10** provides for heating the face **11** exposed to the well **16** to a temperature of at least 300° F.

Preferably, the steam is injected at temperatures of about 550° F. so as to introduce suitable heat energy in a short time-period into the well **16**. It will be obvious that under the varied conditions permissible for injecting steam into the formation **10**, the amount of time required to heat the face **11** to the desired temperature will be varied. However, the desired temperature is for practical purposes obtained by the injection of steam under suitable conditions of pressure and temperature that 50 million B.t.u. of heat energy are introduced into the well 16 within a period of less than 18 hours. Inasmuch as the heat content of the steam is dependent upon the steam quality, it is preferred that the steam be of as high a quality as conveniently obtainable adjacent the well **16**. Usually, a steam generator will easily produce a steam quality of 80 percent or better at the necessary temperatures and pressures. If desired, additives for preventing corrosion within the well, water treatment chemicals, and the like, can be added to the injected steam.

During steam injection into the well **16**, the valves **28** and **29** in the conduits **22** (at inlet **26**) and **23**, respectively, are adjusted to restrict the flow of oxygen-containing gases into the well **16**. If desired, the valve **29** may be opened for a short interval during the injection of steam into the well **16** to permit any air within the well **16** to escape to the atmosphere. As a result, all gases are displaced from the well **16** into the formation **10**, or vented to the atmosphere through available conduit means, during the steam injection step. Therefore, the steam injection into the well **16** heats the formation **10** to the desired temperature while providing an inert atmosphere within the well **16**. The inert atmosphere is of great advantage in preventing explosions of subsequently introduced combustible materials into the well **16**.

When the exposed face **11** of the formation **10** reaches a temperature of at least 300° F., the injection of steam is completed.

The step of injecting steam has additional beneficial effects upon the formation **10**. For example, petroleum is displaced from the face **11** and will not dilute the linseed oil later injected into the well **16**. Also, the injectivity of subsequently introduced fluids is enhanced by cleaning of the formation **10** at the well **16**, and stratification of such fluids is greatly reduced.

The flow of stream into the inlet **24** now is interrupted by closing the valve **27**, or by any other suitable means. Preferably, the valves **27**, **28**, and **29** are also adjusted to restrict the flows of any oxygen-containing gases into the well **16**. Under these conditions after steam injection, the well **16** is sealed and remains heated and pressurized for carrying out the following step of the present invention.

A quantity of linseed oil sufficient to wet the exposed face **11** of the formation **10** is introduced into the well **16** through one of the conduit means. For purposes of description, the linseed oil is introduced under suitable pressure through the inlet **26** of the conduit **22** into the well **16**. The flow of linseed oil in the conduit **22** can be regulated by the valve **28**. The amount of linseed oil need only be sufficiently large to wet the face **11** of the formation **10**. In one instance, it was found that about one gallon of linseed oil for each square foot of the face **11** was sufficient to wet properly the formation **10**. It will be apparent that excessive quantities of linseed oil are not required; especially such large amounts that the permeability to gas flows is reduced in the formation **10**. It will be obvious that a relatively small amount of linseed oil needs to be employed since upon its ignition the resultant combustion front will immediately pass into, and be supported by, the carbonaceous materials present in the formation **10**. Carbonaceous materials remain in the formation **10** after the injection of steam. However, it will be desired in some instances to introduce additional combustibles into the formation **10**. For example, the connate petroleum may leave only small amounts of residuary carbonaceous materials adjacent the well **16** in the formation **10**.

The term "linseed oil," as it is used in the present description of this invention, includes the various materials and products derived from the fluid-extracts of flaxseed. Specifically included in this term are raw linseed oil; boiled linseed oil which may include various oxidation accelerators; and the fatty acid extracts derived directly from linseed oil or thereafter altered by various conversions. The linseed oil may be mixed with any substance which does not significantly interfere with its ready spontaneous ignition in the face **11**.

After introducing linseed oil into the conduit **22**, another step of the present invention is practiced. Steam is passed through the conduit means through which linseed oil was introduced into the well **16**. In this illustrative embodiment, steam is flowed through the inlet **24** to displace the linseed oil from the lower extremity of the conduit **22** into the face **11** of the formation **10**. The flow of steam should be in an amount sufficient only to displace the linseed oil from the conduit **22** into the face **11** of the formation **10**. This flow of steam must not be of such large magnitude as to drive the linseed oil from the face **11** into the formation **10** to a location some distance from the well **16**. It will be apparent that only a small flow of steam is required for this purpose. While this flow of steam continues into the well **16**, the following step is practiced.

A gaseous stream containing free oxygen is injected through other of the conduit means which have not carried the linseed oil into the well **16**. In this embodiment, the gaseous stream is injected through the conduit **23** with its flow into the well **16** being regulatable by the valve **29**. The gaseous stream usually will be air. However, other gases may be employed which contain free oxygen. The gaseous stream is injected with sufficient pressure to be forced to flow from the well **16** into the formation 10. The flow of the gaseous stream is in an amount sufficient to support combustion of the linseed oil which wets the face 11 of the formation 10. Since the linseed oil ignites immediately with this amount of free-oxygen carrying gaseous stream, greater amounts of flow are beneficial and cannot easily "quench" the resulting combustion front. It has been found that the flow of the gaseous stream in rates of about 1.5 million cubic feet per day produces desirable results.

The gaseous stream flows from the well 16 radially outwardly into the formation 10 and the free oxygen which it contains reacts immediately with the linseed oil in the preheated face 11 to produce by spontaneous ignition a combustion front along such face 11 about the well 16. This spontaneous ignition of the linseed oil obviously produces a combustion front which with the continued injection of the gaseous stream moves only radially outwardly from the well 16 through the formation 10. It will be apparent that this result is obtained because the combustion front is created initially only on the face 11 of the formation 10 about the well 16. Thereafter, this combustion front can move only outwardly through the formation 10.

The outwardly moving unidirectional combustion front resulting from ignition of the linseed oil only at the face 11 prevents damage to the well 16 from the high temperatures which in the past occurred where a combustible material was ignited initially in the formation 10 at a location some distance from the well 16. Under these last-mentioned circumstances, a combustion front would expand in the formation 10 countercurrently to the injected gaseous stream and thereby subject the well 16 to destructively high temperatures.

As another step, steam is continually passed through the conduit 22 into the well 16 until the amounts of linseed oil remaining in the conduit 22 are incapable of forming explosive vapors while injection of the gaseous stream into the well 16 is being undertaken. This prevents mixing of free oxygen with any residuary linseed oil under conditions within the well 16 where hazardous and destructive explosions could occur.

The preceding steps have now established a combustion front in the formation 10 moving away from the well 16. At this time other steps to conduct petroleum recovery by in situ combustion procedures may be practiced.

Laboratory experiments were conducted employing a sand pack into which a quantity of petroleum was added to simulate a permeable petroleum-containing subterranean formation. The sand pack was enclosed within a pressure vessel and provided with means for recording temperatures therewithin. The sand pack was heated by a flow of steam to various temperatures. The flow of steam at such temperatures was then interruped and a small quantity of linseed oil was added to wet the upstream face of the sand pack. A stream of air was passed through the sand pack immediately after introduction of the linseed oil. It was found from these tests that when the sand pack face presented toward the inlet of the seal was heated to at least 300° F., immediate spontaneous ignition of the linseed oil occurred and produced a combustion front which readily passed downstream into the sand pack. The conclusion from these tests was inescapable that linseed oil consistently is spontaneously ignited within a formation heated to temperatures of at least 300° F. Temperatures higher than 300° F. can be employed, if desired, at increasing heating costs.

The method of this invention was used successfully in the field to initiate in situ combustion in an oil reservoir. An injection well was equipped with a high temperature wellhead and valves in fluid connection with a string of open-ended tubing set to the top of the formation to be ignited. This formation resided at a depth of 1,146 feet below the earth's surface and had a gross interval of approximately 74 feet opened into the well. Air injection showed that the formation was permeable.

Steam of 80 percent quality was injected through the well into the formation. At the injection pressure, the steam had a temperature of 550° F. The steam, equivalent to 86 barrels of water, was injected within a three-hour interval. The injected steam amounted to a total heat input of about 30 million B.t.u. and heated the formation to the desired temperature.

Steam injection was terminated. A mixture of 55 gallons of boiled linseed oil with 165 gallons of raw linseed oil was pumped into the tubing and displaced into the formation with a reduced rate of steam injection. While steam injection continued, air was introduced at a rate of about 1 million standard cubic feet per day into the casing annulus of the well.

These steps resulted in the immediate spontaneous ignition of the linseed oil to produce a combustion front which then moved outwardly into the formation and away from the wellbore. A short time thereafter, combustion gases appeared in the produced gas stream from an adjacent well to indicate the in situ combustion procedure was operative.

From the foregoing it will be apparent that there has been described a method for initiating in situ combustion within a permeable petroleum-containing subterranean formation and that this method achieves all of the stated objects of this invention by providing safe and certain initiation of in situ combustion in the formation with the resulting combustion front moving unidirectionally outwardly from the injection well through the adjacent formation.

It is intended that the foregoing description of this invention is taken by way of illustration. Various alterations in the described steps may be made by those skilled in the art without departing from the spirit of the invention. In this regard, it is intended that the limitations to the method of this invention are to be found only in the appended claims.

What is claimed is:

1. A method for initiating in situ combustion within a permeable petroleum-containing subterranean formation penetrated by an injection well having at least two conduit means for conveying fluids from the earth's surface to said formation to be ignited, the steps comprising:

(a) injecting steam through one of said conduit means into said formation to be ignited, said steam being at suitable conditions of temperature and pressure to heat the well-exposed face of said formation to at least 300° F., and during at least terminal steam injection said conduit means being restricted to flows of oxygen-containing gas into the well;

(b) introducing into one of said conduit means a quantity of linseed oil sufficient to wet the face of the formation to be ignited while interrupting the flow of other fluids into the formation through said conduit means;

(c) passing steam through said conduit means receiving linseed oil in a flow sufficient only to displace the linseed oil into the face of said formation but not to drive said linseed oil into the formation away from the well, and while the steam yet flows into the well;

(d) injecting a gaseous stream containing free oxygen through other of said conduit means which have not carried linseed oil into the formation in an amount sufficient to support combustion whereby the linseed oil spontaneously ignites at the heated face of the formation and the resulting combustion front thereby moves only radially outwardly from the well into the formation; and

(e) continuing the passage of steam through said conduit means until residuary linseed oil therein is removed to an amount incapable of forming explosive vapors during the time injection of the gaseous stream is undertaken.

2. The method of claim 1 wherein the steam in step

(a) is injected in an amount to provide about 50 million B.t.u. to the well within a period of less than 18 hours.

3. The method of claim **1** wherein the gaseous stream is air injected at a rate up to about 1.5 million cubic feet of air per day.

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STEPHEN J. NOVOSAD, *Primary Examiner.*

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,379,254 — April 23, 1968

Billy G. Holmes

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

Column 4, line 7, "stream" should read -- steam --. Column 5, line 66, "increasing" should read -- increased --. Column 6, line 51, "gas" should read -- gases --.

Signed and sealed this 2nd day of September 1969.

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents