CROSS REFERENCE

SEARCH ROOM

Nov. 8, 1966 R. W. THOMAS 3,284,281

# PRODUCTION OF OIL FROM OIL SHALE THROUGH FRACTURES

Filed Aug. 31, 1964

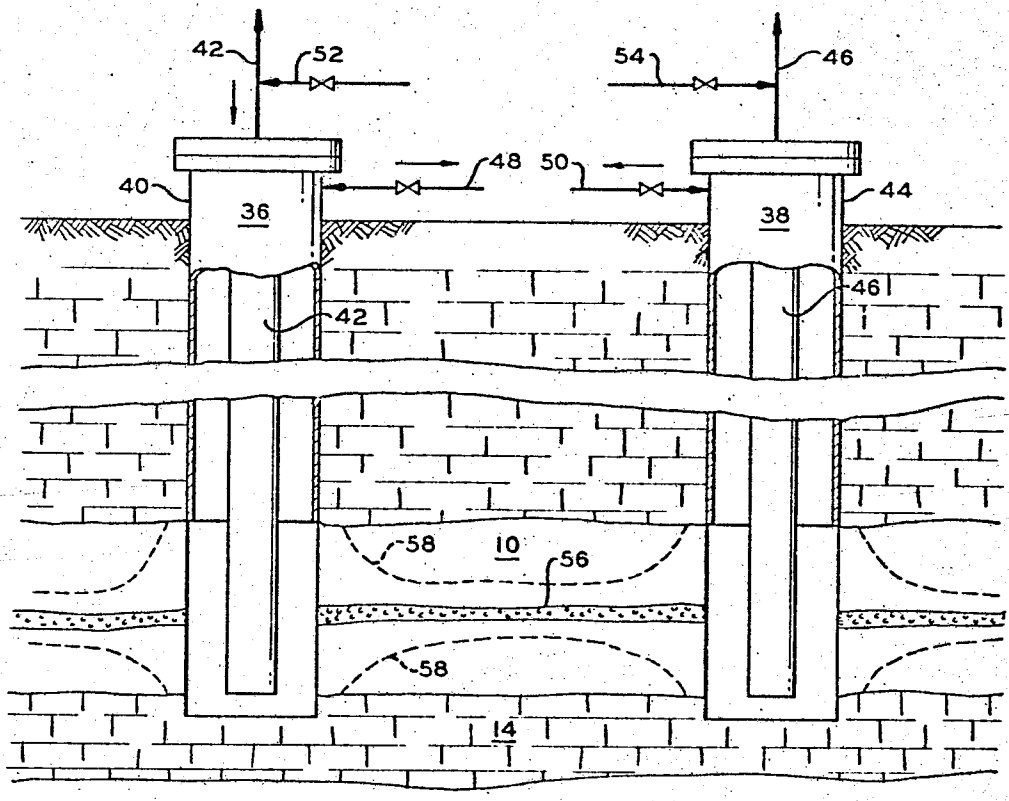


FIG. 2

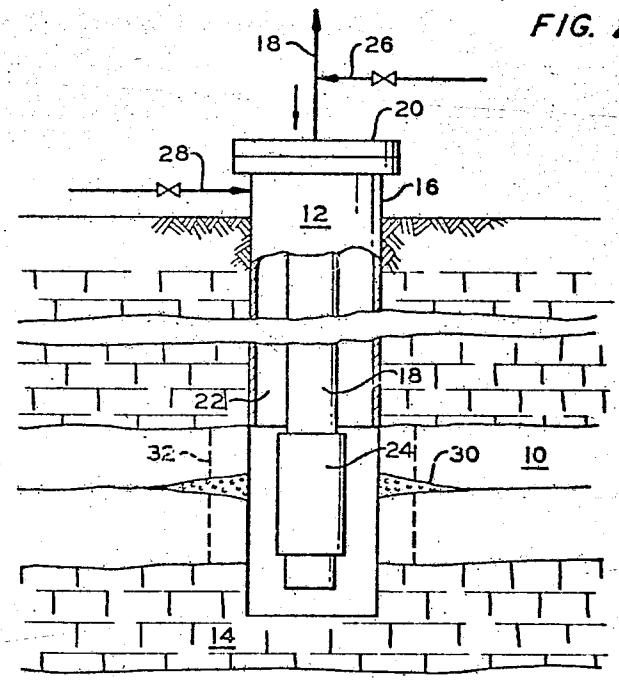


FIG. 1

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# PRODUCTION OF OIL FROM OIL SHALE THROUGH FRACTURES

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The invention relates to the production of oil or fluid hydrocarbons from oil shale (shale containing kerogen).

The production of oil from oil shale by heating the shale by various means such as steam, down-hole combustion of a combustible gaseous mixture, an electrical resistance heater, and injection of hot gases other than steam has been attempted with little success. In situ combustion of shale has also been relatively unsuccessful because of the impervious and the plastic nature of the shale. Fracturing of the shale prior to the application of heat thereto by in situ combustion or other means has been practiced with little success because the shale swells upon heating with consequent partial or complete closure of the fractures.

An early disclosure of fracturing oil shale and applying heat to the fractured shale is found in Hoover et al., U.S. Patent 1,422,204, issued July 11, 1922.

This invention is concerned with a novel method of producing fluid hydrocarbons from shale containing kerogen by application of heat thereto by in situ combustion or by other means.

Accordingly, an object of the invention is to provide a novel process for producing fluid hydrocarbons from the kerogen existing in an oil shale stratum. A further object is to provide a novel process for utilizing a sequential combination of heating and fracturing in the production of oil from oil shale. Other objects of the invention will become apparent upon consideration of the accompanying disclosure.

A broad aspect of the invention comprises heating to an elevated temperature a shale stratum containing kerogen around a well penetrating the stratum thereby causing swelling of the shale in a section adjacent the well, followed by fracturing of the shale thru the swollen section and optionally propping the resulting fractures open, thereafter further heating the shale around the well and the fractures so as to crack the kerogen therein and release fluid hydrocarbons which flow into the same well or another well thru the fractures, and recovering the hydrocarbon fluids from the same or an adjacent well. The initial or subsequent heating of the shale is accomplished by any conventional means such as by injecting superheated steam so that the superheated steam passes in contact with the shale, burning a combustible gaseous mixture adjacent the shale as in a down-hole heater, injecting a hot gas such as air or combustion gas, or use of an electrical down-hole heater, or by combustion of some contained kerogen and/or its decomposition products.

Shale swells and becomes more plastic as it is heated and the contained kerogen begins to crack at a temperature of about 400° F. in a steam-containing ambient (247 p.s.i.g. saturation pressure of steam) and cracking is about 90% complete at about 700° F. In a dry ambient, the kerogen in shale commences cracking at about 600° F. and increases with increasing temperature. The heating and cracking of kerogen produces both gaseous and liquid hydrocarbons. The shale is heated to at least 400° F. when heating in a steam ambient, as with steam injection or in the presence of a subtantial amount of connate water. Heating the shale to a temperature of at least 600° F. is practiced in a dry ambient. The range of 600 to 750° F. is a good operating range for either wet or dry heating. It is readily understood that there will be a temperature gradient in the stratum, with highest temperatures adjacent the heat source.



After the shale has been properly heated in an annular section extending substantially into the stratum, such as a foot or more, and substantial swelling has ensued, fracturing is effected in conventional manner utilizing any suitable fracturing fluid. Hot fluids such as air, $CO_2$, $N_2$ combustion gas, oil, steam, superheated water, or hot liquids, are the preferred fracturing means. Fracturing is effected at a selected level in the oil shale stratum. After initial fracturing the stratum is again heated, preferably, to the prescribed temperature so as to effect cracking of the kerogen and further swelling of the stratum with extension of the swollen section deeper into the stratum along or beyond the fractures. The fractures are extended deeper into the stratum by applying fracturing pressure in the fractures adjacent the well, followed by further heating to extend the volume of shale within which kerogen can eventually be heated above the cracking temperature and production of oil and/or gas thus achieved.

Fracturing at more than one zone within the stratum and simultaneously heating the kerogen adjacent the fracture zones is within the scope of the invention. The fracturing fluid(s) and the heating fluid(s) may or may not be the same. Part or all of the heating may be accomplished by combustion of the hydrocarbons already in the formation to be produced.

Another embodiment of the invention comprises sequentially heating, swelling, fracturing, optionally propping, and producing two or more spaced-apart wells in an oil shale stratum and repeating the heating, swelling, fracturing, propping, and producing steps in one or more wells until flow paths, which remain open upon additional heating, have been established between two or more wells. These operations in the two or more wells may or may not be conducted simultaneously. The heating of the kerogen to the prescribed temperature cracks the kerogen and leaves a carbon residue. Heating the stratum along the fracture system between the wells produces oil, gas, and a carbon residue, and extends the volume of shale to which access may be had by heating means, and/or for extending pressure-induced fractures. After establishment of sufficient permeability to permit continued flow of fluids, hydrocarbon production can be effected by passing steam or other hot gas thru the fractures from one well to another, or by igniting the stratum adjacent one of the wells to establish a combustion zone and moving the combustion zone along the fractures and within the stratum to the other well. The combustion zone is established in conventional manner by heating the hydrocarbon material in the stratum to ignition temperature and contacting the hot material with an $O_2$-containing, combustion supporting field, such as air. After the combustion zone has been established, the same is moved thru the stratum by either direct or inverse drive. Using direct drive, the oxidant is injected thru the ignition well and combustion products and produced hydrocarbon fluids are recovered thru another well. With inverse drive, the combustion-supporting gas is injected thru another well from which its passes thru the fractures to the combustion zone adjacent the ignition well, thereby feeding the combustion zone and causing same to move toward the injection well.

A more complete understanding of the invention may be obtained by reference to the accompanying schematic drawing of which FIGURE 1 is a sectional elevation thru a well penetrating an oil shale and FIGURE 2 is a similar view showing a pair of wells penetrating an oil shale. The penetration may be partial or complete.

Referring to FIGURE 1 an oil shale 10 is penetrated by a well 12 which extends into stratum 14. Well 12 is provided with a casing 16 which extends to the top of stratum 10 and may extend thru this stratum if desired, in which case the casing is perforated for fracturing and injection and withdrawal of fluids in known manner. A

tubing string 18 extends from well head 20 substantially to the bottom of the well forming an annulus 22 with casing 16. When down-hole heating means is utilized in the process, a down-hole heater 24 is positioned on tubing string 18 or on a separate string of pipe. Line 26 connects with tubing string 18 at or above the well head for injection of heating and/or fracturing fluid or for withdrawal of these fluids or of produced hydrocarbons. One or more packers may be used between tubing and and casing or formation. Line 28 connects with casing 15 and annulus 22 for injection and/or withdrawal of fluids from the annulus. Fractures 30 are shown extending radially outwardly from the well, representing one stage of the operation.

In operating with the arrangement shown in FIGURE 1, heat is applied to stratum 10 adjacent the well by any suitable means as heretofore set forth, as by means of a down-hole heater 24, until a substantial annular section of shale around well 16, designated 32, has been effectively heated and swollen. The swelling may produce fractures within the oil shale stratum outside of annular section 32 and/or in the overburden. This fracturing aids in the production of oil from the shale. After the heating and swelling steps, which may result in some hydrocarbon release and recovery, fractures 30 are extended into the stratum beyond annular section 32 by any suitable fracturing technique conventional in the art and propping material such as glass beads, sand, metal balls, etc., may be forced into the fractures.

After fracturing, preferably with propping, has been accomplished, additional heating in the same or different manner is applied to stratum 10 at the well wall and in fractures 30 so as to produce hydrocarbons in well 12 and to extend the swollen shale area beyond section 32. After a substantial period of production in this manner, fractures 30 are enlarged in the area beyond section 32 and extended further into stratum 10 with or without propping agent injected into the extended fractures. This repetition of heating, fracturing, optional propping, and production from well 16 is continued as long as it is economic.

In performing the fracturing and optional propping step, it may be advisable to utilize other wells which are sufficiently close to well 12 to permit extending the fractures to the adjacent wells.

Referring to FIGURE 2, an oil stratum 10 overlying an underburden 14 is penetrated by wells 36 and 38. Well 36 has a casing 40 extending about to the upper level of stratum 10 and a tubing string 42 extending approximately to the bottom of the well. Well 38 is similarly equipped with a casing 44 and a tubing string 46. Line 48 connects with casing 40 near the well head and line 50 connects with casing 44 in similar manner. These lines provide for injection and withdrawal of fluids from the well annuli. Lines 52 and 54 connect with tubing strings 42 and 46, respectively, at or near the well heads for injection and withdrawal of fluids. A fracture system designated 56 eventually is extended from well to well in stratum 10 and swollen area 58 is shown at that stage of the process after fracturing and heating has been applied to the stratum between wells and passage of air or other fluids between the wells is thereby made possible.

In the arrangement shown in FIGURE 2, both wells 36 and 38 are operated in the manner described in connection with well 12 of FIGURE 1. Of course, it is to be understood that the successive fracturing and optional propping steps are sequenced with the heating and production steps as heretofore described until suitable communication has been established for passage of fluids between the wells.

A heating fluid may then be injected thru the fractures 56 from one well to another and produced fluids recovered thru the other well. This heating fluid may comprise superheated steam, hot combustion gas, hot air, or any suitable means. In the event hot air is injected, for example, thru well 36 a combustion zone is established around this well so that a hot combustion wave is moved thru the fractures and adjacent stratum 10 to well 38. In situations in which hot air does not readily ignite the kerogen and fluid hydrocarbon in the stratum adjacent well 36, tubing string 42 may be withdrawn from within the stratum and ignition initiated by a charcoal pack soaked in heavy oil which may be introduced to the well bore within stratum 10 and burned to establish a combustion zone in the adjacent stratum in accordance with conventional methods or by any suitable means. Once the combustion zone is established, the injection of air thru well 36 is continued for a direct drive of the combustion front thru the stratum to well 38 or air is injected thru well 38 and produced fluids are recovered from well 36 thru tubing string 42.

The propagation of a combustion zone thru the stratum between wells produces additional fluid hydrocarbons by cracking the kerogen in the adjacent stratum and this produces additional porous coke which may be burned on a second pass of a combustion zone thru the stratum

While FIGURE 2 shows only a pair of spaced-apart wells, the process may be operated with any well pattern such as a 5-, 7-, or 9-spot pattern or a pattern of parallel lines of wells, well 36 representing a central well in a circular pattern in which a ring of wells 38 surround the central well or wells 36 and 38 may be representative of rows of parallel wells with other parallel rows adjacent these wells.

Certain modifications of the invention will become apparent to those skilled in the art and the illustrative details disclosed are not to be construed as imposing unnecessary limitations on the invention.

I claim:

1. The process for producing oil from oil shale containing kerogen which comprises the steps of:
   (1) heating said shale around a well-penetrating same to an elevated temperature so as to swell a section of the shale around said well;
   (2) fracturing the shale thru and beyond the swollen section radially outwardly from said well;
   (3) following step (2), again heating the shale around said well so as to crack the kerogen therein and cause released hydrocarbon fluids to flow through said fracture into said well;
   (4) recovering said hydrocarbon fluids from said well;
   (5) continuing the heating of step (3) until the shale adjacent the area of the fracture remote from said well swells and closes the fractures in said area;
   (6) following step (5), again applying fluid fracturing pressure on the shale around said well at fracture level so as to extend said fracture deeper into said shale; and
   (7) repeating steps (4), (5), and (6).

2. The process of claim 1 wherein the heating in steps (1) and (3) is effected by burning a combustible fuel-air mixture downhole in said well.

3. The process of claim 1 wherein the heating in steps (1) and (3) is effected by a downhole electric heater.

4. The process of claim 1 wherein the heating in steps (1) and (3) is effected by injecting steam at a temperature of at least 400° F. thru the well into contact with the kerogen-containing formation.

5. The process of claim 1 including the step of injecting a propping agent into the fractures after each fracturing step.

6. A process for producing oil from oil shale containing kerogen and penetrated by a pair of wells which comprises the steps of:
   (1) heating said shale around each of said wells at least to the swelling temperature of said shale thereby swelling a substantial section of shale adjacent the wells;
   (2) fracturing the shale thru and beyond the swollen section radially away from each well at substantially the same bedding plane;
   (3) following step (2), again heating the shale around

each well so as to crack said kerogen, causing resulting fluid hydrocarbons to flow thru the fractures into said wells, and extending the swollen section deeper into the shale;

(4) following step (3) again applying fluid fracturing pressure to the shale in each well at the level of the existing fractures so as to extend the fractures substantially beyond the expanded swollen section;

(5) following step (4), again heating the shale around each well so as to extend the swollen area and produce additional fluid hydrocarbons from the shale thru the fractures;

(6) repeating the fracturing and heating steps in each well until the fractures around each well provide a flow path between wells;

(7) thereafter, passing hot fluid thru the flow path of step (6) so as to produce additional fluid hydrocarbons from the intervening shale; and

(8) recovering fluid hydrocarbons from said wells produced by the foregoing steps.

7. The process of claim 6 including the step of positioning a propping agent into the fractures with each fracturing step.



8. The process of claim 6 including the steps of:

(9) igniting the shale adjacent the fracture at one well to establish a combustion zone;

(10) moving said combustion zone thru said shale adjacent said fracture toward the other well by feeding air thereto so as to produce additional fluid hydrocarbons; and

(11) recovering said additional hydrocarbons from at least one of said wells.


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