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IN-SITU COMBUSTION PROCESS FOR THE PRODUCTION OF OIL

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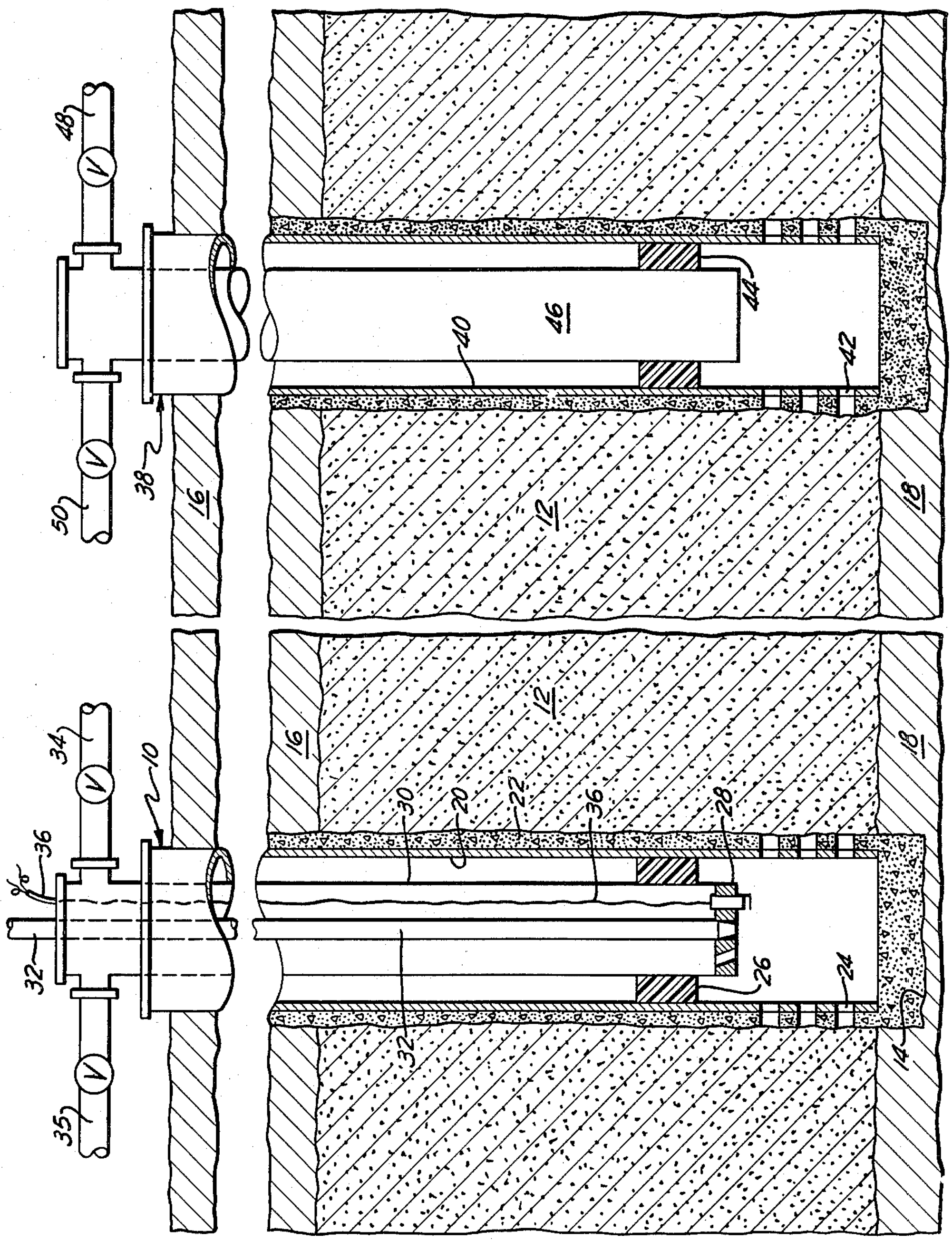

INVENTOR.
ALFRED SCHILD

BY

HIS ATTORNEY

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IN-SITU COMBUSTION PROCESS FOR THE PRODUCTION OF OIL

Alfred Schild, Pittsburgh, Pa., assignor to Gulf Research & Development Company, Pittsburgh, Pa., a corporation of Delaware

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This invention relates to a process for the recovery of oil from oil bearing formations by an in-situ combustion process, and more particularly to a method of increasing the rate of production in an in-situ combustion process.

The primary recovery of oil from oil bearing formations, hereinafter referred to as pay zones, utilizes the natural pressure on the pay zone to force the oil through the permeable formation of the pay zone to the well. The pressure on the pay zone may be sufficient to deliver oil to the well head, or, if the pressure is not adequate, artificial lift is used to raise oil in the borehole to the surface. Usually only a small fraction of the oil present in the oil bearing formation can be recovered by primary recovery process. Secondary recovery methods in which the pay zone is repressured to move the oil through the formation are frequently used to increase the amount of oil recovered. The repressuring can be accomplished by the injection of gas into the upper part of the formation or water into the lower part to provide the pressure necessary to move the oil through the formation. In another secondary recovery process referred to as an in-situ combustion process, oil in the formation is ignited and an oxygen-containing gas is pumped into the formation at an input well to continue the burning. The oxygen-containing gas and products of combustion force oil through the pay zone to an adjacent production well from which the oil is withdrawn.

The conventional in-situ combustion process in which an oxygen-containing gas is injected at an input well to burn a portion of the oil in the formation to force oil in the formation to an adjacent output well has several important disadvantages. The oil moved through the formation ahead of the combustion front is relatively cold, causing the resistance to flow of some highly viscous crude oils to be extremely high even though the permeability of the formation may be satisfactory for the production of less viscous oils. The high resistance to flow caused by the viscosity of the cold oil is aggravated by the fact that the formation through which the oil moves to the production well is also relatively cold. Moreover, water vapor formed during the combustion of the oil is condensed as it moves through the formation and forms a three-phase mixture of water, gaseous products of combustion and oil which seriously reduces the flow capacity of the formation. The water also partially hydrates clays that may be in the formation, causing them to swell and further plug the minute passages within the formation.

This invention resides in an in-situ combustion process in which an oxygen-containing gas is injected into the pay zone at a first well and oil in the pay zone is ignited adjacent that well. The injection of the oxygen-containing gas at the first well is continued for a period during which oil and gas are produced at an adjacent second well. The oxygen-containing gas is then injected into the pay zone at the second well and oil in the pay zone adjacent the second well is ignited to force the oil in the formation to the first well from which the oil is pro-

duced. The reversal of flow may be repeated as indicated to be desirable by changes in the injected gas-produced oil ratio or excessive gas injection pressures.

The single figure of the drawings is a diagrammatic illustration, partially in vertical section, of a well arrangement adapted for use in this invention.

Referring to the drawing, a first well indicated generally by reference numeral **10** is shown extending downwardly through a pay zone **12** to a total depth **14**. The pay zone **12** is between impervious cap rock **16** and an underlying formation **18**. Casing **20** is set in the well through the pay zone **12** and is cemented in place through the pay zone and any higher pay zones from which it may be planned to produce. The cement surrounding the casing **20** is indicated in the drawing by reference numeral **22**.

The casing **20** and cement **22** are perforated at **24**, preferably in the lower portion of the pay zone **12**. A packer **26** is set in the casing above the perforations **24**. Packer **26** may be of any conventional type adapted to withstand the heat developed during the heating and ignition of oil in the pay zone surrounding the casing.

An igniter **28** is run in the well through the packer **26** to a position adjacent the perforations **24** and supported in the lower end of a string of tubing **30**. Igniter **28** may be of any suitable construction such as illustrated in United States Letters Patent No. 2,668,592 of J. J. Piros et al. A fuel supply line **32** extends downwardly through the tubing **30** to discharge a fuel, preferably natural gas or a gas from a gas-oil separator at the lease, from its lower end adjacent the igniter **28**. Tubing **30** is connected at the well head with a line **34** supplying an oxygen-containing gas, preferably air, and a line **35** for delivery of oil produced from the well when the well is used as a production well. Air enriched with oxygen or diluted with an inert gas can also be used. Suitable valves are provided in lines **34** and **35** to permit either of those lines to be isolated from tubing **30** when not in use. The air is discharged from the lower end of the tubing **30** for admixture with the fuel discharged from line **32** and the mixture is ignited by a spark furnished by igniter **28** which is energized through a line **36** connected with a source of electrical energy. The products of combustion are discharged through perforations **24** to heat the oil in the pay zone surrounding the casing **20**. An excess of oxygen-containing gas over that required for burning the fuel introduced through line **32** is supplied through tubing **30** to supply the oxygen required for burning oil in the pay zone. Heating of the oil in the formation to a temperature at which it will ignite can also be accomplished by means of an electric heater in the well.

A second well indicated generally by reference numeral **38** is drilled through the pay zone **12** at a distance from well **10** determined by the well spacing for the particular field. Casing **40** is set and cemented in well **38** in the manner described for the first well **10**. The casing **40** is perforated preferably at **42** near the bottom of the pay zone and a packer **44** is set in the casing immediately above perforations. Tubing **46** is run into the well through the packer **44** and is connected at the well head with a line **48** for delivery of oil from the well and an oxygen-containing gas supply line **50** for the injection of oxygen-containing gas into the second well **38** when it is used as an input well. Lines **48** and **50** are provided with suitable valves to facilitate swinging the well from a production well to an input well. Any suitable means such as a pump, not shown, may be installed in tubing **46** for lifting oil produced from the borehole to the surface.

In the operation of the process of this invention a fuel is delivered through supply line **32** to the bottom of the tubing 30 where it is mixed with an oxygen-containing gas and ignited. Products of combustion pass through perforations 24 and heat the oil in the pay zone surrounding the well 10. When the temperature of the formation becomes sufficiently high to ignite the oil, the flow of fuel through supply line 32 is stopped and the flow of oxygen-containing gas through line 34 and tubing 30 is continued. The rate of injection of oxygen-containing gas into the formation will depend principally on the characteristics of the formation and the estimated radius of the combustion front. For example, air is ordinarily injected at a rate of 100,000 standard cubic feet per day and then increased to a rate which may be as high as 1,000,000 or more, standard cubic feet per day.

Oil in the formation is burned and the products of combustion along with any inert gas that may be in the oxygen-containing gas increase the pressure on the formation to supply energy for moving oil through the formation to the second well 38. The heat of combustion of the oil in the formation raises the temperature of oil adjacent the combustion front thereby reducing its viscosity. Some of the oil is heated sufficiently to cause it to crack to form lighter, less viscous products. The temperature in the formation at the combustion front is high enough to stabilize clays in the formation against hydration upon contact with water, thereby preventing their subsequent swelling and plugging the formation.

Injection of the oxygen-containing gas at the well 10 is continued for any desired period. Ordinarily the combustion is continued for a period calculated to burn oil from the formation for a radius of at least 50 feet, thereby cleaning that portion of the pay zone and stabilizing any clays that may be present before reversing the direction of burning. During this period the pressure on the pay zone increases and oil is withdrawn from the pay zone through perforations 42 of the casing 40 of the second well 38. After burning has continued for a period, which will depend largely on the characteristics of the field, the injection of the oxygen-containing gas into the pay zone 12 from the first well 10 is stopped and the fuel supply line 32 and the igniter 28 are pulled from the first well. The pump or other oil lifting equipment in the second well are pulled and installed in the first well. A suitable igniter such as igniter 28 together with suitable supply lines are positioned in the second well at the bottom of tubing 45. Fuel and an oxygen-containing gas are injected into the second well and the mixture ignited to ignite oil in the pay zone surrounding the second well 38. After ignition, the flow of fuel into the second well is stopped and the flow of the oxygen-containing gas is continued.

The period of burning in one direction before reversal will range from a minimum of about one month upwardly to six months or even more, depending on the well spacing, characteristics of the pay zone, viscosity of the oil, etc. A period of burning in one direction before reversal of two to six months is preferred.

The portion of the pay zone surrounding the first well 10 is clean and hot after the initial combustion, as is the oil nearest the production well. Clays present in that portion of the pay zone have been stabilized and do not swell upon further contact with water. The oil in the pay zone flows readily through the clean and hot formation surrounding the first well 10 and is lifted from the well by any suitable means.

If production from the formation begins to decrease as the heated zone cools, the injection and production wells can again be reversed and the oil delivered to the second well 38 through the hot portion of the formation surrounding that well. In order to facilitate illustration of this invention the first well 10 and well 38 have been illustrated equipped in a manner permitting use only as input and production wells respectively. Clearly each of the wells can be equipped with both ignition devices and tubing down the hole to allow the wells to be rapidly changed over from an input to a production well or vice versa.

In a typical application of this invention, a first well is drilled through a pay zone 25 feet thick. The bottom of the pay zone is at a depth of 4,385 feet. Seven inch casing is set and cemented through the pay zone after which the casing and cement are perforated in the range of 4,375 to 4,385 feet. A second well is drilled on a triangular pattern at a spacing of 600 feet from the first well. The second well is also drilled through the pay zone which is at a depth of 4,380 to 4,410 feet. Seven inch casing is set and cemented through the pay zone in the second well. The second well is then perforated in the bottom ten feet of the pay zone.

An igniter is run in the first well which is then completed and connected for the injection of natural gas and compressed air. Natural gas is pumped down the first well at the rate of 200 standard cubic feet per hour. Compressed air is injected into the well at a pressure to sustain a rate of 4,000 standard cubic feet per hour, and the mixture is ignited. The injection of air and natural gas is continued for 48 hours, after which the injection of natural gas is stopped. The rate of injection of air is gradually increased over a three day period to 500,000 standard cubic feet per day and continued for 60 days. Oil is pumped from the second well during this 60 day period.

At the end of the 60 day period, both wells are shut down. An igniter is run in the second well and the well completed and connected for use as an injection well. The first well is then completed as a production well. Natural gas and compressed air are then injected into the second well and ignited as described above for the first well. After 48 hours, the injection of natural gas is stopped. The rate of injection of compressed air is gradually increased to 500,000 standard cubic feet per day. Injection of air is continued for 120 days, during which oil is lifted from the first well.

The process of this invention supplies energy for moving the oil through the formation to the production well. After the first reversal of the direction of flow, oil is moved through a heated formation in which any clays that may be present are stabilized against hydration and swelling upon contact with water. Moreover, the oil moving to the production well has been heated, thereby greatly reducing its viscosity. Thus, the resistance to flow of the oil through the formation is greatly reduced.

The process of this invention has been described with reference to two wells but is not limited to such an arrangement. Frequently the wells will be in a field in which there are a large number of wells located in a regular geometric pattern. Typical arrangements of wells in such fields are in rectangular, triangular, and 5-spot patterns. In the use of this invention in such fields, it is advantageous to follow a pattern of alternating input and production wells. For example, alternating rows of input and production wells can be used.

I claim:

1. A process for the production of oil by the in-situ combustion of a portion of the oil in a pay zone penetrated by a first well and an adjacent second well comprising injecting an oxygen-containing gas into the pay zone through the first well, igniting oil in the pay zone adjacent the first well, continuing the injection of oxygen-containing gas into the pay zone at the first well to continue combustion of oil in the pay zone and thereby supplying energy moving oil in the pay zone to the second well and heating the formation surrounding the first well to a temperature at which clays are irreversibly dehydrated, simultaneously with the injection of oxygen-containing gas at the first well withdrawing oil from the second well, then stopping the withdrawal of oil from the second well, stopping the injection of oxygen-containing gas through the first well, injecting an oxygen-con-

taining gas into the pay zone through the second well, igniting oil in the pay zone adjacent the second well, continuing the injection of oxygen-containing gas through the second well to burn oil in the pay zone and supply energy moving oil in the pay zone to the first well, and withdrawing oil from the first well.

2. A process as set forth in claim 1 in which the direction of burning is reversed after a period of about 2 to 6 months of burning in one direction.

3. A process as set forth in claim 1 in which a gaseous fuel is ignited in the first well to ignite oil in the pay zone adjacent the first well.

4. A process for the production of oil by the in-situ combustion of oil in a pay zone penetrated by a first well and an adjacent second well comprising setting packing means in each of the first well and the second well near the bottom of the pay zone to divide the pay zone into an upper portion above the packing means and a lower portion below the packing means, injecting an oxygen-containing gas into the lower portion of the pay zone through the first well, igniting oil in the pay zone adjacent the first well, continuing the injection of oxygen-containing gas into the lower portion of the pay zone at the first well to continue combustion of oil in the pay zone and thereby supplying energy moving oil in the pay zone to the second well and heating the formation surrounding the first well to a temperature at which clays are irreversibly dehydrated, simultaneously with the injection of oxygen-containing gas at the first well withdrawing oil from the lower portion of the pay zone into the second well, then stopping withdrawal of oil from the second well and the injection of oxygen-containing gas into the pay zone through the first well, injecting an oxygen-containing gas into the lower portion of the pay zone through the second well, igniting oil in the pay zone adjacent the second well, continuing the injection of oxygen-containing gas through the second well to burn oil in the pay zone and supply energy moving oil in the pay zone to the first well, and withdrawing oil from the first well.

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