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INTERMITTENT IN-SITU BURNING

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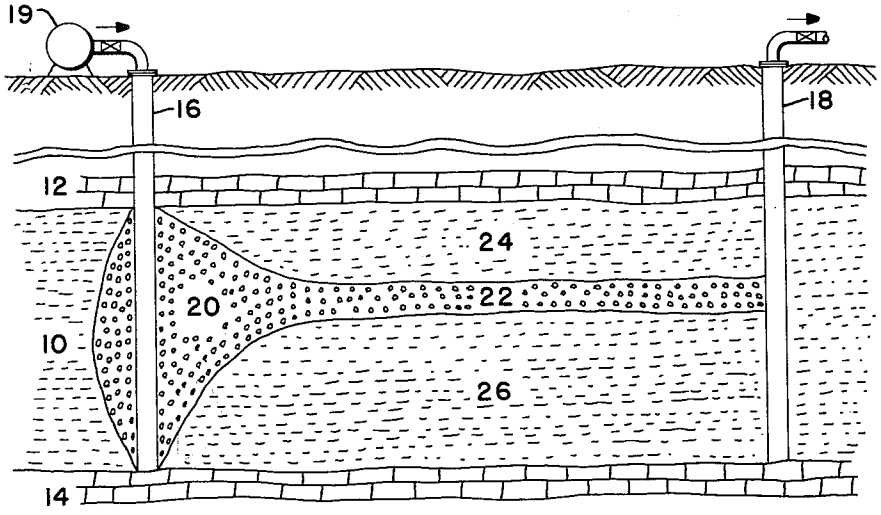


FIG.-1

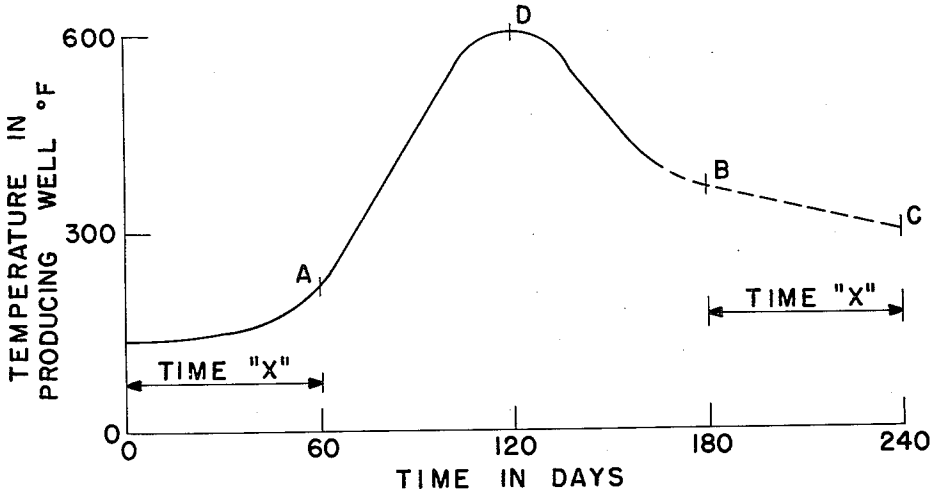


FIG.-2

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INTERMITTENT IN-SITU BURNING

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This invention relates to the recovery of oil and gas from underground reservoirs. It relates particularly to a process of recovering oil by intermittent combustion of a portion of the hydrocarbons within a reservoir.

It is well known that primary or conventional systems of recovering and producing oil and gas from underground reservoirs very seldom result in the recovery of more than 25 percent of the oil originally in place in the reservoirs. Many secondary recovery methods, such as waterflooding, gas or water drive, gas repressuring, etc., have been used in an effort to obtain a greater portion of the oil. Pressure maintenance projects for maintaining reservoir pressure at a preselected level by injection of gas, water, or other fluid as well as various cycling projects have also been tried. Although these methods have been of value in increasing the ultimate recovery of oil and gas from many underground reservoirs, it is well known that these methods do not recover all of the oil in the reservoir.

Thermal means have also been proposed for increasing the oil recovery from underground reservoirs. One of the thermal means suggested has been the "in-situ combustion" method. In the in-situ combustion method, an input well is drilled into an oil-bearing reservoir and a source of heat applied thereto to initiate combustion in that part of the reservoir immediately surrounding the input well. A producing well for recovering the hydrocarbons from the reservoir is drilled or completed a suitable distance from the input well. A suitable oxygen-containing gas is then injected into the input well to support combustion in-situ of the hydrocarbon material present in the formation.

In the practice of the in-situ combustion process, the operators of such processes have diligently strived to maintain continuous combustion, once combustion is initiated in the reservoir, until the desired recovery operations have been completed. The in-situ combustion process is in its infancy, and many operational problems are associated with the process as it is now carried out. For example, in field operations recently conducted, considerable burning and coking in a producing well resulted. This necessitated replacing the original casing liner with a stainless steel liner and the circulation of water or another cooling medium between the casing, the casing liner and the tubing to maintain a temperature low enough not to damage the mechanical equipment in the well. This is obviously a costly operational feature. Attempts to control the burning or coking in the producing well by throttling back on the production well have been found to be of little or no benefit.

It has also been suggested that after combustion has been initiated in a reservoir, the burning should continue until the combustion front has advanced a distance of from 40 to 90% of the distance between injection and production wells. Thereupon the injection of air is to be stopped and then a fluid, not adapted to aid combustion, is forced through the reservoir to facilitate the exhaust of hydrocarbon in the production well. That suggested method is likewise subject to many problems and defects. For example, detecting the location of the combustion front is a rather difficult and usually indefinite

procedure. It has been suggested that temperature wells be drilled between the input wells and the producing wells to determine the location of the combustion front; this of course is quite expensive and presents many engineering problems when the combustion front reaches the temperature well. It is also to be noted that temperature wells must be drilled at varying locations between injection and producing wells if more than one position of the burning front is to be detected. This method also does not lower the compressor or pumping requirements from other known methods, as when the oxygen-containing gas supply is shut off, a second fluid is then injected into the input well and forced through the reservoir.

It will be seen that these problems set out above are either eliminated or overcome to a degree sufficient so as not to pose a serious operational problem in the practice of applicants' invention as will be described hereinafter.

Briefly, the present invention includes a method of recovering oil and gas from a subterranean oil-bearing reservoir which has been penetrated by an input well and a producing well which comprises initially subjecting the reservoir in the immediate vicinity of the input well to in-situ combustion. Air or other oxygen-containing gas is injected into the input well to support the burning of the hydrocarbons in the reservoir from the input well toward the producing well. Air in the burning front channels rapidly through the permeable part of the sand, which results in a layer or channel of said being burned substantially clean from the vicinity of the input well to the vicinity of the producing well. When the temperature in the producing well reaches a preselected level, the injection of the oxygen-containing gas into the reservoir through the input well is stopped. During the period of air injection and when no injection occurs, the well is produced in its normal manner, either by flowing or by pumping means or other lifting processes. The injection of air is ceased for a period until the temperature in the producing well decreases to a predetermined value. During this period, fluid in the reservoir flows into the permeable burnt-out channels from the regions of higher saturations of reservoir fluid, as no oxygen-containing gas or other fluid has been injected through the input well. This "blocks" the permeable channel. When the temperature in the producing well decreases to a predetermined level, an oxygen-containing gas is again reinjected through the input well to the reservoir and combustion is reinitiated in the reservoir. This reinitiation of the combustion is preferably auotmatic. A permeable channel is then again burned out and the cycle recompleted.

It is therefore an object of this invention to provide an improved method for recovering oil and gas from an underground reservoir utilizing intermittent in-situ combustion of a portion of the hydrocarbons in the reservoir.

Other objects and advantages of the present invention will be readily apparent from the following description and drawing in which:

FIG. 1 is a cross-sectional view of the reservoir illustrating a diagrammatic sectional view of an underground reservoir in which the invention is practiced; and

FIG. 2 is a temperature-time curve used in explaining the practice of the invention.

Referring to the drawing, an underground reservoir **10** overlain by shale bed **12** and underlain by shale bed **14** has been penetrated by input well **16** and output or producing well **18**. Combustion may be initiated in the reservoir **10** in the vicinity of input well **16** by use of conventional methods such as electrical methods, phosphorus deposited in the borehole, burning of fuel and air at the bottom of well, or by spontaneous combustion occurring with the injection of air. An oxygen-contain-

ing gas is injected through the input well to support the combustion of the hydrocarbons within the reservoir. A compressor **19** may be used to compress air for injection. The rate and pressure of injection is determined by such factors as depth of the reservoir, reservoir properties such as thickness, permeability, well spacing, etc., and may be determined by one skilled in the art.

One of the problems in prior in-situ burning is that the air in the burning front will channel rapidly through the permeable part of the sand. This resulted in early excessive temperatures in the producing well with accompanying coking, need for special pumps, etc. This heretofore undesirable feature of channeling is utilized to advantage in the present invention. A typical burn-out pattern is illustrated in portion **20** of reservoir **10** and featuring channel **22**. Selective injection of the oxygen-containing gas may, if necessary, be used to encourage the operation of the process as illustrated in FIG. 1. However, it has been found that at normal injection rates of about 10,000 to 1,000,000 c.f.d/vertical foot, which may vary for various depths and reservoirs, channeling normally occurs in any reservoir. The oxygen-containing gas is injected through the input well **16**, and combustion continues in the reservoir until the temperature in well **18** reaches a preselected maximum level, at which time the injection of the oxygen-containing gas is stopped. This preselected maximum is determined primarily by the nature of the oil including its coking properties, etc., with it being a primary object to eliminate coking in the well and well epuipment and to maintain the temperature sufficiently low so as not to damage well equipment. However, it is anticipated that the maximum temperature selected for the producing well **18** will not exceed a maximum of about 600° to 700° F. The temperature of producing well **18** is meant to be that maximum temperature which is detected at any point along the circumferential portion of reservoir **10** which is immediately adjacent the segment of well **18** which penetrates reservor **10**. Thermocouples may be positioned at various selected points within the producing well opposite the reservoir under consideration and readings may be made periodically or may be continuously recorded. As the hydrocarbons in reservoir portion **20** and channel **22** are being burned, a large quantity of heat is liberated and heats the surrounding formation—that is, portions **24** and **26**. The temperature in portions **24** and **26** may rise as high as 1,000° F., depending upon the rock natures, permeability, and the thickness. The heat thus released heats the hydrocarbons in the reservoir and aids in their recovery primarily by lowering the viscosity of the oil and by vaporizing hydrocarbons from the oil which acts as a gas drive.

When the supply of oxygen is shut off from input well **16**, the burning, of course, ceases; likewise, the temperature rise in the formation and in well **18** levels off and starts to decline. The liberated hydrocarbons force the freer-flowing oil toward producing well **18** from where it can be produced either by flowing or by pumping; and the liberated gas or hydrocarbons also force the oil into burned-out portions **20** and **22**, thus "fluid blocking" channel **22**. No injection of any fluid is made through well **16** until the temperature in well **18** has decreased to a predetermined value. A method of determining the predetermined temperature level at which reinjection of air is commenced is explained hereinafter. Due to a time lag from the time air is injected at the input well until heat reaches the producing well, the predetermined temperature at which reinjection is commenced is greater than the preselected minimum temperature desired in the producing well.

When the temperature in well **18** has decreased to a predetermined level, the injection of oxygen-containing gas is once more begun through input well **16**. Combustion will normally be reinstituted automatically, due to the reaction of oxygen with the hydrocarbons. The injection of oxygen-containing gas through input well **16** is continued until the temperature in producing well **18** again reaches the preselected maximum level. This process may be repeated as often as necessary until the reservoir is depleted. It is seen that the recovery of the oil from the reservoir is not dependent upon the additional injection of fluid to flush the reservoir. The heating of the reservoir will reduce the viscosity of the oil and liberate adequate hydrocarbon vapors to propel the freer-flowing fluid or oil to the producing well.

FIG. 2 is an illustrative example of determining the temperature of the producing well at which the reinjection of the oxygen-containing gas should commence. The chart has an abscissa of time and an ordinate of temperature. By considering the coking and other characteristics of the crude oil, one skilled in the art can readily determine a maximum desirable temperature within the producing well. In this case, it is assumed that this temperature is 600° F. By comparing the viscosity-temperature relationship of the oil being produced together with the permeability and other characteristics of the sand and the desired producing rate, it is possible for one skilled in the art to determine the minimum temperature desired in the producing well. It is normally desired to maintain the viscosity of the oil at about one centipoise or less; this can normally be accomplished with minimum temperatures of about 300° F. for low API gravity oil in the range of about 10° to 20° and as low as about 200° F. for medium API gravity oil in the range of 20° to 30° In this case, it is assumed that this minimum producing well temperature is 300° F. A temperature-time curve is plotted from the time injection of the oxygen-containing gas is commenced, the temperature being that of the producing well and the time being in any convenient term, preferably days. When the temperature reaches 600° F. as indicated at D, the oxygen-containing gas injection is ceased. After the injection of the oxygen-containing gas is stopped, the temperature curve may continue rising for a relatively short period of time but begins rather shortly after such injection ceases, a decline which can be plotted from observed temperature readings until a reasonably definite curve pattern is developed; then the curve can be extrapolated until it reaches the minimum temperature of 300° F. desired in the producing well. The extrapolated portion of the curve is represented by the dotted portion of the curve. By observing the chart, it is possible to determine at what time the temperature of the producing well will have dropped to the minimum desired temperature as indicated at C. It is also possible to determine from the chart the time lag from the time air is injected until the temperature in the producing well feels the effects of the in-situ combustion—that is, a temperature rise in the producing well. This is indicated at temperature A and with this time being indicated by time "X" which in this example is 60 days. As the time lag X is known, it can also be determined when the reinjection of the oxygen-containing gas should commence. As indicated on the graph, this would be when the declining temperature of the curve reaches a temperature as indicated at point B, or 60 days after the injection of the oxygen-containing gas was stopped, as indicated at point D. By the time the temperature in the producing well has declined to temperature C, heat resulting from the reinjection of oxygen-containing gas will have reached the producing well and the curve will again start up. It is seen that the temperature in the producing well is thus maintained above the minimum preselected temperature. The accuracy of the extrapolated portion of the curve can be tested by comparison with actual observed temperatures during the decline; and corrections, if any are necessary, may be made on the next cycle of the operation.

Many of the problems associated with in-situ combustion as operated under the prior art are overcome in this operation. For instance, the burning and the coking in the producing well are overcome by controlling

the temperature in the producing well—that is, oxygen-containing gas is shut off so that the temperature in the producing well does not exceed a preselected value. Maintaining control on the maximum temperature in the producing well also eliminates the need for using stainless steel casing. Also, it will not be necessary to circulate water between an inner casing or tubing and the regular casing.

The method disclosed herein also has economic advantages over the methods utilized in the prior in-situ combustion operation. For example, the compressors which compress the air or oxygen-containing gas are run between 25 and 75 percent of the time that they would be run under prior methods. This alone accounts for a very substantial savings in fuel. By eliminating the coking in the wall bore and the excessive heat which may damage the mechanical parts of the well, it is seen that a considerable saving is made in the operation of the intermittent in-situ combustion process described herein. There is less oil burned in the reservoir, and it therefore leaves more oil which can be ultimately recovered therefrom. An additional saving may be realized by using the temperature in the producing well to determine when injection should cease or begin, thus eliminating the necessity of driling holes to determine the temperature of the front, etc.

It is to be understood that various changes and modifications in this invention may be made without departing from the scope thereof.

The invention claimed is:

1. A method of recovering oil and gas from a subterranean oilbearing reservoir which has been penetrated by an input well and an adjacent producing well which comprises initiating a zone of combustion within said reservoir adjacent the bore of said input well, injecting an oxygen-containing fluid into said reservoir through said input well to maintain said combustion thus causing a burned-out channel, stopping the injection of fluids when the temperature in said producing well reaches a preselected maximum whereby fluid in the reservoir flows into the permeable burned-out channel from the regions of higher saturation of reservoir fluid, such preselected maximum being below the temperature which will damage the producing well equipment, reinstituting the injection of said oxygen-containing fluid through said input well when the temperature in said producing well decreases to a predetermined value not less than about 200° F., and producing oil from the reservoir through the producing well.

2. A method as defined in claim 1 in which the process described therein is repeated until the reservoir is depleted.

3. A method as defined in claim 1 in which reservoir fluid is produced through said producing well during all of the steps set out therein.

4. A method of recovering oil and gas from a subterranean oil-bearing reservoir which has been penetrated by an input well and a producing well which comprises injecting an oxygen-containing gas into said reservoir through said input well, initiating combustion of said oil within said reservoir with said combustion advancing from said input well toward said producing well, recording the time lag from the time said injection commences to the time that temperature begins to rise in said producing well, stopping the injection of gas when the temperature in the producing well reaches a preselected maximum which is below that temperature which is destructive to the producing well, detecting the rate of decline of the temperature in said producing well after injection has ceased, reinstituting the injection of said oxygen-containing gas through said input well beginning at a period of time which is equal to said time lag prior to the time that the temperature in said producing well declines to a preselected minimum of not less than about 200° F., as indicated by said rate of temperature decline and producing fluid from said well.

5. A method as defined in claim 4 in which reservoir fluid is produced through said producing well during all of the steps set out therein.

6. A method as defined in claim 4 in which the process described therein is repeated until the reservoir is depleted.

7. A method of recovering oil and gas from a subterranean oil-bearing reservoir having one strip more permeable than the average of the remaining sections of the reservoir which has been penetrated by an input well and a producing well which comprises injecting an oxygen-containing gas into said reservoir through said input well, initiating combustion of the hydrocarbons within said reservoir in the vicinity of the bore of said input well with said combustion advancing from said input well, the leading edge of combustion advancing more rapidly through said more permeable strip, stopping the injection of gas when the temperature in said producing well reaches a preselected maximum not in excess of about 700° F. whereby fluid in the reservoir flows into the burned-out more permeable strip from the region of higher saturation of reservoir fluid, reinstituting the injection of oxygen-containing gas through said input well to cause recombustion to occur in said reservoir with heat therefrom reaching said producing well by the time the temperature in said producing well declines to a preselected temperature of not less than about 200° F., and producing fluid from said producing well.

8. A method as defined in claim 7 in which the process described therein is repeated until the reservoir is depleted.

9. A method as defined in claim 7 in which reservoir fluid is produced through said producing well during all of the steps set out therein.

10. A method of recovering oil and gas from an underground oil-bearing reservoir having highly permeable strips which has been penetrated by an input well and a producing well which comprises injecting only a gas which contains oxygen in sufficient quantities to support combustion within said reservoir through said input well into said reservoir, initiating combustion within said reservoir adjacent the bore of said injection well, ceasing the injection of gas when the temperature in said producing well reaches a pre-selected maximum not exceeding about 700° F., reinstituting the injection of oxygen-containing gas through said input well when the temperature in said producing well decreases to a pre-determined value of not less than about 200° F. and producing fluid from said reservoir.

11. An improved in-situ combustion method of recovering hydrocarbons from a subterranean oil-bearing reservoir in which a combustion front is initiated at an input well and proceeds toward an adjacent producing well in which the combustion is supported by the injection of an oxygen-containing fluid into said reservoir through the input well and hydrocarbons are produced at the producing well, the improvement which comprises: stopping the injection of fluid when the temperature in said producing well reaches a preselected maximum below the destructive temperature and not greater than about 700° F.; and reinstituting the injection of said oxygen-containing fluid through said input well when the temperature in said producing well decreases to a predetermined minimum of not less than about 200° F.

12. An improved in-situ combustion method of recovering hydrocarbons from a subterranean oil-bearing reservoir in which a combustion front is initiated at an input well and proceeds toward an adjacent producing well in which the combustion is supported by the injection of an oxygen-containing fluid into said reservoir through an input well, the improvement which comprises: stopping the injection of fluid when the temperature in said producing well reaches a preselected maximum which is below the destructive temperature of the producing well and

not greater than about 600° F.; reinstituting the injection of said oxygen-containing fluid through said input well when the temperature in the producing well decreases to a predetermined minimum of not less than the temperature which will maintain the viscosity of the hydrocarbons flowing therein to about 1 centipoise or less; and producing hydrocarbons from said producing well.

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