United States Patent

Jones

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[54] IN SITU COMBUSTION PROCESS USING TIME-DEPENDENT SHEAR-THINNING LIQUID BARRIER

[72] Inventor: Lloyd G. Jones, Dallas, Tex.

[73] Assignee: Mobil Oil Corporation

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[21] Appl. No.: 15,702

[52] U.S. Cl. 166/257, 166/259, 166/281, 166/283

[51] Int. Cl. E21b 33/138, E21b 43/24

[58] Field of Search 166/257, 259, 261, 281, 283, 166/308

[56] References Cited

UNITED STATES PATENTS

2,779,735	1/1957	Brown et al.	166/283 UX
2,866,754	12/1958	Cardwell et al.	166/283 X
2,965,172	12/1960	Da Roza	166/308
3,018,827	1/1962	Henderson et al.	166/257
3,055,423	9/1962	Parker	166/257
3,172,470	3/1965	Huitt et al.	166/257
3,179,172	4/1965	Reed et al.	166/283
3,349,843	10/1967	Huitt	166/259

Primary Examiner—Ian A. Calvert

Attorney—William J. Scherback, Frederick E. Dumoulin, William D. Jackson, Andrew L. Gaboriault and Sidney A. Johnson

[57] ABSTRACT

In situ combustion processes in which a barrier formed of a time-dependent shear-thinning liquid is employed to control the vertical migration of the combustion front. The reservoir is fractured in order to form a horizontally extending fracture between the injection and production systems employed in the combustion drive. Thereafter a time-dependent shear-thinning liquid is introduced into the fracture. This liquid undergoes an increase in viscosity with time in order to form the barrier. The invention may be employed in conjunction with in situ combustion drives carried out in multiply completed wells or in horizontally spaced injection and production wells.

5 Claims, 2 Drawing Figures

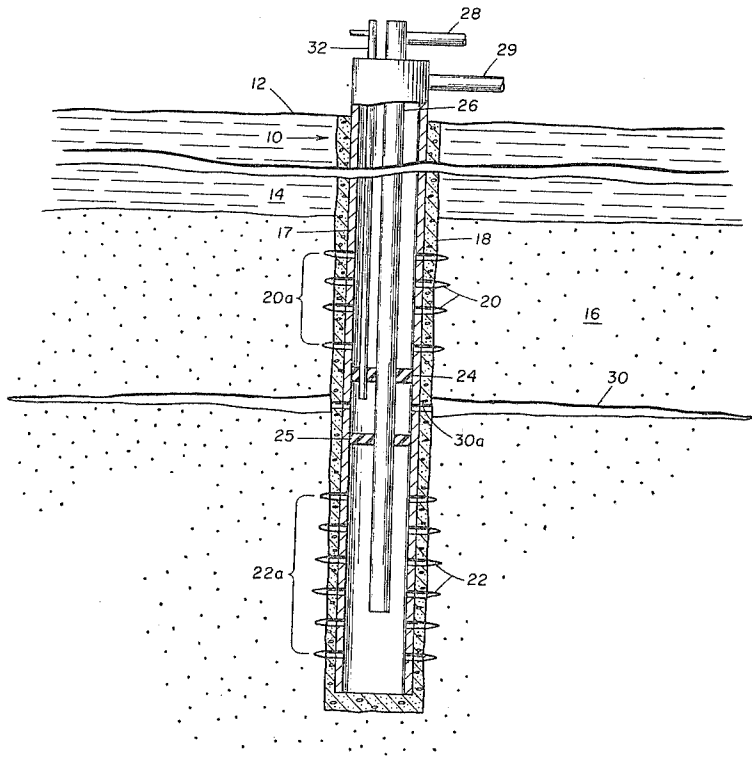
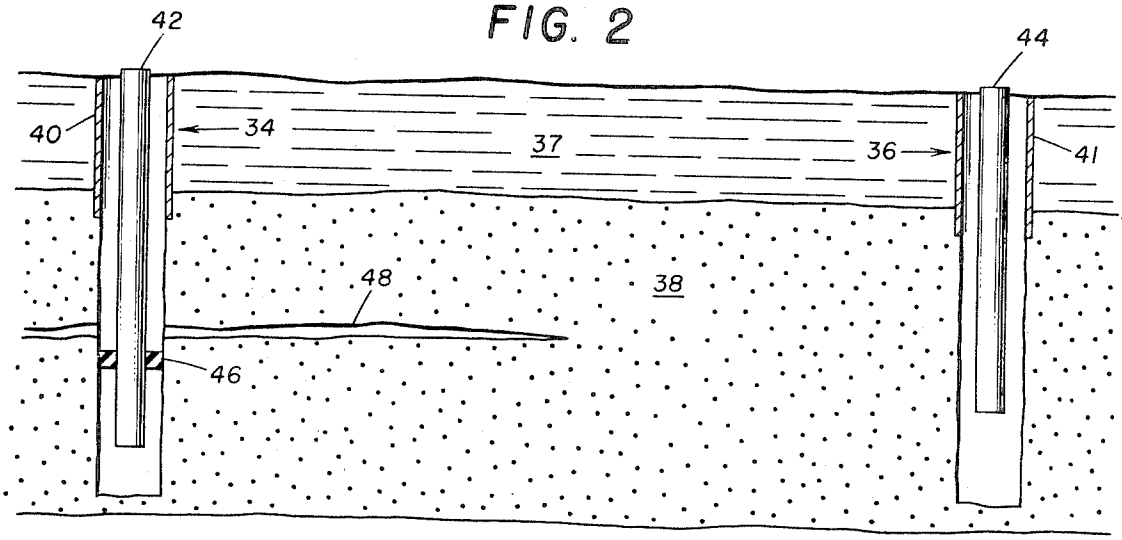


FIG. 2



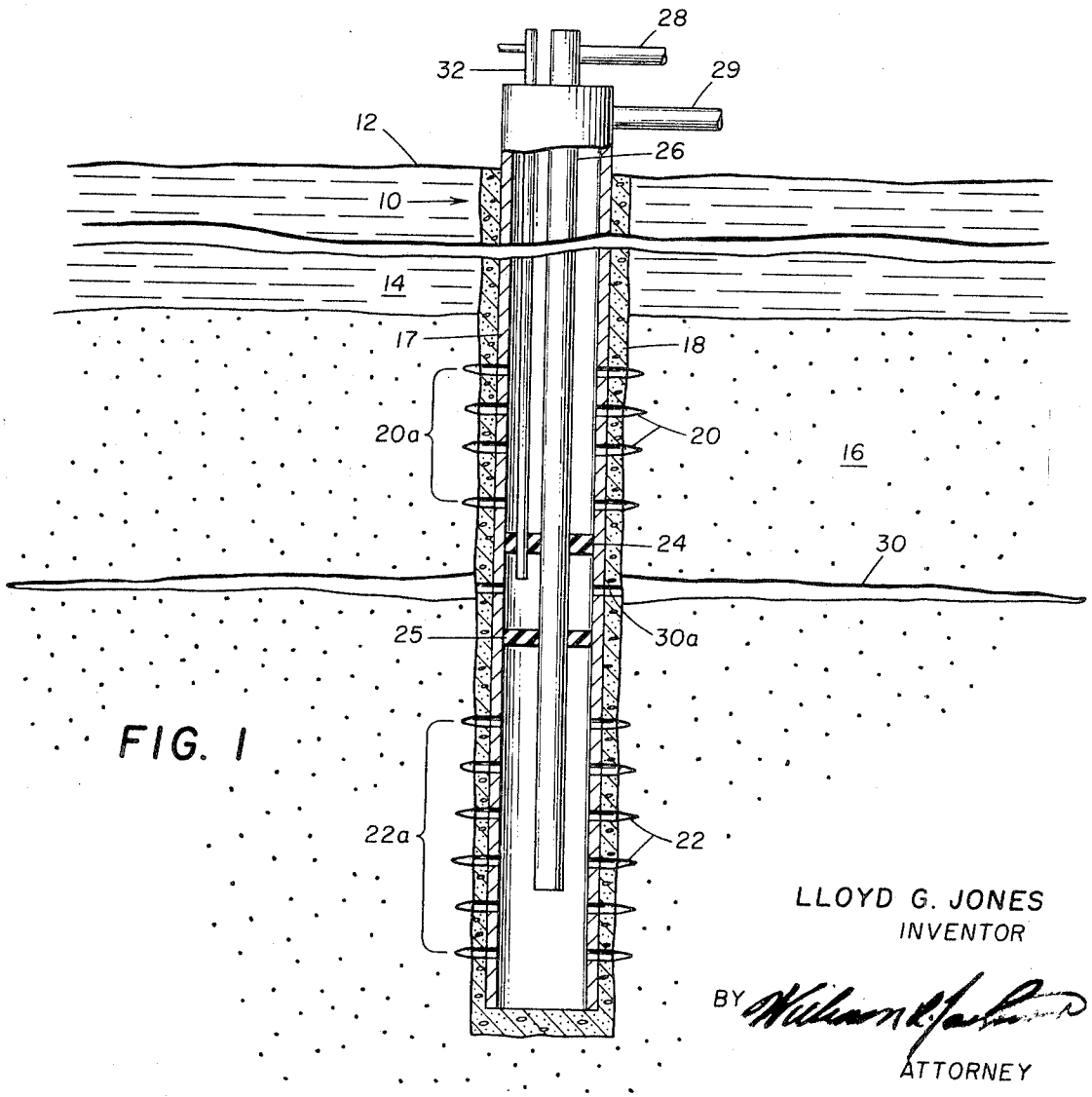


FIG. 1

LLOYD G. JONES
INVENTOR

BY William L. Parker

ATTORNEY

IN SITU COMBUSTION PROCESS USING TIME-DEPENDENT SHEAR-THINNING LIQUID BARRIER

BACKGROUND OF THE INVENTION

This invention relates to the recovery of hydrocarbon fluids from subterranean oil reservoirs and more particularly to the employment of in situ combustion techniques employing a barrier formed by the injection of time-dependent shear-thinning liquid.

In recovery of oil from subterranean reservoirs it usually is possible to recover only a minor portion of the oil in place by the so-called primary recovery techniques, that is, those techniques which utilize only the natural forces present in the reservoir. Thus, a variety of supplemental recovery techniques have been developed in order to increase the recovery of oil from such reservoirs. In these supplemental techniques which are commonly referred to as "secondary recovery operations," although they may be primary or tertiary in sequence of employment, energy is supplied to the reservoir as a means of moving the fluids within the reservoirs to suitable production wells through which they may be withdrawn to the surface of the earth.

Secondary recovery techniques which are showing increasing promise are those which involve in situ combustion. In an in situ combustion process, a portion of the carbonaceous material within the reservoir is burned or oxidized in situ in order to establish a combustion front. The combustion front may be moved through the reservoir by either a direct of inverse drive. In a direct in situ combustion process, the combustion is initiated adjacent one or more injection wells and the resulting combustion front is advanced through the reservoir in the direction of one or more production wells by the introduction of a combustion supporting gas through the injection wells. The combustion front is preceded by a high-temperature zone commonly called a "retort" zone within which the reservoir oil is heated to effect a viscosity reduction and is subjected to distillation and cracking. The resulting hydrocarbon fluids are displaced to the production wells where they are withdrawn to the surface of the earth. In an inverse combustion drive, the combustion front is established adjacent the production well or wells. As the combustion supporting gas is introduced through the injection wells, the combustion front advances countercurrently to the flow of such gas in the direction of the injection wells. The in situ combustion procedure, whether inverse or direct, is particularly useful in the recovery of thick heavy oils such as viscous petroleum crude oils and the heavy tarlike hydrocarbons present in tar sands. While these tarlike hydrocarbons may exist within the reservoir in a solid or semisolid state, they undergo a sharp viscosity reduction upon heating, an in an in situ combustion process they behave somewhat like the more conventional petroleum crude oils. In situ combustion also is employed in the recovery of hydrocarbons from oil shale.

One problem encountered in in situ combustion, whether by direct or inverse drive, is that of controlling the migration of the combustion front. For example, where the combustion drive is a substantially vertical drive between upper and lower completion intervals of a multiply completed well, the combustion front tends to move through the reservoir in a relatively limited zone next adjacent the well. This, of course, leaves unrecovered those hydrocarbons present in the more remote areas of the reservoir. In order to extend the combustion front outwardly in such techniques, it is a conventional practice to introduce a barrier which extends outwardly into the reservoir between the injection and production intervals of the well. For example, in U.S. Pat. No. 3,055,423, to Parker there is disclosed a process wherein an aqueous salt solution is injected into an intermediate portion of the reservoir. The water evaporates from solution under the high-temperature conditions present at the combustion zone and leaves a salt residue which acts as a barrier. In another technique disclosed in U.S. Pat. No. 3,018,827, to Henderson et al. the reservoir is fractured and cement then injected into the resulting fracture in order to form a somewhat similar barrier.

The problem of controlling combustion front migration also is present where the combustion front is advanced more or less horizontally between spaced injection and production wells. In such cases the combustion front tends to preferentially advance through zones of relatively high permeability within the reservoir. For example, as disclosed in U.S. Pat. No. 3,128,203 to Weiss et al. it is common for the combustion front to channel along the top of the reservoir where it may break through into the production wells long before a substantial portion of the reservoir has been subjected to combustion. This tendency to channel along the top of the reservoir is particularly pronounced in direct combustion drives.

SUMMARY OF THE INVENTION

In accordance with the present invention, there is provided a new and improved in situ combustion process wherein a time-dependent shear-thinning liquid is employed to control the vertical migration of the combustion front. In carrying out the invention, a horizontally extending fracture is formed in the reservoir between the injection and production systems employed in the combustion drive. A time-dependent shear-thinning liquid is introduced into the fracture. This liquid undergoes an increase in viscosity with time and forms a barrier which retards the vertical flow of fluid within the formation. A combustion-supporting gas is introduced into the reservoir by way of the injection system in order to propagate the combustion front between the injection and production systems. The barrier formed by the time-dependent fluid functions to control the migration of the combustion front such that the overall sweep efficiency of the combustion process is enhanced.

One embodiment of the invention is employed in an in situ combustion process in which the injection and production systems are formed by vertically spaced intervals of one or more multiply completed wells. In this case, the fracture containing the time-dependent liquid extends outwardly into the reservoir from such a well at a location between the completion intervals employed for injection and production purposes. A further embodiment of the invention is employed to control combustion front migration in a combustion process carried out between horizontally spaced wells. In this case, the fracture containing the time-dependent liquid extends outwardly from one of the wells within an intermediate portion of the reservoir in order to limit the vertical movement of the combustion front.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is an illustration in section of a multiply completed well which may be used in carrying out the invention; and

FIG. 2 is an illustration in section showing separate injection and production wells which may be used in carrying out the invention.

DESCRIPTION OF SPECIFIC EMBODIMENTS

The present invention may be carried out utilizing any suitable injection and production systems. The injection and production systems which may comprise one or more walls extending from the surface of the earth into the subterranean reservoirs. Such injection and production wells may be located and spaced from one another in any desired pattern. For example, a "line drive" pattern may be utilized in which a plurality of injection wells and a plurality of production wells are arranged in rows which are spaced horizontally from one another. Exemplary of other patterns which may be used are the so-called "circular drive" patterns in which the injection system comprises a central injection well and the production system comprises a plurality of production wells spaced about the injection well Typical circular drive patterns are the inverted five-spot, seven-spot, and nine-spot patterns. The above and other patterns are well known to those skilled in the art and for a more detailed description of such patterns reference is made to Uren, L. C., PETROLEUM PRODUC-

TION ENGINEERING—OIL FIELD EXPLOITATION, 2nd Ed. McGraw-Hill Book Company, Inc., New York and London, 1939, and more particularly to the section entitled Water Flooding Process," appearing at pages 444–459. While the well patterns described in Uren are with reference to waterflooding operations, it will be recognized that such patterns are also applicable to in situ combustion procedures.

The present invention also may be carried out utilizing one or more dually completed injection-production well of the type disclosed, for example, in U.S. Pat. No. 2,725,106, to Spearow. In this instance, the injection system may comprise a lower completion interval of one or more multiply completed well of the type described in the aforementioned patent to Spearow and the production system may comprise an upper completion interval of one or more such wells. Of course, the reverse procedure may be used, that is, an upper completion interval may be used for the injection of combustion supporting gas and a lower completion interval used for the recovery of hydrocarbon fluids.

Turning now to FIG. **1**, there is illustrated a dually completed well system which may be utilized in carrying out the present invention. This system comprises a wellbore **10** which extends from the surface **12** of the earth through overburden formation **14** into a carbonaceous reservoir **16**. The well **10** is provided with a casing **17** which is cemented in place by a cement sheath **18**. The casing **17** and the surrounding cement are provided with perforations **20** which define an upper completion interval **20***a* within reservoir **16** and perforations **22** and which define a lower completion interval **22***a* within the reservoir **16**. The completion intervals **20***a* and **22***a* are separated by packers **24** and **25**. A tubing string **26** extends from the surface of the well through the packers and opens the fluid communication with the lower completion interval **22***a*. The tubing string is provided at the surface with a flowline **28** for the introduction and withdrawal of fluids and the casinghead is likewise provided with a flowline **29** which may be utilized to introduce fluids into or withdraw fluids from the tubing-casing annulus.

It will be recognized that the well system illustrated in FIG. **1** is exemplary only that the invention may be utilized in a well completed by any suitable technique. For example, the well may be completed openhole with the casing set at the top of the reservoir **16** and then provided with a tubing string extending through one or more packers such as shown. In this case the openhole portion of the well above the packer would comprise the upper completion interval and the portion of the well below the packer would comprise the lower completion interval.

The well will be described with reference to a direct combustion drive in which the lower completion interval **22***a* is utilized as the injection system and the upper interval **20***a* as the production system. However, it is to be understood that the invention is also applicable for use in conjunction with an inverse combustion drive or that the location of the intervals used for injection and production may be reversed.

As a first step in the combustion drive, a combustion front is established within the reservoir adjacent the interval **22***a* by a suitable technique. Such combustion may be initiated by locating an electrical or gas-fired heater within the lower portion of the well and introducing a combustion-supporting gas such as air into the reservoir via flowline **28**, tubing **26**, and interval **22***a*. Also in some reservoirs the combustion front may be established by autooxidation. In this technique air, which may be enriched with oxygen, is injected through interval **22***a* in order to slowly bring the carbonaceous material within the reservoir up to the combustion temperature without the use of extraneous heating means.

As the combustion front advances through the reservoir, the gaseous combustion products, including carbon monoxide, carbon dioxide, and water are driven through the reservoir ahead of the combustion front and the preceding retort zone. These combustion products act as a displacing and heating medium with respect to the reservoir oil. As the reservoir oil is contacted by the combustion products, it is heated, thus effecting a viscosity reduction, and driven through the reservoir in the direction of the production interval **20***a*. In addition, the reservoir oil will also undergo distillation and/or cracking in the vicinity of the retort zone and the distillation and cracking products are likewise driven ahead of the combustion zone. These products advance through the reservoir along lines of flow which provide the least pressure drop between the injection and production intervals. Thus, the combustion front will tend, in absence of a barrier, to flow upwardly in very close proximity to the well and a large portion of the reservoir at more remote locations will not be affected by the combustion drive.

In accordance with the present invention, the combustion front is directed outwardly away from the well by means of a barrier formed by a liquid which is shear thinning and time dependent. A shear-thinning liquid is one which exhibits a decrease in viscosity with an increase in shear rate. Where the viscosity also changes as a function of time, the liquid is said to be time dependent. Thus, fro a shear-thinning time-dependent liquid, when shear is first initiated at a given shear rate, the shear stress will have a given value. As the shear rate is maintained, the shear stress decreases with time to a lower value. Therefore, as the shear rate is maintained constant and the shear stress is reduced, the viscosity of the fluid is likewise reduced over the time interval. If the shearing force is then removed from the liquid, the viscosity will not immediately increase to its former level but will recover more or less gradually with the passage of time.

Time-dependent shear-thinning liquids at the shear rates commonly encountered upon injection into a subterranean formation, e.g., shear rates on the order of 0.1 to 1,000 sec. $^{-1}$, will upon removal of the shearing force exhibit a viscosity recovery time of at least 5 minutes or more. In fact, the time for complete viscosity recovery may involve days or even months. Conversely, a typical time-dependent liquid will recover its viscosity upon removal of the shearing force almost instantaneously, normally so fast that the recovery time cannot be measured with conventional laboratory instruments.

Time-dependent shear-thinning liquids for use in the invention can be formed by the suspension of suitable colloids in polar solvents such as water, alcohols, and diols. An example of such liquids is a suspension of colloidal alumina in water. For a more complete description of such liquids and their properties, reference is made to U.S. Pat. application Ser. No. 15,553, by Lloyd G. Jones, entitled SECONDARY OIL RECOVERY PROCESS, and filed on even date herewith.

As the first step in forming the barrier, the formation is fractured through perforations **30***a* to provide a horizontally extending fracture **30** which extends outwardly into reservoir between the injection and production intervals. The fracture **30** may be formed by any suitable techniques such as are commonly employed by hydraulic fracturing. Usually the fracture will be filled with suitable propping agent such as sand in order to ensure that it stays open when the fracturing pressure is released.

The fracture **30** is formed so that it is oriented in a generally horizontal plane. In many cases, particularly in relatively shallow reservoirs where the so-called "overburden pressure" is less than the vertical stress characteristics of the reservoir, the fracture will naturally assume a generally horizontal orientation. In other cases it may be desirable to take special steps to promote the formation of a horizontal fracture. For example, the well may be provided with one or more horizontal notches in the wall therefor at the desired location in order to initially provide for horizontal orientation of the subsequently induced fracture.

After formation of the fracture, the time-dependent shear-thinning liquid is injected down the well and into the fracture. Since the liquid is shear thinning, it can be easily introduced into fracture and displaced outwardly thereon to a desired distance from the well. Because of its time-dependent characteristics, the liquid will recover viscosity with time and ulti-

mately provide a barrier to the vertical flow of fluid within the formation. Thus, the injected combustion-supporting gas, and as a result the combustion front, is forced outwardly into the reservoir until it reaches the end of the barrier provided the by the time-dependent liquid. It usually will be desirable to fracture the reservoir and inject the time-dependent liquid prior to initiating the in situ combustion drive. However, these steps may be carried out after combustion is in progress at any time the need for a barrier becomes apparent. In this case, the necessary fracturing and fluid injection steps can be carried out through a second string of tubing 32, which extends from the surface into the interval between packers 24 and 25.

Turning now to FIG. 2, there is illustrated an injection-production system as provided by separate injection and production wells which may be utilized in carrying out the invention. In this case, wells 34 and 36 are shown as extending through an overburden 37 into a subterranean oil reservoir 38. The wells 34 and 36 are shown as completed openhole and thus include casings 40 and 41 which extend just into the top of reservoir 38. Well 34 is utilized as an injection well and well 36 is utilized as a production well. Wells 34 and 36 are equipped with tubing strings 42 and 44, respectively, and well 34 also is provided with a packet 46 through which tubing 42 extends.

The combustion drive in this case is carried out similarly as described above except that here the desired movement of the flame front through the formation is predominantly horizontal. Thus, in a direct drive, combustion is initiated adjacent well 34 and a combustion supporting gas is injected through tubing 42 into the lower portion of the reservoir. As noted previously, the combustion front in such horizontal drives exhibits a tendency to migrate toward the top of the reservoir. This effect is particularly pronounced in direct combustion drives due to the tendency of the oil as its viscosity is reduced to drain downwardly thus increasing the relative permeability to gas of the upper portion of the reservoir. In order to alleviate this, the injection well 34 is fractured at an intermediate portion of the reservoir in order to form a horizontally extending fracture 48. A time-dependent shear-thinning liquid is then injected into fracture 48 in accordance with the techniques as described above with reference to FIG. 1. As the combustion front moves outwardly from the injection well, upward movement is limited by the barrier formed by the time-dependent liquid.

What is claimed is:

1. In the recovery of hydrocarbons from a subterranean oil reservoir penetrated by spaced injection and production system, the method comprising:
   a. establishing a horizontally extending fracture in said reservoir between said injection and production system,
   b. introducing into said fracture a viscosity time-dependent shear-thinning liquid in order to form a barrier to retard the vertical flow of fluid within said reservoir, and
   c. introducing a combustion-supporting gas through said injection system into said reservoir to propagate a combustion front between said injection and production system.

2. The method of claim 1 further comprising the step of introducing additional viscosity time-dependent shear-thinning liquid into said fracture in order to extend said barrier after said combustion front has advanced a portion of the distance between said injection and production system.

3. The method of claim 1 wherein said injection and production systems comprise vertically spaced intervals of at least one multiply completed well and said fracture extends outwardly into said reservoir from said well at a location between said intervals.

4. The method of claim 1 wherein said injection and production systems comprise horizontally spaced wells and said fracture extends outwardly from one of said wells within an intermediate portion of said reservoir.

5. The method of claim 4 wherein said fracture extends from at least one injection well comprising said injection system and said combustion-supporting gas is injected into said reservoir through an interval in said injection well located below said fracture to propagate said combustion front toward said production system in a direct combustion drive.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,637,013 Dated January 25, 1972

Inventor(s) Lloyd G. Jones

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

Column 1, line 8, before "time-dependent" insert -- a -- ; line 10, before "recovery" insert -- the -- ; line 28, "of" should read -- or -- ; line 29, after "direct" insert -- drive -- ; line 51, "an", first occurrence should read -- and -- . Column 2, line 7, "3,128,203" should read -- 3,138,203 -- ; line 30, "fluid" should read -- liquid -- ; line 60, after "systems" delete "which", after "may" insert -- each -- ; "walls" should read -- wells -- . Column 3, line 4, before "Water", insert --"The -- ; line 9, "well" should read -- wells --; line 13, "well" should read -- wells -- line 30, before "which" delete "and"; line 34, after "opens", "the" should read -- into -- ; line 41, after "only" insert -- and -- ; line 59, "a" should read -- any -- . Column 4, line 21, "fro" should read -- for -- ; line 37, "time-dependent" should read -- time-independent -- ; line 55, "by" should read -- in -- ; line 56, before "suitable" insert -- a -- ; line 67, "therefor" should read -- thereof -- ; line 73, "thereon" should read -- therein -- . Column 5, line 4, after "provided" delete "the"; between lines 12 and 13, insert the attached page; line 17, "an" should read -- the -- ; line 23, "packet" should read -- packer -- . Column 6, line 3, after "outwardly" insert -- away -- ; line 9, "system" should read -- systems -- ; line 11, "system" should read -- systems -- line 18, "system" should read -- systems -- ; line 23, "system" should read -- systems -- .

Signed and sealed this 14th day of November 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

FORM PO-1050 (10-69)

USCOMM-DC 60376-P69
* U.S. GOVERNMENT PRINTING OFFICE : 1969 O—366-334.

The use of a time-dependent shear-thinning liquid to form a barrier in accordance with the present invention offers a number of advantages. The liquid can be injected easily and economically into the fracture without the use of such special equipment as may be required in cementing procedures. Further, since the liquid is subject to a viscosity reduction upon further shearing, the barrier can be progressively moved outward as the flame front progresses. Thus, in the early stages of the combustion process, only a limited amount of time-dependent liquid need be injected in order to fill only a portion of the fracture. This partial barrier will retard vertical flow of fluids through the reservoir immediately adjacent the well thereby forcing the combustion front outwardly in its initial stages. At the same time the distance traveled by the fluids between the injection and production intervals will not be so great as to cause a prohibitively high pressure drop. During a later stage of the process in which the combustion front is advanced further out into the formation, additional time-dependen liquid may be injected through tubing 32 and into fracture 30, thus extending the barrier even deeper into the reservoir. This increases the distance which the fluids must travel between the injection and production intervals. However, the resistance to flow within the reservoir normally will be lower because of the reduced viscosity of the oil and the increased permeability of that portion of the reservoir traversed by the combustion front. Thus, the increased flow distance will not result in an unacceptably high pressure drop between the injection and production intervals.