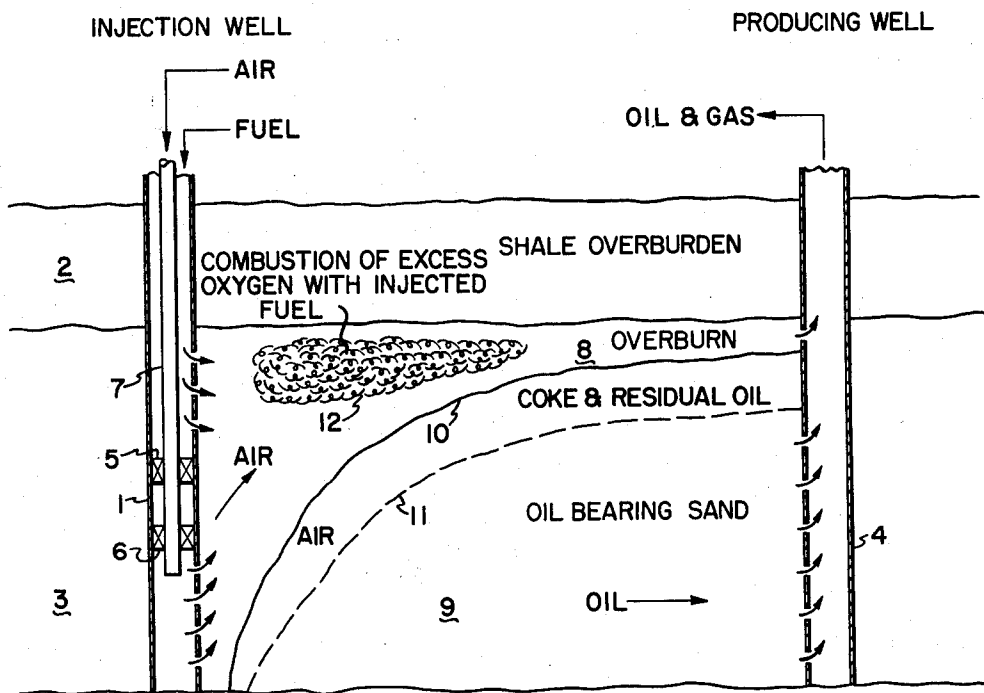


April 30, 1963

E. R. ELZINGA
IN SITU COMBUSTION PROCESS

3,087,541

Filed May 9, 1960



Eugene R. Elzinga Inventor

By *W. C. F. Heilman*

Patent Attorney

1

3,087,541

IN SITU COMBUSTION PROCESS

Eugene R. Elzinga, Scotch Plains, N.J., assignor to Jersey Production Research Company, a corporation of Delaware

Filed May 9, 1960, Ser. No. 27,666

3 Claims. (Cl. 166—11)

The present invention is concerned with thermal methods for the recovery of petroleum from subterranean reservoirs. The invention is more particularly related to a unique technique for recovering oil from partially depleted reservoirs by the in situ combustion of some of the carbonaceous materials present in such reservoirs. The invention especially relates to an improved in situ combustion process wherein the maximum utilization of oxygen is secured and breakthrough of the oxygen to the production well with resultant corrosiveness is prevented. In essence the operation comprises a two-stage technique wherein in the second stage fuel and the oxygen are so injected so as to secure combustion in the area previously burnt out in the initial stage.

In the recovery of oil from subterranean reservoirs, there have been substantial advances in primary recovery techniques so as to substantially increase the recovery of oil. However, an appreciable quantity of the oil remains in the reservoir after termination of the primary recovery methods. It is estimated that only about 30 to 50% of the oil can be economically recovered by primary recovery techniques. A greater amount may be recovered by other secondary techniques, such as re-pressuring treatments following the primary method.

Thus, there exists a great interest in secondary recovery methods. Secondary recovery is the recovery of additional quantities of oil from a reservoir after it is no longer economical to recover oil by primary recovery methods. For example, a secondary operation may be conducted by drilling one or more injection wells into a permeable oil bearing formation within suitable proximity to a producing well or wells which are drilled into this same permeable oil bearing formation. Injection of liquids or gases through the injection well is generally effective in increasing the oil production from the producing well or wells. This technique of secondary recovery enables the recovery of substantially more oil than can be produced by primary recovery methods.

As pointed out, the use of a number of secondary recovery procedures for removing oil from subterranean oil reservoirs are well known in the petroleum industry. It is the function of such procedures to make possible the recovery of oil from reservoirs after primary production methods are uneconomical. In general, all secondary recovery procedures employ a driving medium such as a liquid or gas for displacing additional oil from a reservoir.

Other desirable methods for recovering oil from partially depleted underground reservoirs comprise in situ combustion methods. These methods in essence involve the establishment of a combustion front within the reservoir in the vicinity of one or more injection wells and the subsequent introduction of a combustion-supporting gas behind the combustion front in order to move the combustion front through the reservoir toward one or more production wells. As the combustion front advances, the heat liberated results in the vaporization of oil from a high temperature zone preceding the front. Cracking and the formation of coke which serves as fuel for the process also occur. The resulting oil vapors are carried forward with the combustion products and condensed in cooler portions of the reservoir. Heat transfer to cold oil in sections of the reservoir in front of the advancing high temperature zone leads to a reduction in viscosity of the oil and facilitates its displacement from the reservoir. A

2

mixture of oil and gases is withdrawn from the reservoir at the production well and the oil contained therein is subsequently recovered.

Although these processes known in the art are promising, there exist some difficulties associated with them. One disadvantage is that the combustion front and the associated high temperature zone finger through high permeability sections of the reservoir instead of advancing uniformly. This leads to breakthrough of the combustion front into the production well as an early stage in the process when only a small area of the reservoir has been burnt through. After such a breakthrough occurs, the high temperature combustion products, the oxygen and the oil flow into the production well simultaneously, creating a danger of fire in the wellbore and in the associated equipment. Furthermore severe corrosion of the equipment in the producing well or wells occurs.

Difficulties of the type described above are encountered in both stratified and unstratified reservoirs. In stratified reservoirs, some of the strata frequently have much greater permeability than others. Breakthrough of the combustion front at the producing well through a high permeability stratus results in a direct channel through which the injected oxygen may pass from the injection well to the production well without encountering significant quantities of unburned hydrocarbons. Recovery from the adjacent strata of relatively low permeability is slow and must be carried out in the face of undesirably high temperatures and free oxygen in the production well.

In unstratified reservoirs, breakthrough generally occurs at the production well near the top of the producing formation due to overburning. Utilization of the injected oxygen thereafter depends primarily upon the diffusion of gaseous oxygen from the burned out area at the top of the reservoir down into the unburned zone. The distance through which the oxygen must diffuse increases as the thickness of the burned-out zone increases and hence the portion of the injected oxygen utilized to support combustion is apt to decline as the operation progresses. The result is a continual increase in the difficulties occasioned by the presence of free oxygen in the production well.

Summarizing increased crude production is achieved in the underground burning process due to heat released when air is injected underground to burn part of the crude in place. The efficiency of the process depends upon how much air is required to produce a barrel of oil which in turn is tied to how much injected oxygen is consumed by combustion. Unfortunately, laboratory and field experiments have shown that for a substantial part of the process, 60% or more of the injected oxygen is not consumed or is consumed in the producing well. The present invention is concerned with a method for increasing oxygen utilization in the reservoir where it will do the most good and in addition will cut down on corrosion problems in the producing well.

As mentioned heretofore one reason for low oxygen utilization is that injected air fingers through the top of the reservoir between injection and producing wells. After the residual oil in this finger is consumed the air flowing through this region no longer comes into direct contact with oil and hence only that portion of its oxygen which can diffuse down to the combustion front is utilized. Since a large portion of the injected air flows through this burned-out region, because of its lower resistance to flow, large quantities (60%) of oxygen bypasses the combustion zone. Under these circumstances, combustion can take place in only two regions—the first region is by direct contact of oxygen with oil in the reservoir and the second region is in the producing well. The combustion in the reservoir produces heat which is utilized

3

in the process. On the other hand, combustion in the producing well is bad for two reasons: first heat released at the producing well is not effective in reducing oil viscosity in the bulk of the reservoir. Secondly, as a consequence of the concentrated heat released at the producing well, temperatures increase to a point where corrosion becomes a serious problem.

In accordance with the present invention these harmful effects are eliminated by a technique wherein all the injected oxygen is consumed before the oxygen reaches the producing well. This is accomplished by the injection of either liquid or gaseous hydrocarbons from the injection well into the overburnt section in a manner to react the thick hydrocarbons with oxygen which is also injected into the overburnt section or region. It is important that the fuel is not mixed with the injected air until after the fuel has flowed away from the injection well, otherwise a situation will exist similar to that previously described with respect to in situ combustion. This nonmixing of the hydrocarbon and oxygen is accomplished by injecting the fuel near the top of the formation while the air is injected near the bottom of the oil sand. Thus, sufficient oxygen for combustion is not encountered until the fuel has traveled well out into the reservoir. Even if some combustion should occur near the injection well, serious corrosion will not occur since the corrosive products of combustion do not flow into the injection well.

A typical operation, for example, will proceed in the following manner. Air is injected into the reservoir in order to establish gas permeability of the formation between the injection well or wells and the producing well or wells. Combustion is then initiated in any satisfactory manner such as by heaters, by chemical methods, or by spontaneous ignition. The process is then continued in a conventional manner until an overburn region has been established and until oxygen is produced at the producing well. In a second phase or stage liquid or gaseous fuel is injected near the top of the formation in order to react with the oxygen flowing through the overburnt region which oxygen is introduced at a lower point, preferably near the bottom of the oil-bearing sand. The fuel injection rate as well as the oxygen injection rate is controlled in order to give little or no oxygen in the produced gases from the production well.

By the present invention, more heat is liberated in the right place/unit of injected air. Therefore, more oil will be produced with this air. Secondly, the producing well temperatures will be lower, thereby reducing and minimizing corrosion. The fuel introduced at the injection well may comprise produced hydrocarbon gases or produce crude from the production well.

The present invention may be fully understood by referring to the drawing illustrating one adaptation of the same.

Referring now to the figure, reference numeral 1 designates an injection well drilled through overburden 2 into an oil-bearing reservoir 3. Production well 4 has been drilled into the reservoir at a point removed from the injection well. In accordance with the present invention, packer elements 5 and 6 are positioned in the annular area between the drill string 7 and the bore hole wall. These packer elements may be adjusted along the pipe string either upwardly or downwardly so as to positively control the point of injection of the fuel and of the oxygen containing gas. The distance separating the injection and production wells will depend upon a number of factors, including the extent of the reservoir, the permeability and porosity of the subsurface strata, the reservoir pressure, and the recovery pattern utilized. This distance may vary widely but will generally range between about 300 feet and about 3,000 feet. The injection and production wells will normally be cased and perforated opposite the producing strata in the conventional manner but in some instances uncased wells may be used. Conventional facili-

4

ties for introducing air and other gases at the injection well and for recovering and separating oil and gaseous products from the production well are provided on the surface.

In the first phase of the present invention in situ combustion is carried out in the reservoir by establishing a combustion front in the vicinity of the injection well and thereafter injecting air in order to propel the front through the reservoir toward the production well. A number of methods for establishing such a front are well known, including the injection of high temperature combustion products into the reservoir, the use of electrical devices to ignite a mixture of fuel gas and oxygen in the injection well opposite the producing formation, and the injection of pyrophoric materials and a stream of combustion-supporting gas into the reservoir through the injection well. As shown in the drawing, overburning occurs in area 8 as the combustion front thus established progressed through the reservoir. The upper portion 8 of the reservoir was substantially burned out and thus depleted of oil. The lower section 9 of the reservoir, on the other hand, was relatively unaffected by passage of the combustion front and hence still contains appreciable quantities of oil. Reference numeral 10 designates the boundary between the burned and unburned sections. Dotted Line 11 indicates the additional depth to which it can be expected burning will occur in the reservoir by the present technique. Breakthrough of the combustion front in the initial phase occurred in the production well near the top of the producing zone. As a result of the overburning and premature breakthrough of the combustion front, continued injection of air or oxygen by conventional methods into the reservoir would result in combustion near or in the production well. A substantial portion of the injected oxygen thus would flow through the high permeability burned-out zone at the top of the reservoir and would be lost for the generation of heat within the reservoir. In situ combustion in the section of the reservoir below the burned-out zone depends largely upon the diffusion of oxygen downwardly into the cooler region at the bottom of the reservoir. Since this occurs only to a limited extent, utilization of oxygen and overall efficiency of the process would be poor.

In carrying out the process of the present invention, the conventional injection of air or oxygen at injection well 1 is discontinued upon breakthrough of the combustion front at production well 4. Imminent breakthrough of the combustion front can often be detected by observing the production well temperature. A substantial rise in temperature over a relatively short period of time generally indicates that combustion is occurring in the area immediately surrounding the production well. The appearance of oxygen in the product gases indicates that breakthrough has occurred.

At this point the first phase is finished and combustion is carried out in the following manner. A combustible gas or liquid is introduced into the top of the formation above packer 5 through the annular area between the pipe string 7 and the bore hole wall. An oxygen containing gas is introduced downwardly within the pipe string and is forced into the formation below packer element 6. In this manner combustion will occur in the burnt out area 8, particularly in sub-section 12. The amount of fuel and oxygen introduced is so controlled that substantially no combustion occurs at the production well. By this technique the burnt out area 8 is maintained continuously with a relatively high temperature, which temperature will diffuse downwardly into area 9 and will thus cause oil to flow from the oil-bearing sand into producing well 4.

The pressures at which the gases are introduced may range from values slightly in excess of the formation pressures up to values approaching pressures at which fracturing of the reservoir occurs. Pressures between about 100 p.s.i.g. and about 1,000 p.s.i.g. are generally preferred. Heat liberated due to combustion of the fuel gas is carried toward the production well by conduction

of the hot gases. The temperature of the portion of the reservoir down stream from the combustion front through which the gases flow rises. Overlying and underlying portions of the reservoir are heated by conduction. As heat diffuses into the oil-saturated rock below the burned zone, the viscosity of the oil is reduced. The oil moves toward the producing well by the imposed pressure gradient between the wells and by the hydrostatic pressure of the oil.

While the invention has been particularly described in conjunction with a secondary recovery operation, it is to be understood that the technique may be also utilized in primary operations, particularly, in producing heavy crudes. In essence, the operation is concerned with an in-situ technique wherein oxygen does not reach the production well, thereby materially reducing corrosion and greatly increasing the production of oil.

What is claimed is:

1. An in situ combustion process for the production of oil from an oil-bearing subterranean reservoir penetrated by an injection well and a production well, said reservoir being characterized by a tendency to overburn, which comprises injecting an oxygen-containing gas into said reservoir through said injection well, igniting said reservoir oil in the vicinity of said injection well thereby generating a combustion front; propagating said combustion front toward said production well by continuing said injection of oxygen-containing gas; producing oil from said production well; continuing to inject oxygen-containing gas until said combustion front reaches the vicinity of said production well; thereafter, while combustion of reservoir oil continues, introducing a fuel into

the burned region of said reservoir through which said combustion front has passed, said step of introducing fuel being commenced before the temperature of said burned region has fallen below the ignition temperature of said fuel; concurrently and separately introducing additional quantities of oxygen-containing gas into said burned region of said reservoir, whereby combustion of said introduced fuel is achieved in said burned region simultaneously with the continued combustion of reservoir hydrocarbons; continuing said concurrent and separate injection of fuel and oxygen-containing gas in said burned region, whereby continued combustion in said burned region causes a heat front to move downwardly within said reservoir, thereby forcing additional quantities of oil toward said production well; controlling the rate of injection of said fuel in order to provide a substantial absence of oxygen in the gases produced from the production well; and producing additional quantities of oil from said production well.

2. Process as defined by claim 1 wherein said introduced fuel comprises a fuel produced from said production well.

3. Process as defined by claim 1 wherein said fuel is introduced into the upper area of said reservoir and wherein said additional quantities of oxygen-containing gas are introduced into the lower area of said reservoir.

References Cited in the file of this patent

UNITED STATES PATENTS

2,793,697	Simm et al. -----	May 28, 1957
2,913,050	Crawford -----	Nov. 17, 1959