

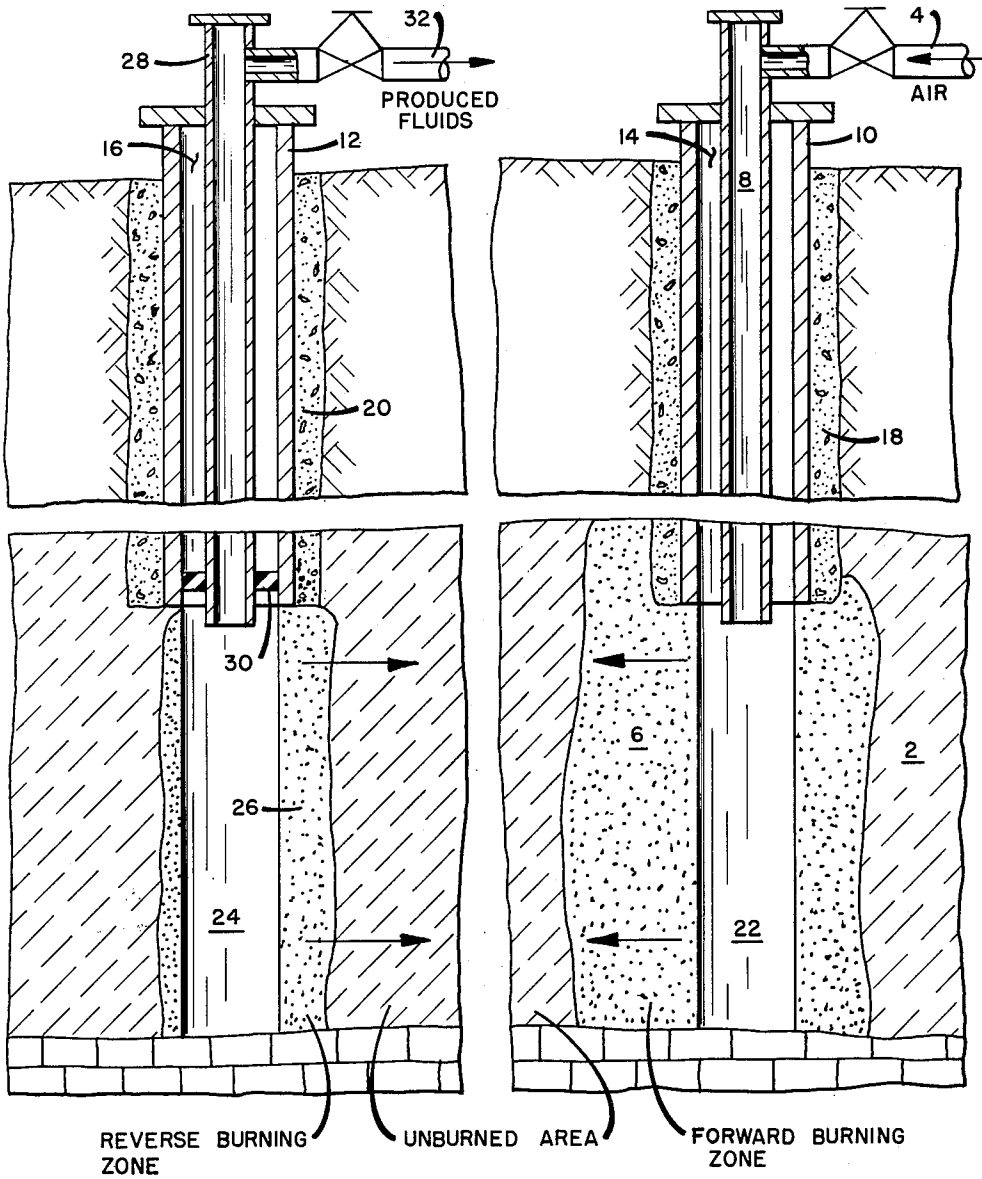
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UNDERGROUND COMBUSTION PROCESS

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UNDERGROUND COMBUSTION PROCESS

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The present invention relates to an improved method for recovering petroleum by means of in-place combustion. More particularly, it is concerned with a means for utilizing more completely the oxygen supplied to a hydrocarbon reservoir during the combustion process.

Briefly, the process of my invention is based on the observation that in many cases where forward combustion is employed in a hydrocarbon reservoir, free oxygen is present in the effluent gas. In some instances this free oxygen may amount to as much as 12 to 15 percent of said effluent gas. In applying this principle of my invention where such a condition prevails, I ignite or heat that portion of the producing well face penetrating said reservoir up to a temperature of at least about 500° F. after forward combustion is in progress and thereby initiate reverse combustion on a limited scale. In other words, my invention involves conducting reverse and forward combustion processes simultaneously in a hydrocarbon reservoir. The advantages of this procedure and the problems which it overcomes will be discussed in further detail below.

In many cases where forward combustion of petroleum deposits is performed, the effluent gas contains appreciable amounts of free oxygen. The presence of such oxygen not only gives rise to corrosion problems and a potential explosion hazard in producing wells and surface treating facilities, but it represents a waste of heat and of costly compressed air. For example, in one combustion project the produced gas on occasion has contained as much as 12 percent oxygen and throughout the life of the operation fully one third of the air injected. It is apparent that if such waste could be materially reduced or eliminated, the economics of the forward combustion operation would be markedly improved.

Accordingly, it is an object of my invention to provide a method whereby excess oxygen occurring in produced gas from forward combustion operations can be utilized to advantage both from the standpoint of improving the economics of the process and from reducing the hazards and difficulties ordinarily accompanying the production of such free oxygen. It is a further object to provide a method for increasing the rate at which wells produce in a forward combustion process. It is another object to apply the principles of my invention to already-producing wells not involved in a combustion operation but which have fallen off in production owing to plugging of the formation in the vicinity of the well bore with wax or other combustible or fusible materials.

In one embodiment of my invention, I ignite or heat the face of the producing formation traversed by one or more producing wells which are a part of a forward combustion operation. As previously indicated, this embodiment of my invention is generally applicable where substantial quantities of oxygen, e.g., at least about 5 percent, are found in the produced gas. The face of the formation in the producing wells may be ignited or heated by any of the known methods, after which the wells are returned to production. With the flow of unconsumed oxygen into the producing wells, reverse combustion occurs and the burning front resulting therefrom moves slowly out into the formation. Although the over-all concentration of unconsumed oxygen in the produced gas prior to initiation of the reverse combustion is relatively small, a high oxygen flux and, therefore, a high temperature, i.e., 1000

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to 1200° F., can be maintained in the vicinity of the producing well bore because of the small area involved.

The increased temperature at or near the producing wells has many advantages. It reduces the viscosity of the oil in the critical region near the producing wells and also greatly reduces emulsion-forming and plugging tendencies characteristic of producing wells in a forward combustion process. By reducing the oil viscosity in this manner, I am able to greatly increase the producing rate of the wells and, therefore, to materially improve the economics of the combustion process. A further incidental but important benefit derived from heating the producing well formation in accordance with the method of my invention is that less oxygen is required for the over-all process. This follows from the fact that the basic purpose of underground combustion is to heat the reservoir, causing the oil to be in a more producible condition. Whether the heat is generated by forward or reverse combustion is generally immaterial. If some heat is generated by reverse combustion in accordance with my invention, i.e., using only oxygen that would have otherwise been wasted, it is apparent that less air is required to heat the reservoir. This means a lower air-to-oil ratio, which, in turn, results in a process of improved efficiency. Moreover, fuel consumption in such a reverse combustion step is negligible. For example, in one case where 500 M.c.f. of air was injected daily in a forward combustion operation, producing 70 b.o.p.d., and the produced gas contained 12 percent oxygen, only 6 b.o.p.d. would have been consumed during reverse combustion if all of the oxygen in said gas were used. However, the heat generated in burning this quantity of oil resulted in the production of many times this volume.

While discussing the benefits afforded by heating the formation in accordance with the process of my invention, I would also like to refer to the advantages provided in situations other than those involving primarily underground combustion. Thus, in the case of ordinary producing wells that have become partially or completely plugged due to wax or other combustible or fusible materials, such wells can be stimulated and original producing rates restored by igniting the face of the producing well bore in the usual manner, then injecting air into it until the combustion front thus formed has moved out into the formation for a distance of one or two feet from the well bore, thereby burning this critical region free of objectionable materials. Thereafter, air injection is discontinued and normal production resumed at a substantially increased rate. A similar result could be accomplished by igniting the face of the producing well bore in the usual manner, thereafter injecting air into a nearby offset well to establish a combustion front at said face and continuing injection of air until said front has progressed into the formation for a distance of about two feet, after which air injection is stopped and production continued.

Further I wish to point out that, while the process of my invention may be employed to advantage in cases where the produced gas contains at least 5 percent oxygen, there are circumstances under which said injection can be used with favorable results where the oxygen concentration of the produced gas is substantially less than 5 percent. This is true in cases where certain strata in the formation involved produce higher oxygen concentrations but the composite gas stream from the production well or wells contains less than 5 percent oxygen. In such instances reverse burning can be maintained at or near the strata where a stream relatively rich in oxygen enters the well bore to secure the advantages enumerated. At the same time waste of oxygen is avoided. The occurrence of such locally rich oxygen streams in underground combustion is possible for a number of reasons, one of which is the existence of highly permeable oil-

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depleted or oil-free strata. Also, in cases where a water sand underlies a burning oil deposit in a formation which is relatively permeable, a portion of the air tends to flow down and through the water sand owing to the lower viscosity of the water and the resulting path of least resistance. Likewise, fractured reservoirs tend to permit air to avoid the combustion zone and flow into the producing well unconsumed. For example, in the case of an injection well in a forward combustion operation having a horizontal fracture extending about 100 feet into the formation, unconsumed oxygen can bypass the combustion zone (as long as the combustion front is less than about 100 feet from the well), because the air flowing through the fracture does not come into contact with sufficient fuel to burn all the oxygen present.

In addition to the foregoing situations where free oxygen can be found in the produced gas, there is a further circumstance which gives rise to the presence of free oxygen in said gas. Thus, formations containing oil which do not lay down coke readily upon heating or burning tend to permit oxygen to pass through the combustion zone. Light crudes, for example about 40° API and higher, are typical of oils leaving little or no residual coke on burning. Accordingly, in a preferred embodiment of my invention the process should be carried out under conditions such that the oil and/or the flow characteristics of the rock containing such oil do not favor the deposition of coke when forward combustion is carried out therein.

The process of my invention will be further illustrated by reference to the accompanying drawing in which forward combustion is carried out in oil-bearing formation 2 by injecting air through line 4 and into heated portion 6 of said oil-bearing formation via tubing 3. Casing 10 and 12 in wells 14 and 16, respectively, is run approximately to the top of formation 2 and cemented to the surrounding formation at 18 and 20, leaving open hole sections 22 and 24 from that level substantially to the bottom of oil-bearing formation 2. After forward combustion is under way in the portion of oil-bearing formation 2 traversed by injection well 14, a substantial part or all of the face of the formation in open hole section 24 is ignited by means of a gasoline torch, a thermite bomb, or other equivalent means. In the forward combustion process that is in progress, the gases passing the burning front and proceeding toward production well 16 contain approximately 10 percent unconsumed oxygen. This oxygen is used and is substantially entirely consumed in supporting reverse combustion toward injection well 14, the reverse combustion zone being defined by shaded area 26. Liquid hydrocarbons and gases produced, entering open section 24 of well 16, are withdrawn through tubing 28 set in production packer 30 and are removed from the well via line 32.

From the foregoing description it will be apparent to those skilled in the art that the process of my invention may be varied and modified in a number of ways without departing from the scope thereof. Accordingly, any procedure based on the idea of employing a reverse combustion process to stimulate the producing rate or to otherwise improve the over-all efficiency of a well producing by conventional methods or by means of underground combustion is considered to lie within the scope of my invention.

I claim:

1. In a process for conducting a forward combustion operation in a liquid hydrocarbon reservoir penetrated by an injection well and a production well by first igniting the face of said reservoir adjacent said injection well to establish a combustion front followed by introducing

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an oxygen-containing gas into said reservoir via said injection well to drive said front toward said production well, said reservoir containing highly permeable strata prior to initiation of said forward combustion operation and wherein the oxygen concentration in the gaseous effluent from a stratum penetrated by said production well is at least about 5 percent, a method of stimulating and sustaining flow of hydrocarbons into said production well which comprises subjecting that portion of said reservoir adjacent said production well to a heating step, thereby increasing the temperature of said portion to at least about 500° F. and establishing a reverse combustion front by contacting said heated portion with free oxygen entering said production well from said reservoir, whereby forward and reverse combustion are carried out simultaneously in said reservoir, and recovering hydrocarbon fluids from said production well.

2. In a process for conducting combustion in a hydrocarbon reservoir penetrated by an injection well and a production well by first igniting the face of said reservoir adjacent said injection well to establish a combustion front followed by introducing an oxygen-containing gas into said reservoir via said injection well to drive said front toward said production well, said reservoir containing highly permeable strata prior to initiation of said forward combustion operation, and wherein the oxygen concentration in the effluent gas from said production well contains at least about 5 percent of free oxygen, the method of stimulating and sustaining flow of hydrocarbons into said production well which comprises subjecting that portion of said reservoir adjacent said production well to a heating step, thereby increasing the temperature of said portion to at least about 500° F. and establishing a reverse combustion front by contacting said heated portion with free oxygen entering said producing well from said reservoir, whereby forward and reverse combustion are carried out simultaneously in said reservoir, and recovering hydrocarbon fluids from said producing well.

3. The method of claim 2, in which the hydrocarbons present in said reservoir consist essentially of a crude oil having an API gravity of at least about 40°.

4. In a process for conducting combustion in a hydrocarbon reservoir penetrated by an injection well and a production well by first igniting the face of said reservoir adjacent said injection well to establish a combustion front followed by introducing an oxygen-containing gas into said reservoir via said injection well to drive said front toward said production well, said reservoir containing highly permeable strata prior to initiation of said forward combustion operation, and wherein the oxygen concentration in the effluent gas from said production well contains at least about 5 percent of free oxygen, the method of stimulating and sustaining flow of hydrocarbons into said production well which comprises igniting that portion of said reservoir adjacent said production well and establishing a reverse combustion front by contacting said last-mentioned ignited portion with free oxygen entering said production well from said reservoir, whereby forward and reverse combustion are carried out simultaneously in said reservoir, and recovering hydrocarbon fluids from said producing well.

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