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METHOD OF OIL RECOVERY BY IN SITU COMBUSTION

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This invention relates to the recovery of oil and gas from underground reservoirs, and more particularly to an improved process for the recovery of such oil and gas from oil-bearing formations by in situ combustion of a portion thereof. The invention is especially concerned with an underground retorting process which involves the injection of a limited bank of water into the subterranean oil reservoir prior to the initiation of combustion. By this means there is provided a process wherein excessive formation of coke by the in situ combustion front is markedly reduced. The prevention of excessive coke lay-down, adds greatly to the utility of the method as the combustion process thus can be operated with the injection of a minimum amount of combustion-supporting gas. Costly air compression requirements during the practice of in situ combustion are thereby substantially reduced.

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 forty percent of the oil originally in place in the reservoirs. Numerous secondary recovery methods involving waterflooding, a gas or water drive, gas repressuring, and the like have been used in an effort to obtain a greater proportion 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 such methods have been of value in increasing the ultimate recovery of oil and gas from many underground reservoirs, it is well known that such methods do not result in recovery of all the oil in the reservoir. This has been especially true in the case of reservoirs containing viscous oils where recovery has been particularly low compared with that involving light oils.

Since the very early days of production of oil from subterranean formations, thermal methods for improving recoveries by lowering viscosity and through distillation and cracking have been proposed. One of the most promising of these has been the "in-situ combustion" method which is characterized by propagation of a high temperature zone coupled with an internal combustion wave front within the oil-bearing formation. The high temperature zone is expanded in a relatively horizontal direction within the formation in such a manner as to sweep out residual oil by force of a heat transmissive gas flow. Such a combustion wave front is generated within the formation and then maintained in relation to the high temperature zone or heat transfer wave so as to continuously revivify the heat content of the expanding hot zone. As injected gas flows through the formation from an injection well to the zone of combustion, it is heated by contact with rock as it approaches the burning zone. When the temperature of the gas stream flowing through the porous formation reaches ignition temperature level, combustion of fuel with oxygen in the gas stream occurs with the release of heat. As the hot gas stream passes through the combustion zone into the cooler rock formations in the direction of the production well, the gases are cooled by direct contact with the rock formation. This transfer of heat from the rearmost to the foremost portion of the combustion zone results in the forward advance of the zone of high temperatures.

Thus, the in situ combustion process depends on the fact that as the hot zone moves forward through the porous formation, residual oil is vaporized, with the heaviest fractions undergoing a form of retorting. The resulting vapors are carried by the gas stream into the cooler portions of the formation ahead of the combustion zone where they are condensed and driven forward by the action of the flowing gas. A mixture of gas, oil, and water enters the production well and reaches the surface as a gas stream containing entrained droplets of oil and water.

It has been known that a temperature in the combustion zone of the order of 800° F. is required to effect the combustion of natural gas in an underground formation. A temperature of approximately 1000° F. is adequate to obtain substantially complete combustion of natural gas. With hydrocarbon fuels of high molecular weight, however, lower temperatures have been satisfactorily employed. For example, at temperatures of 500° to 600° F. residual oil fractions will burn at a high rate. Consequently, it has become desirable to operate combustion processes without the addition of natural gas or other extraneous fuels to the injected gas stream, by using a portion of the oil contained in the reservoir to fuel the combustion process. The fact that in such a process, carbonaceous fuel is deposited in the porous formation by retorting of the residual oil in place has heretofore been recognized and in general the effect has been thought of as being advantageous, as most of the heat requirements for a combustion process can be supplied by the combustion of the solid carbonaceous matter formed ahead of the combustion zone.

It has been found that air compression requirements during the practice of in situ combustion processes are directly related to the amount of petroleum coke formed ahead of the combustion zone. Carbonaceous fuel which is deposited in the reservoir must be completely burned-out before the combustion front can effectively advance. Heretofore, field experience has indicated that the amount of coke formed in many cases, particularly with heavy oils, has been in excess of the amount required to supply fuel for the process. This not only has resulted in reduction of oil recovery by the amount of excess coke formed, but has greatly increased the cost of operating the process by reason of the large volumes of compressed air required to burn the excess coke and advance the combustion zone. The present invention obviates these and other disadvantages of the prior art and provides a novel combustion process wherein excessive coke formation is markedly reduced. Further, the process of the present invention provides increased recovery of the oil contained in the formation by effecting increased steam distillation of the residual oil. The process is of particular utility as it can be employed at greatly reduced cost and at the same time provides for increased recovery.

Briefly, the present invention provides a method of recovering oil and gas from a subterranean oil-bearing reservoir which has been penetrated by an injection well and a spaced production well which comprises injecting in the range of 0.05 to 0.55 pore volume of water through the injection well into the reservoir to form a limited water bank therein, and then establishing a combustion front within the reservoir by initiating combustion of the oil therein in a limited zone in the vicinity of the bore of the injection well. The high temperature combustion front thereafter is expanded in a relatively horizontal direction within the formation by conventional means which involve injecting a combustion-supporting gas through the injection well into the reservoir at a pressure sufficient to advance the combustion front toward the production well, thereby sweeping out residual oil by force of the heat transmissive gas flow.

Following the rapid injection of the limited bank of water, there is propagated a high temperature zone within the formation. This can be accomplished, for example, by forcing hot combustion gases into the reservoir for a period of time sufficient to heat up the surrounding sand structure and to produce gas and/or oil flow from one or more nearby production wells. When a high temperature zone in the range of 500° to 1200° F. which surrounds the injection well for a considerable distance has been established, ignition can be discontinued, and the movement of the heat zone horizontally out of the formation can be achieved by injecting cold combustion supporting gases through the injection well.

In a preferred embodiment of the present process, in the range of 0.05 to 0.20 pore volume of water is injected into a subterranean oil reservoir prior to initiation of the in situ combustion oil recovery process. The injection of the above volume of water provides a limited water bank within the oil stratum, sufficient to provide efficient steam distillation and vaporization of the oil ahead of the combustion front. By this novel method, subsequent excessive formation of coke by the combustion front is substantially reduced. The amount of water utilized in this process depends to some extent on the amount of connate water present in the formation. This "bound" water associated with the formation will generally occupy in the range of 0.05 to 0.50 of the pore volume. When the amount of connate water is low, the quantity of injected water most advantageously used will be greater than with high connate water reservoirs. Broadly, an amount of water in the range of 0.05 to 0.55 pore volume can be injected advantageously.

The process in accordance with the present invention can be employed effectively in any partially depleted oil-bearing formation. Preferably, however, it is practiced in the production of heavy viscous crudes consisting essentially of hydrocarbon oils having viscosities in excess of about 25 centipoises at reservoir temperature and pressure. Heavy oil fields typically have high initial oil saturation, low primary recovery, and are not particularly suited for common secondary recovery methods. It is a further feature of the present invention that the process can be advantageously employed with such heavy crudes as a primary recovery process.

Oil fields to which the method of this invention is applicable are preferably those in which the oil-bearing stratum to be so treated is deep enough that sufficient overburden exists to permit injection of air at satisfactory rates yet shallow enough to avoid excessively high well drilling costs. Most advantageously, this process of recovery is applied to oil-bearing strata lying in the range of 200 to 5000 feet below the surface of the earth. The oil-bearing formation preferably is one which has a net thickness in the range of 10 to 100 feet, and barriers of shale or other material of sufficient thickness above and below the interval to prevent vertical gas communication to other zones.

By appropriate conventional techniques combustion can be initiated in reservoirs of the above thickness in the vicinity of the injection well to establish a relatively uniform combustion front, as by the use of electrical heating or sparking devices, thermit or phosphorus deposited in the bore hole, burning of fuel and air at the bottom of the well, or spontaneous combustion, and the like.

The present process is generally operated at temperatures in the range of 450° to 2000° F. Excellent recovery is effected at operating temperatures in the range of 500° to 1200° F. Only weak combustion occurs below 500° F., the upper limit being established by the fusion or sintering temperature of the structure which is ordinarily somewhat above 2000° F. Incipient sintering below the fusion temperature seldom affects permeability adversely.

Initially, the limited water bank is injected into the formation at a sand face pressure, for example, in the range of 0.5 to 1.0 p.s.i./foot of depth. Suitable water injection means are well known in the art and need no further description. Thereafter, a high temperature front is propagated within the formation and combustion gases which result are forced into the porous oil-bearing stratum for a length of time sufficient to raise the temperature of the large body of sand surrounding the well to a temperature above the ignition temperature of the residual oil. Because the strata overlying and underlying oil-bearing formations are impervious while the formation is relatively permeable, there are essentially no heat losses by convection. Some losses by conduction do occur but they are not excessive because of the low thermal conductivities of shale and other materials commonly found as bounding strata. Moreover some of these heat losses can be returned to the formation and picked up again by the cold gas flow.

The gas drive pressure will vary according to the distance between production and injection wells, the thickness and permeability of the oil-bearing stratum, and the oil and water content of the formation. Similarly, the quantity of gas introduced will be affected by the desired pressure, temperature of the input air, and the conditions and heat capacity of the oil-bearing stratum. Pressures in accordance with the present process are moderate and, of course, are ultimately limited by the overburden. Preferably, injection and formation pressures are maintained as low as possible to minimize compression costs and to favor large volume of gas and water in the formation to strip the oil of all distillable components. In order to obtain available oil recovery with a single pattern, it is desirable that wells be able to produce at rates about equal to the rate of oil displacement. For this reason well stimulation may be necessary in order to maintain adequate oil rates.

As has been stated above, the method of recovering oil and gas from a subterranean reservoir in accordance with the present invention is particularly applicable to heavy oil fields. Typically such fields have high initial oil saturation, low primary recovery, and are not well suited for common secondary recovery methods. It is a feature of this invention that the process which has been discovered advantageously can be applied as a primary recovery means for reservoirs containing a heavy crude, that is, a highly viscous petroleum oil, a substantial portion of which comprises heavy oils having viscosities in excess of about 25 centipoises at reservoir temperature and pressure.

In one embodiment of the present invention, the process is employed in a secondary recovery operation where old wells, drilled, for example, in five-spot pattern, can be utilized. At the start of the operation in the range of 0.05 to 0.20 pore volume of water is rapidly injected into the oil-bearing stratum. Combustion is then started by burning fuel with air and later recycled gas to give temperatures of combustion of about 1200° F. to 2000° F. until, for example, in the order of 180,000,000 cubic feet per well of total gas have been put in. To introduce combustion gas into the formation, high pressure burners are lowered through the well casings to formation level. The burners are of conventional design and comprise an elongated combustion chamber to which fuel gas and primary air are separately introduced through concentric piping by means of a mixing plate. The gaseous mixture can be ignited by a spark plug centrally located in the mixing plate. The inner gas line and outer pipe are extended to the surface with ordinary piping and primary air and fuel gas are supplied in approximately theoretical proportion for perfect combustion. Secondary air to dilute the combustion gases and control the flame temperatures is admitted through the oil well casing around the burner tubing and the combustion chamber. Fuel is burned at a rate in sufficient quantity for heat release approximating 500,000 B.t.u. per hour until combustion within the reservoir is initiated. Thereafter, the burner can be extinguished and a cold air drive maintained without burning extraneous fuel or depositing excessive coke.

While not fully understood, it is believed that in the process which has been discovered, the limited bank of water moves ahead of the combustion zone by alternate vaporization and condensation. The limited bank of water is then believed to supplement the natural reservoir water and permit an efficient and essentially complete steam distillation of the reservoir oil ahead of the combustion front. Thus, there is a substantial reduction in the amount of residual heavy oil from the steam distillation. It is this residual oil which in conventional combustion processes is believed to be partially or wholly converted to coke by the complicated cracking and polymerization reactions which occur within the combustion zone itself. Because the major cost of the in situ combustion processes of the prior art is involved in the air compression requirements, the present process, which provides for a considerable reduction in the amount of coke, results in more favorable economics as considerably less air is required. At the same time, the process increases the oil recovery by the amount of excess coke which is prevented from forming by the instant technique. Thus, it is seen that the method disclosed herein has economic advantages over methods utilized in prior in situ combustion operations. By eliminating excess coking it is seen that a considerable savings is made in the amount of high cost compressed air required in the conventional in situ combustion process. There is less oil burned in the reservoir and therefore more oil which can be ultimately recovered.

With such a large number of variables, it is not possible to specify any single set of conditions which is optimum for carrying on an improved combustion operation in a given reservoir in accordance with the present invention. In the foregoing, however, an attempt has been made to indicate the interrelation of some of these variables so that some idea can be gained as to how variation of each may be expected to affect the progress of an underground combustion operation carried out according to the teaching given herein. Accordingly, modifications of the process will be readily apparent to those skilled in the art, and the scope of the invention should not, therefore, be considered to be limited to the specific details set forth.

What is claimed is:

1. An improved oil recovery process which consists essentially of injecting from about 0.05 to about 0.55 pore volume of water into an underground oil-bearing reservoir to form a water bank about an injection well penetrating said reservoir, establishing a combustion front in said reservoir behind said water bank by initiating combustion of crude oil in the immediate vicinity of said injection well, injecting a combustion-supporting gas into said reservoir through said injection well to advance said combustion front and water bank toward a production well penetrating said reservoir and secure steam distillation of crude oil in advance of said water bank, and recovering oil, gas and water from said reservoir through said production well.

2. A process as defined by claim 1 wherein from about 0.05 to about 0.20 pore volume of water is injected into said reservoir to form said water bank.

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