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3,285,336 METHOD OF THERMAL STIMULATION OF OIL FIELDS

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This invention relates to a method for recovering petroleum from underground reservoirs by the thermal stimulation of the reservoir, and more particularly it relates to a thermal stimulation process characterized by the broad distribution of heat in the interior regions of a reservoir.

Many oil containing reservoirs have been discovered in which the oil is too viscous to be recovered by primary recovery techniques. The future discovery of many additional reservoirs possessing this characteristic is a certainty. When oil recovery from reservoirs of this type is desired, well stimulation by some appropriate technique is necessary in order to produce the viscous oil in economic amounts. The application of heat by one of various methods is the most commonly used stimulation technique for viscosity reduction of the reservoir oil. The injection of hot fluids such as steam, hot water and hot gases directly into the formation has been used. However, the heat cannot be transported more than a relatively short distance from the well bore when this heated fluid is injected into the formation. Although ordinary forward drive in situ combustion performs satisfactorily in some reservoirs, it usually cannot be employed to recover viscous, immobile oils.

In an effort to get heat into the interior of oil-bearing formations containing viscous oil it has been proposed that one or more fractures extending deeply into the formation be formed and propped. These fractures are then used as conduits for conducting heated fluids laterally into the formation or they are used as the zone for in situ combustion. This approach offers the disadvantage that fracturing is an expensive procedure and cannot be used in many formations which possess lithologic characteristics which resist fracturing.

According to my invention the oil bearing reservoir is heated by in situ combustion over a broad zone deeply into a formation without requiring fracturing. While hot fluid injection may not penetrate in some instances further than 10 feet from a well bore, in accordance with my invention the formation may be heated in a zone ranging as much as 10 to 200 feet from the well bore. My process possesses an added advantage that in situ combustion of the cheap reservoir oil is utilized as a source of heat as compared with the relatively expensive above ground heating of an auxiliary injection fluid such as steam. Although the heated zone resulting from my method is broad and extensive; it does not include the input well thereby protecting the well casing and equipment against heat damage.

In accordance with my invention a well, which is non-productive by ordinary primary recovery methods but which contains an appreciable amount of viscous oil, is made to produce the oil. Once it is ascertained that the reservoir contains recoverable amounts of a viscous oil my process is put to practice. A relatively small quantity of a liquid of low viscosity which is miscible with the reservoir oil, such as liquefied petroleum gas, is injected as a slug into the formation adjacent to the well bore driving the reservoir oil ahead of it away from the well bore. This is followed by the injection of an oxidizing gas such as air at a high pressure which is insufficient to fracture the formation. The miscible slug functions as

a barrier separating the oxidizing gas from the oil. Since the low viscosity liquid and the high viscosity oil exhibit a high mobility ratio, the driving gas will finger deeply into the formation in a great multiple of fingers driving the low viscosity liquid ahead of it and displacing the oil in these fingers. As the fingers move deeply into the formation the low viscosity liquid occupies a layer of decreasing thickness until it is effectively dissipated by thinning out and intermixing with the oil permitting the oxidizing gas to contact the reservoir oil over a broad front along the peripheries of the fingers. Continuing the injection of oxidizing gas now in direct contact with the reservoir oil over this broad front initiates and maintains combustion of the oil resulting in a progressive heating of the interior of the reservoir. Since the miscible fluid drives the reservoir oil away from the input well, there is insufficient oil immediately adjacent the input well to support in situ combustion in this region.

After heating of the reservoir in this manner has progressed for a sufficient time measured in days or weeks to heat a recoverable quantity of oil, the injection of oxidizing gas is stopped and oil is produced from the injection well. A further advantage of my process is that the oil possesses a lowered viscosity as a result not only of the heating but in addition as a result of its admixture with the low viscosity fluid. This fluidized oil flows to the well as the result of any natural drive existing in the reservoir and by the combined effect of gravity flow and the driving force of the combustion gases which are confined in the reservoir under pressure as well as from the pressure exerted by any vaporized hydrocarbons. The well is produced until the flow of oil has reduced to an economic minimum. When this results, injection of oxidizing gas is repeated. If the fingers have become plugged with high viscosity reservoir oil, the injection of a slug of miscible fluid is repeated to re-establish the fingers. However, if the integrity of the fingers has been maintained further use of a miscible fluid is not required.

The use of miscible drive has previously been considered for the recovery of reservoir oil by secondary recovery techniques. It has been recognized that a miscible fluid has the tendency to finger into the formation particularly in situations in which high mobility ratios are involved. Much work has been directed towards the attainment of miscible drive in a radial front. By my invention the tendency of the miscible fluid to finger through the formation is used to advantage and, in fact, this tendency, hitherto considered to be undesirable, is enhanced by utilizing miscible liquids which provide large mobility ratios.

A specific use of my process is now described. An exploratory well has located a ten foot thick oil-bearing formation at a depth of 2,000 feet. No natural drive is present. A core sample of the formation is obtained and the oil and formation characteristics are analyzed above ground in a laboratory. The oil is ascertained to be non-flowable having a viscosity of about 1,000 centipoises at the reservoir temperature of 200° F. It is further determined that this oil is amenable to self-ignition in the presence of oxygen in accordance with in situ combustion techniques. The formation is also found to be well consolidated and to have suitable permeability characteristics. It is concluded that the oil can be recovered by my process.

Open hole completion is used since the formation was discovered to be sufficiently consolidated. Two thousand barrels of liquefied petroleum gas are injected into the formation over a period of three days. This is followed by the injection of air at a pressure of 1,500 p.s.i. This air injection is continued for about a week until about ten million s.c.f. of air has been injected. At this point

extensive fingering has occurred in the reservoir to a radius approximately 100 feet from the well bore and combustion has taken place over a broad front. Air injection is stopped and the well is allowed to produce at a rate in excess of 100 barrels per day. This oil is pumped to the surface for recovery of the liquefied petroleum gas and subsequent refining. When oil production reduces to less than 10 barrels per day, air injection is renewed and the cycle is repeated until the well become economically unproductive.

The air is injected in this process at a flux as high as possible without fracturing the formation. A fracture would provide a path of very high permeability and would prevent the uniform fingering of the surrounding formation. Air injection is stopped after a predetermined amount has been injected or after the reservoir pressure exceeds a predetermined amount to avoid excessive compressor costs. The amount of air that is injected is not critical but rather determines the extent of the formation that is heated and the amount of oil that can be recovered in the production phase. However, air injection should be discontinued and the well put into production before the heat loss to adjacent non-productive formations becomes excessive and preferably well before this heat loss approaches the amount of heat being generated.

It has been determined that at least one hundred fifty barrels of miscible liquid should be injected for each foot of formation thickness in order to develop a good fingering pattern. It has also been determined for optimum results that the injected miscible fluid should amount to about three to six percent of the oil in place in the volume to be fingered and heated for oil recovery. If the oil is produced in about twice the volume of the injected miscible liquid, the flow channels will remain open and a second slug of miscible liquid will not be required when the cycle is repeated. However, it is generally preferred to produce the oil as long as it is flowing in suitable volume.

By this process it is possible to heat and recover viscous oil up to 200 feet or more from a well bore. Recovery of the heated, mobilized oil may be from the injection well by a cyclic process as described or it may be produced into one or more neighboring wells if they are sufficiently close to the injection well. In this latter instance air injection is continued until combustion breakthrough into the production well is imminent. In either instance in situ combustion and resultant heating occurs over a broad volume in the plurality of fingers formed by this method.

It is evident that utilization of this process requires an oil which is self-ignitable in the formation in the presence of an oxidizing gas which is injected under pressure. Furthermore, the formation should possess sufficient permeability that the oxidizing gas and miscible fluid can be driven into the formation. The process can be utilized in both open wells or cased perforated wells with single point or multiple point perforations.

Either liquefied petroleum gas or a similar light petroleum fraction is preferred as the miscible liquid. However, other low viscosity organic liquids including halogenated and oxygenated hydrocarbons, such as carbon tetrachloride and lower alcohols, can be used either alone or admixed with light petroleum fractions. It is important that the miscible liquid is not self-ignitable in the presence of oxygen and that it have a sufficiently low viscosity that extensive fingering will occur. It is preferred that the mobility ratio of the miscible fluid and reservoir oil be at least 100 to 1 in order to accomplish superior fingering. As previously indicated the miscible liquid may be recovered from the product oil for reuse.

Air is the preferred oxidizing gas for economic reasons. However, any oxidizing gas may be used in accordance

with accepted knowledge in situ combustion technology. For example, oxygen enriched air oxygen itself may be utilized. Furthermore, other oxidizing gases may be added to the air to enrich it. The particular oxidizing gas used is not critical but rather determines the total volume of gas as a function of its usable oxygen content which must be injected to accomplish a specific amount of reservoir heating.

By this invention a process is provided for the recovery of viscous non-flowable oils in an extensive volume of the reservoir without the relatively expensive procedure of formation fracturing and without being restricted to shallow formation heating which is the result of hot fluid injection methods. It is particularly suited for viscous oils having a viscosity greater than 500 centipoises at reservoir conditions in reservoirs which possess some permeability with insufficient natural drive. It combines the concurrent heating of a broad volume of the reservoir with the production of flow channels for the oil which becomes mobilized from the heat and by dilution with the low viscosity liquid. Although it is particularly applicable with respect to recovery-resistant oils, it also has general utility in a great variety of reservoirs as convenience or economics may determine.

I claim:

1. An in situ combustion process for recovering oil from an underground oil-bearing formation penetrated by at least one well bore characterized by the broad distribution of heat in the interior regions of the reservoir which comprises the steps, injecting a slug of a low viscosity, oil-miscible liquid into the formation from an input well, said oil-miscible liquid being not self-ignitable in the presence of oxygen, injecting an oxidizing gas into the well at a sufficiently high pressure that it will drive the miscible liquid and the oil ahead of it to form a great multiple of fingers projecting deeply into the formation with the miscible liquid forming a separating layer between the oxidizing gas and the oil, injecting additional oxidizing gas under high pressure to cause the miscible liquid layer to move further from the well, whereby said layer is thinned out and dissipated and whereby the oil in the formation contacts said gas to cause the oil to be ignited along the peripheries of the fingers, maintaining the injection of oxidizing gas at a high rate to cause the concurrent combustion of the ignited oil over a wide radial front to heat a substantial volume of the reservoir, and producing the mobilized oil from said formation at least partially through said fingers.

2. A process in accordance with the claim 1 in which the mobility ratio of the miscible liquid and oil is at least 100 to 1 and the oxidizing gas is air.

3. A process in accordance with claim 2 in which the miscible liquid is a hydrocarbon having from three to eight carbon atoms.

4. A process in accordance with claim 2 in which said miscible liquid is liquefied petroleum gas.

5. A process in accordance with claim 1 in which the oil is produced from the injection well.

6. A process in accordance with claim 1 in which the oil is produced from at least one well other than the injection well.

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