When utilizing air as the oxidizing gas, the injection rate or air flux should be maintained in the range of 5 to 15 standard cubic feet per hour per square foot of cross section at the oxidation front. Faster injection rates can be utilized with air diluted with an inert gas such as CO₂ or nitrogen to reduce the O₂ concentration substantially below 20 volume percent. Thus, control of the oxidation rate at a suitable level can be effected by the utilization of diluted air with an oxygen concentration in the range of about 5 to 16 or 18 volume percent. It is also feasible to dilute the autoignitable fuel with a crude oil preferably taken from the stratum to be produced, or other heavy oil such as diesel oil, gas oil, and other heavy fuel oils. When utilizing diluted fuel, the concentration of the autoignitable fuel is maintained in the range of about 10 to 60 volume percent of the fuel mixture injected into the stratum. Diluting the autoignitable fuel permits oxidation thereof in contact with air or other oxidizing gas at a sufficient rate to build the heat up to the required level for oil production in combination with the fluid drive but does not raise the temperature of the in-place crude oil to ignition point.

Autoignitable fuels which can be utilized in the process include boiled linseed oil, dehydrated castor oil, tung oil, linseed oil fatty acids, tall oil fatty acids, red oil (olie acid), and crude tall oil. The amount of autoignitable fuel injected into the stratum is in the range of 0.1 to 0.5 pore volume of the sweep pattern of the stratum. When the fuel is admixed with a higher ignition point fuel, the amount is based upon the mixture. The injection of the fuel or fuel mixture is followed by the injection of a non-oxidizing gas for a sufficient length of time to properly disperse the fuel within the sweep pattern. One method of determining the extent of the dispersion is to inject the non-oxidizing gas until breakthrough of the fuel at the offset well(s), assuming a central injection well and a ring of offset wells. It is to be understood that the process is applicable to other well patterns, such as parallel lines of wells.

Non-oxidizing gases which may be used include nitrogen, combustion gas, normally gaseous hydrocarbons, etc. Normally gaseous hydrocarbons are preferred, methane, propane, and natural gas being illustrative of these gases. In some instances, it is desirable to incorporate in the injected fuel a suitable oxidation catalyst such as cobalt naphthenate. Other catalysts include oil soluble salts and other components or materials listed as oxidation catalysts in Berkman et al., "Catalysis," Reinhold Publishing Corp., 330 W. 42nd St., New York, N.Y., 1940, pages 797-809.

The oxidation may be effected in the stratum in the presence of minor amounts of connate water which is converted to steam by the oxidation process and that steam has some dispersing properties with reference to the crude oil. In some instances it is preferred to air-dry the stratum by injecting air therethrough between wells to dry out the sweep pattern prior to the injection of the fuel. When this is practiced, a substantial slug of inert gas is injected after the air-drying step and prior to the fuel injection so that autoignition of the fuel does not take place when contacting the previously-injected air.

After the fuel is injected into the stratum through one or more injection wells and dispersed therein with a non-oxidizing gas, injection of the oxidizing gas, preferably air, is commenced either through the original injection well or through one or more of the offset wells. In either event, the injected air contacts the autoignitable fuel within the stratum and slow oxidation is initiated. The slow oxidation reaction builds up a heat front similar to that created in an in situ combustion operation but the temperature of the heat front is materially lower than the
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700 to 1500° F. temperature of the in situ combustion front. This heat front is moved through the formation with continued injection of oxidizing gas (air) and crude oil heated in the heat front and downstream thereof becomes more fluid (less viscous) and is driven through the stratum toward one or more production wells by the oxidation products, vaporized hydrocarbon material from the crude and vaporized connate water. The produced oil, in both liquid and vapor form, is recovered from the offset production wells in admixture with oxidation gases and water vapor.

It is feasible to operate the process with the “huff and puff” technique. This technique comprises positioning the autoignitable fuel in the stratum containing the crude oil to be produced and dispersing the fuel in the usual manner in a large annulus surrounding the injection well. Ring wells or offset wells in any pattern are closed to production while the oxidizing gas is injected through the injection well so as to effect slow oxidation of the fuel and movement of a heat front into the stratum a substantial distance, such as several feet. After a soaking period, the injection well is open to production and the heated crude oil is forced into the injection well by the pressure built up in the stratum during the injection and soaking periods. The produced oil is then recovered from the injection well and the injection of air or other oxidizing gas is resumed with another period of soaking and production into the injection well.

In strata of low permeability, the fracturing of the strata to be produced is beneficial to the production of oil by the technique of this invention. It is also feasible to produce an annular section of stratum around a single well by the invention. This method comprises packing off the annulus of the well within the stratum and injecting the required fluids either through the annulus or through the tubing stream, with production being effected through the other of the two conduits.

Certain modifications of the invention will become apparent to those skilled in the art and the illustrative details disclosed are not to be construed as imposing unnecessary limitations on the invention.

I claim:

1. A process for producing oil from a crude oil stratum penetrated by an injection well and at least one offset well, which comprises the steps of:

   (1) injecting an autoignitable fuel into said stratum through said injection well in an amount in the range of 0.1 to 0.5 pore volume toward said offset well;

   (2) driving said fuel into said stratum and dispersing same therein by injecting a non-oxidizing gas through said injection well behind said fuel;

   (3) thereafter, injecting an oxygen-containing oxidizing gas into said stratum through one of said wells and into contact with said fuel to spontaneously oxidize said fuel and move a heat front through said stratum toward the other of said wells;

   (4) controlling the rate of oxidation in step (3) so as to maintain the temperature in the oxidation zone below the in-place ignition temperature of the crude oil and avoid burning any substantial proportion of the crude oil; and

   (5) recovering produced fluids including crude oil and oxidation gases from said other well.

2. The process of claim 1 wherein said fuel in step (2) is dispersed substantially through the production pattern to the offset well.

3. The process of claim 1 wherein air is injected as the gas of step (3).

4. The process of claim 1 wherein said fuel is injected into a barren section of stratum contiguous with a crude oil section and heat generated by the oxidation of step (3) heats and fluidizes the crude oil in said contiguous section.

5. The process of claim 1 wherein the injection in step (2) is continued until breakthrough of said fuel in said offset well.

6. The process of claim 1 wherein air is injected as said gas in step (3) and the rate is maintained in the range of about 5 to 15 standard cubic feet per hour per square foot of cross section of stratum in the oxidation front.

7. The process of claim 1 wherein said autoignitable fuel is admixed with a heavy non-autoignitable petroleum oil prior to introduction to said stratum.

8. The process of claim 7 wherein said fuel is tung oil and same is admixed with said petroleum oil in a concentration in the range of 10 to 60 volume percent.

9. The process of claim 1 wherein an oxidation catalyst in minor but effective concentration is incorporated in said fuel.

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