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Hoyt et al.

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[54] **TERTIARY RECOVERY OPERATION**

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[52] **U.S. Cl.** **166/245,** 166/263

[51] **Int. Cl.** **E21b 43/16**

[58] **Field of Search** 166/245, 256, 273–275

[56] **References Cited**

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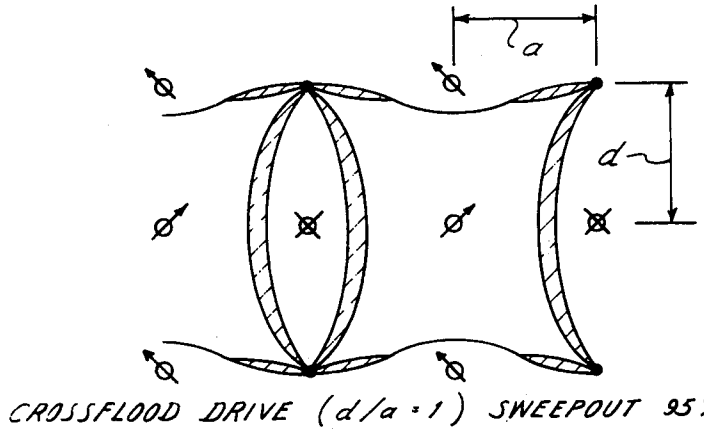
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[57] **ABSTRACT**

At the conclusion of a secondary recovery operation after breakthrough of the driving fluid at the production wells in a direct line drive, injection wells in alternate series are shut in and the production wells in the adjacent series are converted to injection wells, for tertiary recovery via the remainder of the production wells by the imposition of a new set of flow gradients.

3 Claims, 4 Drawing Figures



CROSSFLOOD DRIVE (d/a = 1) SWEEPOUT 95%

Fig. 1

- PRODUCTION WELL
- SHUT IN WELL
- SECONDARY INJECTION WELL
- TERTIARY INJECTION WELL

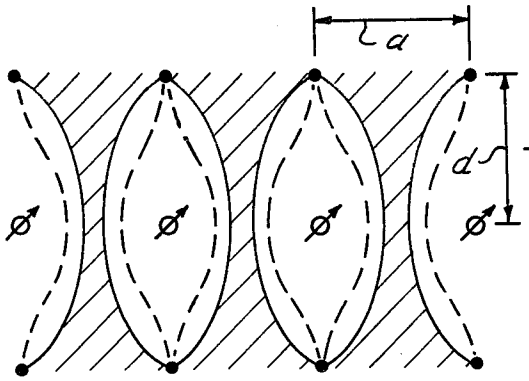
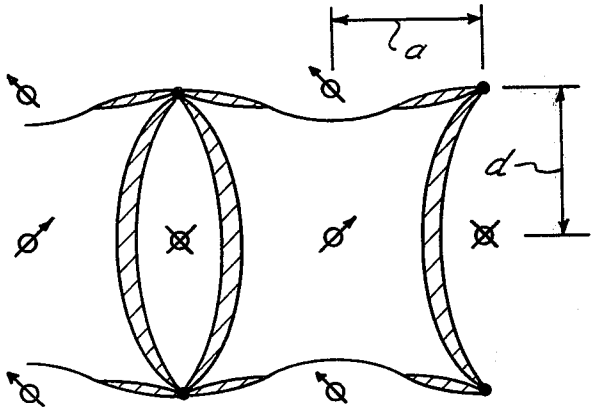


Fig. 2

BREAKTHROUGH INTERFACE SWEEPOUT ~57%
d/a = 1

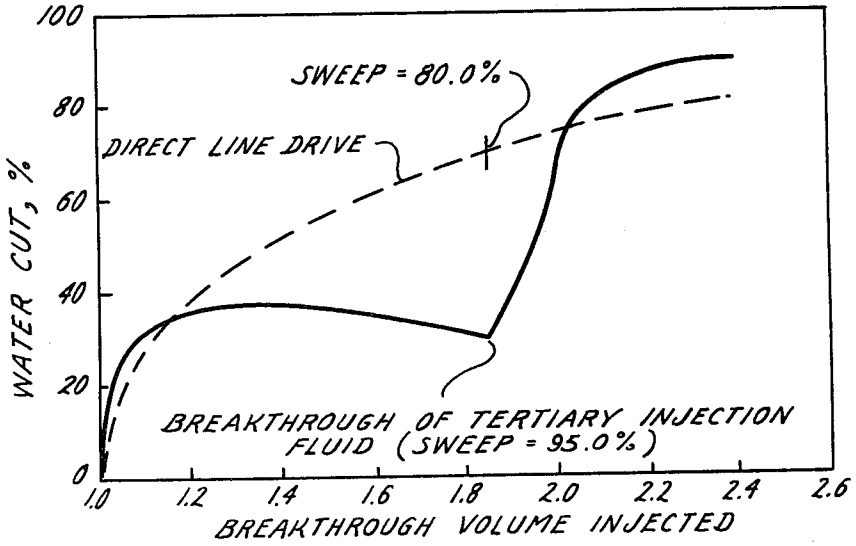
90% WATER PRODUCTION RATE · SWEEPOUT ~ 70%

Fig. 3



CROSSFLOOD DRIVE (d/a = 1) SWEEPOUT 95%

Fig. 4



TERTIARY RECOVERY OPERATION

FIELD OF THE INVENTION

This invention relates generally to the production of hydrocarbons from subterranean hydrocarbon-bearing formations, and more particularly, to a method for increasing the efficiency of the production of hydrocarbons therefrom.

DESCRIPTION OF THE INVENTION

In the production of hydrocarbons from permeable subterranean hydrocarbon-bearing formations, it is customary to drill one or more boreholes or wells into the hydrocarbon-bearing formation and produce formation fluids including hydrocarbons, such as oil, through designated production wells, either by the natural formation pressure or by pumping the wells. Sooner or later, the flow of hydrocarbon-bearing fluids diminishes and/or ceases, even though substantial quantities of hydrocarbons are still present in the subterranean formations.

Thus, secondary recovery programs are now an essential part of the overall planning for exploitation of oil and gas-condensate reservoirs in subterranean hydrocarbon-bearing formations. In general, this involves injecting an extraneous fluid, such as water or gas or other displacing compounds, into the reservoir zone to drive formation fluids including hydrocarbons toward production wells by the process commonly referred to as "flooding." Usually, this flooding is accomplished by injecting through wells drilled in a pattern, e.g., the direct and alternating line drive and the more commonly used 5-spot pattern.

When the driving fluid, e.g. water, from the injection well reaches the production wells of a direct line drive, the areal sweep efficiency is 57 percent. By continuing production considerably past breakthrough, it is possible to produce more of the remaining unswept portion of the formation although continued injection will not reduce oil saturation much further.

In secondary recovery programs, sweepout is generally given as the percent of available volume invaded by the driving fluid at breakthrough into the production wells. This is done because production past breakthrough, while nearly always attempted, is an uncertain thing. For example, assuming water to be the driving fluid, the water-oil ratio may rise gradually over a period of many years or a well or pattern may go to 100 percent water within months. Much depends on how easily and quickly the water phase envelops the well to such an extent that the relative permeability to oil is reduced to zero.

In many cases, particularly in close spacing, the envelopment is a natural result of the fact that the strongest gradients and highest fluid velocities are on the line between the injection and production wells. In addition, if there is another production well in that same line beyond the first one, then the process of envelopment is accelerated considerably. In such a situation, the water-oil ratio may be expected to increase very sharply, and it is observed usually to do so.

A procedure to inhibit the growth of the cusp at a production well, so that the percentage of oil produced per bbl. of produced formation fluids will be greater for a longer time, to provide for more recovery, more quickly, than in present procedures, involves the imposition of a new set of forces (flow gradients) shortly after breakthrough, directed in such a way that the new pattern of flow gradients will inhibit the normal tendency of a cusp to swell and envelop a production well.

From a potentiometric model study, by continued production past breakthrough of a secondary recovery program in a direct line drive, using the same injection and production wells, the sweepout can eventually approach 90 percent, if the well continues to produce. However, in an actual hydrocarbon reservoir, the cusp of the driving fluid swells so rapidly in this case that the water-oil ratio goes very quickly to over 90 percent. By this time, the water saturation around the well will be so high that continued flow of the oil phase is very unlikely and the pattern may have to be abandoned at about 70 percent total sweepout.

With the injection wells of alternate series of the line drive pattern of wells being closed in and the alternate production wells of the adjacent series of wells being converted to injection wells, the interface positions at breakthrough of driving fluid from the converted wells shows that the cusp of previously injected fluid is still small, and the water-oil production ratio by calculations based on shape is about 30 percent, and the pattern sweepout is now 95 percent. This principle of imposing new flow gradients by changing the functions of certain wells can be applied in virtually any reservoir whether drilled on a pattern or not.

SUMMARY OF THE INVENTION

It is an overall object of the present invention to provide an improved recovery procedure involving initially three wells in line as one of a series in a direct line drive as part of a well pattern arrangement for exploiting a hydrocarbon-bearing formation, by shutting in alternate intermediate injection wells and the production wells in the adjacent series of the pattern are converted to injection wells, while maintaining production from the wells of the series containing the shut in intermediate injection wells.

A three well group of a series in a direct line drive is arranged in line so that the intermediate well is completed for injection and the remaining two wells are completed for production. Flooding is initiated at the intermediate well by injection of a driving fluid, such as water, thereinto and proceeds until breakthrough of the flood front occurs at the production wells, at which time, injection via the alternate intermediate wells is terminated and the wells shut in. Then, the original production wells in the adjacent series are converted to tertiary injection wells while the remainder of the production wells, viz. those in the series with the shut in intermediate injection wells, are maintained on the original function.

Other objects, advantages and features of this invention will become apparent from a consideration of the specification with reference to the figures of the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 discloses the symbols used in the remaining figures of the drawing;

FIG. 2 illustrates two phases of a secondary recovery program of a direct line drive;

FIG. 3 discloses the termination of the tertiary phase of a direct line drive recovery procedure; and

FIG. 4 discloses the differences in water cuts during production past breakthrough of a direct line drive and a cross flood line drive.

The objects of the invention are achieved by shutting in, at time of the breakthrough of the driving fluid at the production wells, alternate injection wells, and converting alternate production wells to injection wells to produce a new set of flow gradient forces to inhibit cusp expansion at the remainder of the production wells.

The specification and the figures of the drawings schematically disclose and illustrate the practice and the advantages of the invention, examples of which have been observed in potentiometric model studies which simulate secondary and tertiary recovery operations. The model studies indicate a sweepout obtained in an ideal reservoir, although the recovery from an actual sweepout of a particular field may be greater or less, depending on field parameters.

Throughout the figures of the drawings, the same symbols will be maintained as disclosed in FIG. **1**, viz. a solid circle indicates a production well, a crossed open circle a shut in well, an open circle with a first quadrant arrow indicates an original injection well, and an open circle with a fourth quadrant arrow, a converted injection well.

Referring to FIG. **2**, there is disclosed symbolically a direct line drive in a secondary recovery procedure, wherein the original injection wells are aligned with the production wells with a d/a of **1**. The frontal position upon breakthrough of the driving fluid at the production wells, with a sweep efficiency of 57 percent, is indicated by the dash lines. The solid lines indicate a sweepout of about 70 percent when production is continued after breakthrough, when the water production rate reaches 90 percent.

Referring to FIG. **3**, following breakthrough as indicated by the dash lines in FIG. **2**, the original injection wells in alternate series of the direct line drive program are shut in, the production wells in the other series of the program are converted to injection wells and the original production wells of the series with shut in injection wells remain on production, as driving fluid is injected into the formation via the converted wells and the original injection wells not shut in, until the calculated sweepout of the pattern has reached about 95 percent, as disclosed in FIG. **4**. This figures discloses that with the cross flood, the water cut falls off with an increase in sweep efficiency to 95 percent.

Thus, there has been shown and described the manner by which a tertiary recovery operation may be initiated with favorable economic results following the conclusion of a secondary recovery operation following breakthrough of driving fluid at the production wells, by introducing a new set of flow gradients to affect cusp formation.

As will be apparent to those skilled in the art in the light of the accompanying disclosure, other changes and alterations are possible in the practice of this invention without departing from the spirit or scope thereof.

We claim:

1. At the conclusion of a secondary recovery operation in a method of producing formation fluids including hydrocarbons from a subterranean hydrocarbon-bearing formation by a direct line drive which comprises penetrating said formation with a plurality of wells disposed in a linear pattern and comprising a series of a pair of production wells and an intermediate injection well, injecting an extraneous fluid into each formation via said intermediate injection well of said series to displace formation fluids including hydrocarbons in said formation toward said production wells, producing said formation fluids including hydrocarbons from said formation via said production wells till breakthrough of said extraneous fluid thereat, thereupon initiating a tertiary recovery operation by imposing a new set of flow gradients comprising the steps of shutting in the intermediate injection wells in alternate series and converting production wells in the series adjacent thereto into injection wells, and thereupon injecting said extraneous fluid via the remainder of the intermediate injection wells of said series and the converted production wells of said series, and producing formation fluids via the remainder of said production wells.

2. In the method as defined in claim **1**, said intermediate injection well and said pair of production wells being disposed in a common row of a series thereof.

3. In the method as defined in claim **2**, said intermediate injection well and said production wells being disposed respectively in common rows.

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