TERTIARY RECOVERY OPERATION

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ABSTRACT

Upon termination of predetermined periods during a secondary recovery operation in a direct line drive, the intermediate injection wells in each series are shut in and the production wells in alternate 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, one predetermined period occurring at breakthrough of the driving fluid at the production wells and another upon injection of a predetermined breakthrough volume, production being continued past breakthrough.

7 Claims, 8 Drawing Figures
Figure 14.1
- PRODUCTION WELL
- SHUT IN WELL
- SECONDARY INJECTION WELL
- TERTIARY INJECTION WELL

Figure 14.2
- ESTABLISHED CHANNELS
- NEW CHANNELS

Figure 14.3a
SWEEP 57% (d/a = 1)

Figure 14.3b
SWEEP 62.3%

Figure 14.3c
CONVERTED LINE DRIVE (ENHANCED RECOVERY)
SWEEP = 93.7%
DIRECT LINE DRIVE
SWEEP = 74.4%
DIRECT LINE DRIVE
SWEEP = 85.0%
BREAKTHROUGH OF TERTIARY INJECTION FLUID
SWEEP = 82.3%
Production past breakthrough, 1.5 BTV injected
Water cut = 56%  Sweep 72.6% (a/h = 1)

Converted line drive
Sweep = 91.8%

Direct line drive
Sweep = 81.8%

Converted line drive
Breakthrough of tertiary injection fluid
Sweep = 96.9%
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 unsweped 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 cusps at a production well, so that the percentage of fluid hydrocarbons 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 gradi-

ents) 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 95 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 fluid hydrocarbon phase is very unlikely and the pattern may have to be abandoned at about 70 percent total sweepout.

With the intermediate injection wells of the series of the line drive pattern of wells being shut in and the alternate production wells of the series of wells being converted to injection wells, the pattern sweepout may exceed 90 percent. This principle of imposing new flow gradients by changing the functions of certain wells may be applied to 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 the intermediate injection wells and converting alternate production wells in the series of the pattern into injection wells, while maintaining production from the remaining wells of the series. The conversion of the production wells may occur upon breakthrough of the driving fluid thereat or at some predetermined period thereafter.

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 wells by injection of substantially equal quantities of a driving fluid, such as water, thereinto and proceeds until breakthrough of the flood front occurs at the production wells, as an example of the first predetermined time, whereupon injection via the intermediate wells is terminated and the wells shut in, and alternate production wells in the series are converted to tertiary injection wells while the remainder of the production wells are maintained on their original function. As another example of the predetermined period, production after breakthrough may be continued until 1.5 breakthrough volumes have been injected. A breakthrough volume is defined, for each pattern unit, as the volume of driving fluid injected at the time breakthrough occurs at the production wells.

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 the principle of the invention;
FIG. 3a illustrates the breakthrough phase of a secondary recovery program of a direct line drive;

FIG. 3b discloses the termination of the tertiary phase of an enhanced direct line drive recovery procedure according to this invention;

FIG. 3c discloses the differences in water cuts during production past breakthrough of a direct line drive and a cross flow line drive as disclosed herein;

FIG. 4a illustrates the secondary recovery sweep pattern of a direct line drive with production continued past breakthrough;

FIG. 4b discloses the termination of the tertiary phase of an enhanced direct line drive recovery procedure following production past breakthrough according to FIG. 4c; and

FIG. 4c discloses the differences in water cuts during production past breakthrough of a direct line drive and a cross flow line drive as disclosed herein.

The objects of the invention are achieved by shutting in all of the intermediate injection wells at time of the breakthrough of the driving fluid at all of the production 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. Alternatively, the injection wells are shut in when 1.5 breakthrough volumes have been injected, production being continued after breakthrough.

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 secondary injection well, and an open circle with a fourth quadrant arrow, a converted tertiary injection well.

FIG. 2 illustrates the manner of changing the direction of the flow gradients shortly after breakthrough of the driving fluid at a production well. Thereupon, the original injection well is shut in, since channels for the flow of the driving fluid have been established and the direction of the flow gradients is changed by switching the injection of the driving fluid to a converted production well, offset from the line between the original injection well and the production well with breakthrough. The indicia in this figure are self explanatory of the phenomenon desired.

Referring to FIG. 3a, 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 indicated is at breakthrough of the driving fluid at the production wells, with a sweep efficiency of 57 percent. Series of two production wells and an intermediate injection well in line are shown with equal quantities of driving fluid being injected through the latter wells so that breakthrough at the production wells occurs substantially simultaneously. Where the underground formation features are well known, the rates of injection of the driving fluid can be controlled to provide for simultaneous breakthrough.

Referring to FIG. 3b, following breakthrough as indicated in FIG. 3a, the original injection wells in the series of the direct line drive program are shut in, the production wells in alternate series of the program are converted to injection wells and the remaining production wells of the series are maintained on production, as driving fluid is injected into the formation via the converted wells until the calculated sweepout of the pattern has reached more than 82 percent, as disclosed in FIG. 3c, with a drop in water cut. Continuation of the cross flow line drive will increase sweep efficiency to about 94 percent.

Referring to FIG. 4a, the frontal position of the driving fluid is shown when production is continued after breakthrough until 1.5 breakthrough volumes (BTV) of driving fluid have been injected, with a sweep of better than 72 percent.

Thereafter, as shown in FIG. 4b, the intermediate injection wells are shut in and alternate production wells are converted to injection wells, the remaining wells being continued on production. For the next 0.6 BTV injected, the water cut is reduced and the sweep is nearly 92 percent, as shown in FIG. 4c.

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. A method of producing formation fluids including hydrocarbons from a subterranean hydrocarbon-bearing formation by a direct line drive in a secondary recovery operation 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 substantially equal amounts of an extraneous driving fluid into said formation via the intermediate injection well in each 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, said producing of said formation fluids and said injecting of said extraneous driving fluid being for a first predetermined period, thereafter initiating a tertiary recovery operation by imposing a new set of flow gradients comprising the steps of shutting in the intermediate injection well in each of said series and converting production wells in alternate series into injection wells, and thereafter producing formation fluids via the remainder of said production wells while injecting said extraneous driving fluid into said formation via the converted production wells for a second predetermined period.

2. In the method as defined in claim 1, said first predetermined period terminating upon breakthrough of said extraneous driving fluid at said production wells.
3. In the method as defined in claim 2, said second predetermined period terminating when the sweep exceeds 82 percent.

4. In the method as defined in claim 1, said first predetermined period terminating upon injection of about 1.5 breakthrough volumes of driving fluid.

5. In the method as defined in claim 4, said second predetermined period terminating when the sweep exceeds about 92 percent.

6. 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.

7. In the method as defined in claim 6, said intermediate injection well and said production wells being disposed respectively in common rows.

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