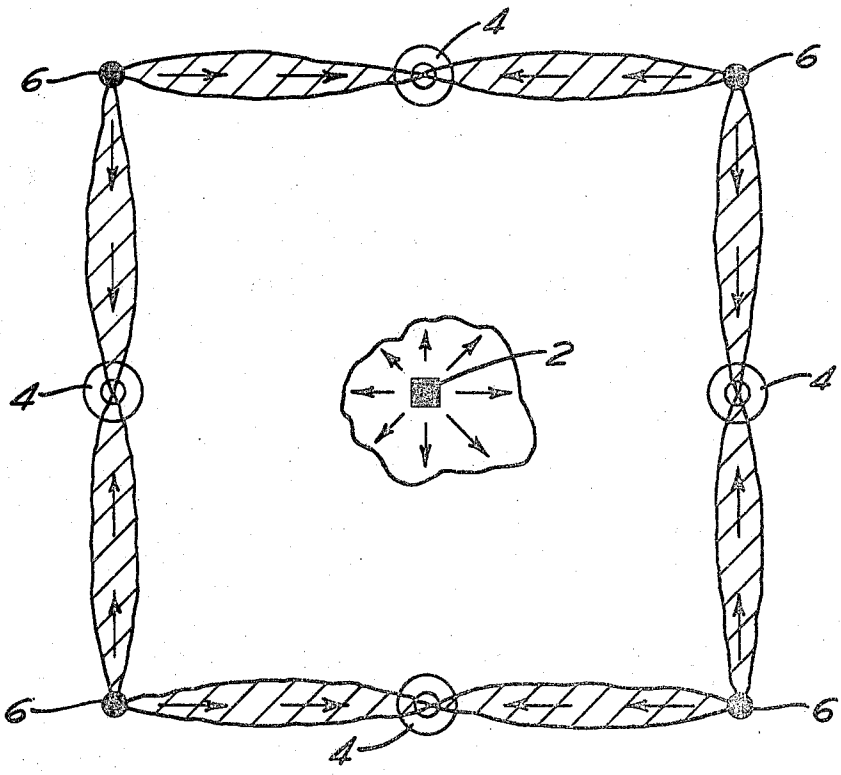
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COMBUSTION DRIVE WELL STIMULATION

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COMBUSTION DRIVE WELL STIMULATION

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This invention relates to an improved method of stimulating production where in situ combustion drive producing techniques are employed.

A large number of oil fields in the United States employ the technique of burning in-place oil or injected inflammable gases into a reservoir thereby subjecting the reservoir fluids to an artificial driving force. This driving force is created by the increase in volume that is caused by the increased temperature as combustion takes place within the reservoir.

In the utilization of in situ techniques to produce reservoir fluids, air is injected into a centrally located well to support combustion and extend the combustion front greater distances from the well bore. The increased pressure, caused by combustion within the reservoir, operates to drive the in-place fluids through the reservoir toward a remote producing well at which point they may be delivered to the surface and recovered. Owing to the large distances to which these fluids must be moved and the viscosity of the fluids, a great deal of the created differential pressure is utilized to move oil into the producing well. A more efficient in situ operation would be achieved by decreasing the resistance of flow into the producing well thereby permitting the utilization of a greater portion of the created pressure differential to establish a pressure front and move in-place fluids ahead of the combustion front.

My invention resides in an in situ recovery project wherein the fluid's resistance to flow into the producing wells is decreased thereby creating a condition whereby a greater portion of the pressure differential caused by combustion within the reservoir may be utilized to move the fluid bank ahead of the combustion front through the reservoir. The operation of my invention requires an injection liquid, such as condensate, gasoline or other low viscosity, high gravity liquid hydrocarbons, which are miscible with oil. This low viscosity liquid is injected into a few wells surrounding the air injection well. Liquid injection is continued to move and channel the injected liquid through the reservoir and into the producing wells. The channels formed by the continuous injection of low viscosity liquid will provide a less restricted flow path from the reservoir to the producing well. These created channels, hereafter referred to as flowing sinks, will also function to reduce the viscosity of the reservoir fluids entering the flowing sinks owing to the mixing of the high-viscosity reservoir fluids with the low viscosity injected liquids within the flowing sinks. By reducing the viscosity of the in-place fluids and providing a less restricted flow path into each producing well, the efficiency of the in situ producing operation is increased.

The single figure of the drawing is a diagrammatic view of a nine-spot in situ combustion operation being conducted in accordance with this invention. Different geometric well spacings may employ the techniques of this invention and this nine-spot pattern is utilized only for illustrative purposes.

Referring to the drawing, number 2 indicates an injection well into which air is injected to supply oxygen to support in situ combustion that is initiated by heating the reservoir in the vicinity of the gas injection well. As preferred in this invention, the corner wells of the nine-spot rectangular pattern surrounding the injection well 2 function as injection wells 6. The remaining wells of the nine-spot pattern are producing wells 4 and function to deliver fluids from the reservoir to the surface of the earth.

In the operation of this invention, a low-viscosity liquid which is soluble in the reservoir oil is injected into the injection wells 6. Injection is continued until this injected liquid is moved through the formation and into the producing wells 4 thereby forming a flowing sink.

During the forming of this flowing sink, the injected liquids move outward from the well bore of the injection wells 6 in a fairly uniform pattern. However, as the injected liquid breaks into the producing well 4 a path of less flow resistance will be formed from the liquid injection wells to the producing wells. Subsequently injected liquids will follow this less restricted channel and form a well-defined flowing sink through which low viscosity liquids will flow from the injection wells 6 to the adjacent producing wells 4 during the life of the in situ combustion technique.

As the combustion front of the air injection well is extended by the injection of combustion supporting air, a bank or pressure plateau will be created around the air injection well and function to force the in place reservoir fluids through the formation.

Where the sinks of this invention are not formed a portion of the reservoir fluids immediately surrounding the producing wells will find ready access to the surface through the well bore of the producing well, however, portions of the in-place fluid located at positions remote from the straight line path between the air injection well and the producing well may often be forced through the boundaries of the nine-spot pattern and hence away from the producing well. The absence of flowing sinks also may cause the utilization of large amounts of the created driving pressure to move the fluid greater distances through the dense more flow restrictive untreated matrix.

If a nine-spot combustion technique incorporates the practice of forming boundary line flowing sinks of this invention, all in-place fluids are provided a less restricted flow path to the producing well. Portions of the in-place fluid tending to be driven in a direction past the producing well and through the boundaries of the nine-spot, encounter the flowing sink and readily change directions, thereafter following in the flowing sink toward the producing well.

This direction change of reservoir fluids is caused by the decreased flow resistance path formed by the flowing sink. The moving reservoir fluids will naturally follow the path of least resistance which will be along the flowing sink toward the producing wells.

The viscosity decrease caused by the mixing of in-place fluids with the low viscosity liquids in the flowing sink will further decrease the resistance to flow within the sink. The decrease in resistance to flow through the flowing sink will also decrease the amount of pressure required to drive the in-place reservoir fluid to the producing well. The pressures created by the in situ combustion technique are thereby more efficiently utilized to form a more uniform bank or pressure plateau around the injection well.

An added advantage to the employment of this technique is found in the characteristics of the produced fluids. Owing to the reservoir fluid mixing with injected liquid within the flowing sink, the produced fluids will possess a higher API gravity. Such lighter weight fluids will facilitate the separation and removal of water from these produced fluids.

It is preferred in this invention that the amount of low viscosity liquid continuously injected into a liquid injection well should be in the range of 5 to 15 percent of the total produced fluids. In the drawing, fluid injected into one liquid injection well may flow into more than one producing well. It is therefore advisable that the volume injected into any one liquid injection well should be

calculated by prorating to the injection well the proportionate percentage of total fluid produced by the various producers which are interconnected with said injection well.

Examples of different geometric well spacing patterns that may employ the techniques of this invention are five-spot patterns with two corner producing wells and nine-spot patterns with corner producing wells. This invention is readily adaptable to various field units and is not restricted to the nine-spot pattern illustrated in the drawing.

This invention will thereby increase the efficiency of combustion drive secondary recovery techniques. The production method of this invention will also increase the ultimate recoveries from the reservoir and facilitate the handling of these fluids after recovery.

Therefore I claim:

1. In a method of increasing production from a subterranean reservoir stimulated by in situ recovery techniques wherein combustion supporting gas is injected into the reservoir through a centrally located gas injection well, combustion is initiated within said reservoir, and additional combustion supporting gas is injected into the reservoir to maintain combustion and displace the reservoir fluids through the reservoir toward a plurality of wells surrounding the gas injection well, the improvement comprising:

injecting into a well adjacent the gas injection well, a liquid which is soluble in oil and has a lower viscosity than the reservoir fluids;

continuing injection of the liquid to displace the liquid through the reservoir and into an adjacent producing well;

lowering the pressure within the producing well; and

producing the injected liquid and the reservoir fluids which enter the producing well.

2. In a method of increasing production from a subterranean reservoir stimulated by in situ recovery techniques wherein combustion supporting gas is injected into the reservoir through a centrally located gas injection well, combustion is initiated within said reservoir, and additional combustion supporting gas is injected into the reservoir to maintain combustion and displace the reservoir fluids through the reservoir toward a plurality of wells surrounding the gas injection well, the improvement comprising:

injecting into a well adjacent the gas injection well, a liquid which is soluble in oil and has a lower viscosity than the reservoir fluids;

displacing the injected liquid through the reservoir to communicate with a producing well and form a sink of injected liquid flowing from the liquid injection well to the adjacent producing well;

delivering to the surface the injected liquid and the reservoir fluids which enter the producing well; and

adjusting the rate of liquid injected into the liquid injection well to maintain the volume of produced injected liquid in the range of 5 to 15 percent of the fluids produced by the adjacent producing well.

3. A method of increasing production from a subterranean reservoir stimulated by in situ techniques wherein combustion supporting gas is injected into the reservoir through a centrally located gas injection well surrounded by a plurality of wells comprising:

injecting into a well adjacent the gas injection well, a liquid which is soluble in oil and has a lower viscosity than the reservoir fluids;

continuing injection of the low viscosity liquid to displace the liquid through the formation to an adjacent producing well and form a flowing sink flowing from the liquid injection well into the producing well; and

producing the injected liquids and the reservoir fluids which enter the producing well.

4. A method as set forth in claim 3 wherein the injected liquid is condensate.

5. A method of increasing production from a subterranean reservoir stimulated by in situ combustion wherein combustion supporting gas is injected into the reservoir through a centrally located gas injection well surrounded by a plurality of wells comprising:

injecting gasoline into a plurality of wells adjacent the gas injection well;

continuing injection to displace the gasoline through the formation and in communication with adjacent producing wells; and

delivering to the suface the gasoline and the reservoir fluids which enter the producing wells.

6. A method of increasing production from a subterranean reservoir stimulated by in situ combustion wherein combustion supporting gas is injected into the reservoir through a centrally located gas injection well surrounded by a plurality of wells comprising:

injecting into a plurality of wells adjacent the gas injection well, a liquid which is soluble in oil and has a lower viscosity than the reservoir fluids;

displacing the injected liquid through the reservoir to communicate with a plurality of producing wells adjacent the gas injection well and form sinks of the injected liquid flowing from the liquid injection wells to adjacent producing wells;

delivering to the surface the injected liquid and the reservoir fluids which enter the producing wells; and

adjusting the rate of liquid injected into the liquid injection wells to maintain the volume of produced injected liquid in the range of 5 to 15 percent of the fluids produced by the adjacent producing wells.

7. A method as set forth in claim 6 wherein the producing wells are positioned at the corners of the rectangular nine well pattern and the liquid injection wells are positioned on the sides of the rectangular nine well pattern.

8. A method of increasing production from a subterranean reservoir penetrated by nine well bores geometrically spaced to form substantially a rectangle having three wells positioned on each side of the rectangle and a well centrally positioned within the rectangle comprising:

injecting a combustion supporting gas down the well bore of the centrally located well and through the adjacent formation;

igniting the hydrocarbon fluids surrounding the centrally located well;

continuing injection of the combustion supporting gas to maintain combustion and displace the in-place reservoir fluids outwardly through the reservoir;

injecting down the four well bores positioned at the corners of the rectangular nine well pattern, a liquid which is soluble in oil and has a lower viscosity than the reservoir fluids;

displacing the injected liquid from the four liquid injection wells, through the formation and into the four adjacent producing wells positioned on the sides of the rectangular nine well pattern, thereby forming sinks flowing from each liquid injection well into the adjacent producing wells;

lowering the pressure within the well bore of the four producing wells; and

delivering to the surface the injected liquid and the reservoir fluids which enter the producing wells.

9. A method of increasing production from a subterranean reservoir penetrated by five well bores geometrically spaced to form a rectangle having a well positioned on each corner of the rectangle and a well centrally positioned within the rectangle comprising:

injecting a combustion supporting gas down the well bore of the centrally located well and through the adjacent formation;

igniting the hydrocarbon fluids surrounding the centrally located well;

continuing injection of the combustion supporting gas to maintain combustion and displace the in-place reservoir fluids outwardly through the reservoir;

injecting down two well bores positioned at the corners

of the rectangular five well pattern, a liquid which is soluble in oil and has a lower viscosity than the reservoir fluids;

displacing the injected liquid from the two liquid injection wells, through the formation and into the two adjacent producing wells positioned on the corners of the rectangular five well pattern thereby forming sinks flowing from the liquid injection wells into the adjacent producing wells;

lowering the pressure within the well bore of the two producing wells; and

delivering to the surface the injected liquid and the reservoir fluids which enter the producing wells.

References Cited

UNITED STATES PATENTS

2,885,002	5/1959	Jenks	166—2 X
3,064,728	11/1962	Gould	166—11 X
3,120,870	2/1964	Santourian.	
3,165,154	1/1965	Santourian	166—11
3,252,512	5/1966	Baker et al.	166—2
3,253,652	5/1966	Connally et al.	166—11 X
3,316,962	5/1967	Lange	166—11
3,332,480	7/1967	Parrish	166—11 X

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