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METHOD OF SECONDARY RECOVERY OF HYDROCARBONS

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This invention relates to the recovery of petroleum hydrocarbons from subterranean formations and particularly the secondary recovery of hydrocarbons from a plurality of adjacent subterranean strata within a formation, the strata having varying permeabilities and being traversed by a plurality of well bores.

The secondary recovery of hydrocarbons refers to those recovery efforts applied to formations which incorporate the utilization of extraneous energy as the recovery force, that is, those methods which are utilized after the naturally occurring formation energy has been substantially expended. Methods of secondary recovery which have been developed in the art are numerous, such as water flooding, gas pressurization, miscible flooding, in situ combustion drive, and combinations of these, but none of the foregoing have been overly successful in recovering hydrocarbons from subterranean formations containing adjacent strata having appreciable differences in permeability and being in communication with each other.

A primary object of this invention is to provide a method of secondary recovery for producing the hydrocarbons from adjacent, contiguous strata of a formation having varying permeabilities.

Another object of this invention is to provide a method of secondary recovery wherein hydrocarbons in the less permeable strata of several adjacent strata are not bypassed.

A further object of this invention is to provide a method of secondary recovery whereby the economics of the media utilized in the flooding are advantageous.

Other objects and advantages of this invention will be evident from the following detailed description of the invention.

Stated broadly, the invention may be defined as a method for the secondary recovery of hydrocarbons from adjacent strata within a producing formation, the strata being in communication with each other and having varying permeabilities, with said formation being traversed by well bores, said method comprising injecting a volume of hydrocarbon miscible liquid into said formation, injecting a gaseous hydrocarbon into said oil reservoir comprising several strata while recovering hydrocarbons therefrom, diminishing the pressure in said reservoir whereby the hydrocarbons flow from the more permeable strata into a recovery well and from the less permeable strata into the more permeable strata, and repeating the foregoing procedure until substantially all of the hydrocarbons are displaced into the more permeable strata and into the recovery well.

The invention is applicable to any hydrocarbon bearing reservoir having a plurality of adjacent strata therein of appreciably different permeabilities, regardless of the degree of pressure depletion, particularly including one which has been substantially depleted of naturally occurring energy capable of producing said hydrocarbons. The reservoir is necessarily traversed by a plurality of wells; but for the purpose of simplicity, the following description will be particularly directed to a reservoir having only two adjacent strata and being traversed by only single injection and recovery wells.

The initial step of the subject invention is the injection of a volume of hydrocarbon miscible liquid, or a mixture

thereof, such as liquefied low molecular weight normally gaseous hydrocarbons or a mixture thereof, carbon dioxide, etc. The amount to be injected is variable, though it is preferable that an amount equal from about five to about ten percent of the reservoir hydrocarbon pore volume should be injected. This hydrocarbon miscible liquid is injected at conditions of substantial pressure sufficient to maintain the miscibility of the liquid with the hydrocarbon in the reservoir, generally in the range of at least 1100 p.s.i., but preferably not greater than the original reservoir pressures. The hydrocarbon miscible liquid is inherently displaced into the strata of the formation in amounts in proportion to the permeability of the strata, that is, greater volumes and distances into the more permeable stratum and lesser amounts and distances into the less permeable stratum, wherein it displaces substantially all of the reservoir hydrocarbons which it contacts during displacement toward the recovery well for production in a conventional manner.

The second step of the present invention is the injection of a gaseous hydrocarbon, such as natural gas, methane, etc., which displaces the previously injected hydrocarbon miscible liquid into the strata of the reservoir. This gaseous hydrocarbon, either miscible or immiscible with the previously injected liquid, is injected at conditions of substantial pressure, preferably the same pressure as the hydrocarbon miscible liquid, wherein the volume of said hydrocarbon injected into each stratum is also proportionate to the permeability of the stratum. This injection is continued until substantially all of the reservoir hydrocarbons are displaced from the most permeable stratum and proportionate amounts of hydrocarbons are displaced from the less permeable stratum to such an extent that the hydrocarbon miscible liquid is displaced through the complete distance of the most permeable stratum into the recovery well, which is evidenced by the recovery of said liquid from the most permeable stratum in substantial amounts. This step utilizes the inherent fingering tendency of hydrocarbon miscible liquids and hydrocarbon gases when being displaced through a formation in order that these fluids pass through the permeable stratum with greatest rapidity, while obtaining the normally high displacement efficiency of a combination of said fluids. This provides a means for displacing the reservoir hydrocarbons from the more permeable stratum and furnishes a suitable depository wherein the hydrocarbons of less permeable stratum can flow for subsequent recovery by conventional methods.

The third step of the subject method is depressurization and further recovery of reservoir hydrocarbons, which is accomplished by suspending injection of the gaseous hydrocarbon into the formation upon attaining a breakthrough into the recovery well of the hydrocarbon miscible liquid from the more permeable stratum as evidenced by the production of appreciable amounts of said liquid from the recovery well. Thereafter the injection well is closed in while production by the depressurization is continued from the recovery well in a conventional manner. This production is normally accomplished by controlling the rate of depressurization by means installed in the recovery well, such as choke valves and the like, rather than opening the recovery well to the atmosphere and allowing the pressures within the formations to be depleted rapidly. The pressure is thereby reduced in the recovery well traversing the strata of varying permeability which creates a pressure drop in the formation adjacent the recovery well, whereby the hydrocarbons in the more permeable stratum flow into the recovery well in response to this pressure drop about the well. In turn this extends the pressure drop into that portion of the formation from which those hydrocarbons are removed whereby the hydrocarbons contained in the adjacent stratum of lesser

permeability are concurrently drawn into the more permeable stratum due to the pressure drop within the more permeable strata, the essence of this step of the method is to flow the hydrocarbons from the more permeable stratum into the recovery well to be produced and from the stratum of lesser permeability into the stratum of more permeability and eventually into the recovery well. This step of the method is conducted until the injected gaseous hydrocarbon commences to be produced from the recovery well in substantial quantities disproportionate to the hydrocarbons being recovered, or until specific pressure is reached, or until flow from the well has decreased to an impractical rate, dependent on the economics of each reservoir system.

The foregoing cycle of steps results in the recovery of substantially all of the original hydrocarbons from the more permeable stratum and a portion of the hydrocarbons from the stratum of lower permeability. Though substantially all of the original reservoir hydrocarbons have been recovered from the more permeable stratum, the reservoir is in substantially the same relative condition as before the cycle of recovery steps, due to flow of hydrocarbons from the stratum of lesser permeability to the stratum of greater permeability, except that the concentrations of hydrocarbons in the strata have been reduced accordingly. Thereafter, further recovery of the hydrocarbons from the reservoir is accomplished by a repetition of the foregoing steps in the order as set forth. This repetition is preferably conducted at approximately the same pressures as the original cycle of steps, in which case, the recovery well is closed in until sufficient amounts of the hydrocarbon miscible liquid and the hydrocarbon gas have been injected to restore the reservoir to the desired pressure level. These steps of the repetition can also be conducted at a reduced pressure level from that of the prior cycle of operations as conditions of the individual reservoirs require. This repetition of cycles can be conducted as many times as it is economically feasible, or until all of the hydrocarbons are withdrawn from the strata of the reservoir.

While a particular embodiment of the invention has been described, it will be understood, of course, that the invention is not limited thereto, since modifications may be made; and it is contemplated to cover by the appended claims any such modifications as fall within the true spirit and scope of the invention.

The invention having been thus described, what is claimed and desired to be secured by Letters Patent is:

1. A method for the recovery of hydrocarbons from a subterranean reservoir of stratified permeability having a first stratum of greater permeability than a second stratum adjacent thereto and being traversed by at least one injection well and recovery well which comprises:

(*a*) Injecting a hydrocarbon miscible liquid through said injection well into said first stratum and said second stratum at substantial pressure whereby essentially all hydrocarbons contacted in said first stratum and a portion of said hydrocarbons in said second stratum are displaced and produced through said recovery well;

(*b*) Injecting a gaseous hydrocarbon through said injection well into said first stratum and said second stratum at substantial pressure whereby said hydrocarbons and said hydrocarbon miscible liquid are displaced from said first stratum and produced through said recovery well;

(*c*) Suspending the injection of said gaseous hydrocarbon after substantially displacing said hydrocarbon miscible liquid from said first stratum;

(*d*) Depressuring said reservoir through said recovery well whereby said hydrocarbons, said hydrocarbon miscible liquid, and a large portion of said gaseous hydrocarbon are produced from said first stratum and a portion of said hydrocarbons from said second stratum are displaced into said first stratum;

(*e*) Conducting a plurality of this sequence of operations whereby said hydrocarbons of said second stratum are displaced and produced through said first stratum and said recovery well.

2. A method for the recovery of hydrocarbons as set forth in claim 1 wherein said hydrocarbon miscible liquid is injected in an amount from about five percent (5%) to about ten percent (10%) of the hydrocarbon pore space of said reservoir.

3. A method for the recovery of hydrocarbons as set forth in claim 2 wherein said hydrocarbon miscible liquid is a liquefied low molecular weight normally gaseous hydrocarbon.

4. A method for the recovery of hydrocarbons as set forth in claim 2 wherein said hydrocarbon miscible liquid is a mixture of liquefied low molecular weight normally gaseous hydrocarbons.

5. A method for the recovery of hydrocarbons as set forth in claim 2 wherein said hydrocarbon miscible liquid is carbon dioxide.

6. A method for the recovery of hydrocarbons as set forth in claim 1 wherein said hydrocarbon miscible liquid is injected at a pressure of at least 1100 p.s.i.

7. A method for the recovery of hydrocarbons as set forth in claim 1 wherein said gaseous hydrocarbon is a mixture of naturally-occurring hydrocarbon gases.

8. A method for the recovery of hydrocarbons as set forth in claim 1 wherein said gaseous hydrocarbon is methane.

9. A method for the recovery of hydrocarbons as set forth in claim 1 wherein said gaseous hydrocarbon is injected at a pressure of at least 1100 p.s.i.

10. A method for the recovery of hydrocarbons as set forth in claim 1 wherein said gaseous hydrocarbon is miscible wtih said hydrocarbon miscible liquid.

11. A method for the recovery of hydrocarbons as set forth in claim 1 wherein said gaseous hydrocarbon is immiscible with said hydrocarbon miscible liquid.

12. A method for the recovery of hydrocarbons as set forth in claim 1 wherein said reservoir has a plurality of adjacent strata of varying permeabilities.

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