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[54] **RECOVERY OF OIL BY A VERTICAL MISCIBLE FLOOD**

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

[58] **Field of Search** 166/266, 269, 270, 273, 166/274

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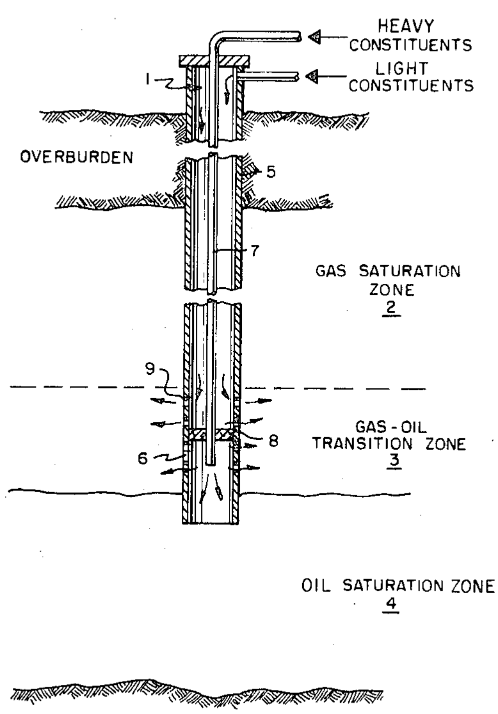
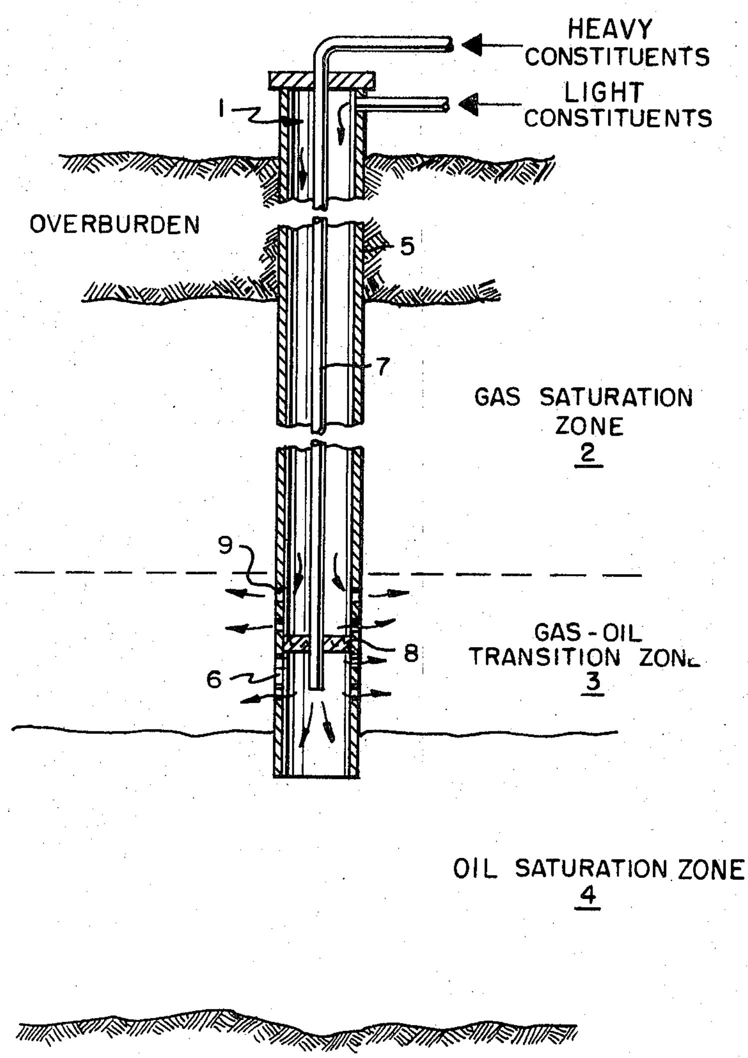
[57] **ABSTRACT**

A vertical miscible recovery process for the recovery of oil from an oil-bearing reservoir wherein a miscible slug is established "in-situ," at the crest of the oil column or at the gas-oil interface by the separate and simultaneous injection of a stream of the light constituents and a stream of the heavy constituents comprising the miscible slug, followed by the injection of a driving fluid to displace the slug and the reservoir oil downward thru the reservoir.

14 Claims, 1 Drawing Figure




HEAVY
CONSTITUENTS
LIGHT
CONSTITUENTS
1
OVERBURDEN
5
7
GAS SATURATION
ZONE
2
9
GAS - OIL
TRANSITION ZONE
3
8
6
OIL SATURATION ZONE
4

RECOVERY OF OIL BY A VERTICAL MISCIBLE FLOOD

FIELD OF THE INVENTION

This invention relates to a process for recovery of oil by a vertical miscible flood wherein the light constituents and the heavy constituents of a miscible solvent are injected separately and simultaneously into the reservoir via an injection well in communication with the reservoir at the crest of the oil column to form in-situ a slug at the interface, and thereafter a driving fluid is injected to drive the slug vertically downward thru the reservoir, thereby displacing the reservoir oil toward a production well traversing the lower horizon of the oil-bearing reservoir, from which the oil is produced.

PRIOR ART

In the recovery of oil from an underground oil-bearing reservoir, one method that his been suggested for increasing oil recovery is that of miscible flooding wherein a solvent that is miscible with the reservoir oil is injected as a slug, and thereafter a driving agent is injected to drive the solvent slug and the oil thru the reservoir.

The process of miscible flooding is extremely effective in stripping and displacing the reservoir oil from the reservoir thru which the solvent flows. This effectiveness is derived from the fact that a two-phase system within the reservoir and between the solvent and the reservoir oil is eliminated at the conditions of temperature and pressure of the reservoir, thereby eliminating the retentive forces of capillarity and interfacial tension which are significant factors in reducing the recovery efficiency of oil in conventional flooding operations where the displacing agent and the reservoir oil exist as two phases in the reservoir.

In a miscible flood the solvent slug is capable of mixing completely with the reservoir oil, forming a transition zone at the leading edge of the solvent slug between the oil and the solvent in which miscibility exists between the solvent and the oil. Thereafter, a driving fluid, such as a gaseous hydrocarbon is injected to drive the slug and the reservoir oil thru the reservoir. A second transition zone is formed at the trailing edge of the solvent slug between the solvent and the driving agent and miscibility may exist between the solvent and the driving fluid, dependent upon the reservoir conditions and the composition of the solvent and the driving fluid.

In steeply dipping reservoirs or thick reservoirs having good vertical permeability, vertical displacement processes are known to improve the displacement efficiency resulting in increased recovery. Thick reservoirs may include reef reservoirs which herein mean oil-bearing formations whose matrix is a reef vis-a-vis a sandstone sediment or limestone deposit.

In a vertical displacement method, the displacing fluid such as a gas is injected at or near the crest of the oil-bearing reservoir to displace the reservoir oil vertically downward toward production wells that penetrate the lower horizons of the oil-bearing reservoir.

In order to realize economic benefits, vertical miscible displacement processes have also been employed using a displacing solvent slug which is driven downward by a driving fluid. In operation, a solvent bank of the slug or a so-called "blanket" is first established at the crest or top of the reservoir and thereafter the solvent bank or slug is moved downward by injection of a driving fluid into the upper horizons of the reservoir. The oil is displaced downward and produced via production wells penetrating the lower horizons of the reservoir.

The composition of the solvent used for the miscible slug is generally a light hydrocarbon such as propane or LPG, or a mixture of light hydrocarbons having from two to six carbon atoms in the molecule, although high molecular weight hydrocarbons can be used under certain conditions. The solvent may also include in its composition methane or a lean gas, that is, a gas containing methane with minimum amounts of C_2–C_6 hydrocarbons. In determining the composition of the solvent to be used, the criteria is that the solvent be miscible with the reservoir oil.

In the miscible flood process where a slug of solvent is used and is thereafter driven by a driving agent, the success of the process is greatly dependent upon maintaining the integrity and discreteness of the slug so that miscibility is retained during the flooding operation. At the same time, in order to attain optimum economic benefits, the size of the slug should be minimal.

One of the difficulties that has been realized in the miscible slug process is the disintegration of the slug with consequent loss of miscibility. This disintegration is principally caused by undesirable mixing due to adverse convective mixing resulting from temperature gradients. It is thus an object of this invention to overcome this difficulty and minimize the undesirable mixing, thereby maintaining the integrity of the miscible slug. It is another object of the invention to minimize the size of the slug thereby realizing optimum economic benefits.

BRIEF DESCRIPTION OF THE FIGURE

The accompanying FIGURE illustrates the solvent injection well as used in the practice of the invention.

DESCRIPTION OF THE INVENTION

This invention may be applied to steeply-dipping reservoirs or thick reservoirs having good vertical permeability. In the practice of this invention, the reservoir is penetrated by at least one crestal injection well into the upper horizon of the oil-bearing reservoir and at least one production well that penetrates the lower horizon of oil-saturated zone of the reservoir.

In its broadest aspect, this invention provides for a solvent injection well that penetrates the top several feet of the oil column. In reservoirs that do not contain a gas cap, the solvent injection well or wells are completed in or near the crest penetrating several feet into the oil column or oil-bearing reservoir adjacent the overburden stratum. In reservoirs that contain a gas cap, either present initially or formed by production and gravity drainage, the solvent injection well or wells penetrate the reservoir at least to the depth of the gas-oil transition region. This region is a transition region between the upper gas-saturated zone and the lower oil-saturated zone in which the fluid saturation changes from one of predominantly gas-saturation to one of oil-saturation. This transition region is often referred to as the gas-oil interface.

The injection well is completed so as to provide for the injection of the constituents of the slug separately and simultaneously, i.e., the light constituents of the miscible slug are injected via the annulus between the casing and the tubing and into the upper portion of the transition region, and the heavy constituents are injected via the tubing into the lower portion of the transition region.

The terms "light constituents" and "heavy constituents" are defined within this invention in particular relation to the composition of the miscible slug. Within the meaning of this invention and referring specifically to the composition of the slug, the term "light constituents" means a mixture having substantially in its composition hydrocarbons containing from one to four carbon atoms per molecule and possibly including some amounts of carbon dioxide, hydrogen sulfide, etc. This material would generally be in the gaseous phase. The term "heavy constituents" means a mixture having substantially in its composition hydrocarbons that have from three to six carbon atoms per molecule and may contain the above chemical compounds and also compounds having a boiling range similar to that of straight run gasoline. Normally, this material would be liquid or possibly a dense gas. Furthermore, within the invention, the miscible slug is a blend of the "light constituents" and "heavy constituents."

The invention can be illustrated by the following miscible flood operation wherein the desired composition of the miscible solvent slug is obtained from a blend of a residue gas stream from a gas plant and a heavier "LPG" stream. In this example the composition of the slug is such that miscibility is achieved both with the reservoir oil and with the gas drive. The blend at ambient temperature, i.e., 70° F., is injected at the top of the oil column in a formation having a formation temperature of 167° F. The compositions of the constituents of the gas streams and the blended miscible slug are as follows:

Constituent	Residue Gas Stream (%)	"LPG" Stream (%)	Miscible Slug (%)
N_2	2.31	0.12	1.07
C_1	59.80	0.10	25.61
C_2	28.54	2.15	13.40
C_3	9.12	29.74	20.93
C_4	0.23	67.52	38.78
C_5^+	Trace	0.37	0.21

The densities for the formation fluids, the component gas streams and the miscible slug blend are as follows:

	Residue Gas from Gas Plant	"LPG" Stream from Gas Plant	Miscible Slug Blend	Reservoir Gas	Reservoir Oil
Density 70°F. (lb/ft^3)	10.03	33.60	26.50	—	—
Density 167°F. (lb/ft^3)	8.67	30.00	23.56	8.67	43.00

In the conventional method of operation relating to establishment of the slug, where the miscible slug, blended prior to injection, is injected at the temperature of 70° F., an examination of the densities of the fluids involved at the injection temperature and at the formation temperature shows that differential density difference of the injected slug will result in a density inversion over the vertical distance of the formation into which the slug is injected. This inversion, together with the differences in temperatures, results in substantial undesirable mixing.

To overcome this undesirable mixing, by the method of the invention, the establishment of the slug is caused to occur in-situ by the simultaneous injection of the two separate streams, wherein the upper stream is the residue gas stream, i.e., the light constituents of the miscible slug, and is at least as dense as the formation gas, and the lower stream, i.e., the heavy constituents of the miscible slug, is the "LPG" stream from the gas plant. This method of operation results in a minimal adverse density profile over a substantially smaller vertical depth. In this manner of operation thus the integrity of the slug is maintained, and the size of the slug is minimized.

A preferred method of operation of the invention can be illustrated by referring to the accompanying FIGURE which depicts the situation where the reservoir has an oil-saturation zone containing liquid hydrocarbons, a gas-oil transition zone or interface which is adjacent the uppermost region of the liquid hydrocarbons, a gas saturation zone, and is overlain by overburden. The solvent injection well **1** traverses the gas-saturation zone **2** of the hydrocarbonbearing reservoir to the depth of the gas-oil transition zone **3**, which is above the oil-saturation zone **4**. A primary casing **5**, traversing the gas saturation zone **2** to at least the uppermost region of the oil saturation zone is cemented in place and is perforated in two intervals in the gas-oil transition zone as shown by perforations **6** and **9**, thereby forming a first and second set of perforations. Thereafter a tubing **7** is inserted into the casing to a depth intermediate between the two sets of perforations. A packer **8** is then set in the annulus formed by the tubing and the casing, positioned intermediate between the two sets of perforations, that is above perforations **6**, and below perforations **9**. The lower end of the tubing **7** is open to provide communication with the formation via the perforations **6**.

In a reservoir having no gas cap and no gas saturation zone, a similar type of well completion is used. The injection well is completed at least to the region adjacent the liquid hydrocarbon-bearing reservoir adjacent the overburden which is the uppermost region of the liquid hydrocarbon zone. Thereafter, casing, tubing and perforations are provided at the top of the oil column by completing the well in a manner similar to that described above.

Referring again to the accompanying FIGURE illustrating a reservoir having a gas saturation zone or gas in the oil column, after the solvent injection well has been completed, the miscible slug "blanket" is established "in situ" within the reservoir by the following procedure. The heavy constituents, as defined heretofore, of the solvent slug are injected via the tubing **7** and into the gas-oil transition zone via the perforations **6**. Separately and simultaneously, the light constituents as defined heretofore are injected via the annulus and into the gas-oil transition zone via the perforations at 9. Injection is continued in this manner until a sufficient amount of the slug constituents has been injected to form a blanket of the desired solvent at the gas-oil transition zone. By the method of the invention there is established a miscible slug or blanket, with minimal undesirable mixing due to adverse density and convective effects.

After having established the slug or blanket within the reservoir a driving fluid is injected to displace the slug or blanket downward thru the reservoir, thereby displacing the reservoir oil downward to the production well from which the oil is produced. The solvent injection well (or wells) may be used for driving fluid injection or a separate crestal well or wells may be used.

The driving fluid employed may be any gaseous material, that is gaseous at reservoir conditions. Additionally, the driving fluid may be miscible with the hydrocarbon solvent slug. The preferred driving fluid is a dry, relatively, inexpensive gas, such as a gas containing substantially methane, as natural gas, flue gas or a gas from a gas-processing facility. Other gases, however, which may be employed include ethane, carbon dioxide, nitrogen, air and mixtures thereof. The displacing agent is injected in amounts sufficient to displace the solvent slug thru the reservoir and is injected at a rate so that the preferred rate of movement thru the reservoir is from about 0.03 to about 10.0 feet per day.

In the application of this invention, the reservoir may be repressured, if required, by the injection of other fluids to establish at least saturated reservoir conditions prior to or during the injection of the solvent slug. Fluids that may be used for repressuring include methane, natural gas, carbon dioxide, nitrogen, air, water and mixtures thereof.

It is within the scope of the practice of this invention to include miscible floods that are termed "instant miscible" floods, and "conditional miscible" floods. In the former type, miscibility occurs on contact of the injected solvent fluid and the reservoir oil. In the latter type, miscibility is attained within the formation either by the vaporizing of the lighter constituents of the oil into the solvent fluid or by the absorption of the heavier constituents of the solvent into the oil. The composition of the solvent for the type of miscible flood desired may be determined by means of laboratory tests such as slim tube which involve techniques well-known in the art.

In the summary, in accordance with the practice of this invention a vertical miscible flood is carried out in the following manner. There is introduced into the reservoir at the top of the oil column, a mixture of the light constituents of a hydrocarbon slug, and separately and simultaneously, a mixture of the heavy constituents of a hydrocarbon slug, forming in situ the hydrocarbon solvent slug that is miscible with the reservoir oil, and thereafter injecting a driving fluid to displace the solvent and the reservoir oil downward toward a production well from which the reservoir oil is produced.

We claim:

1. A method for the recovery of liquid hydrocarbons from a subterranean reservoir containing same and penetrated by an injection well and a production well, comprising the steps of:

a. injecting via said injection well into said subterranean reservoir adjacent the uppermost region of said liquid hydrocarbons in said reservoir a first light hydrocarbon fluid and separately and simultaneously, and below said first hydrocarbon fluid, a second heavier hydrocarbon fluid,

b. continuing said injection for a time sufficient to establish in-situ and adjacent said uppermost region a slug consisting of a mixture of said first fluid and said second fluid,

c. injecting into said reservoir a driving fluid thereby displacing said slug and said reservoir hydrocarbons thru said reservoir toward said production well,

d. producing said hydrocarbons via said production well.

2. The method of claim 1 wherein said injection well is completed by setting a casing to at least said uppermost region of said liquid hydrocarbons in said reservoir, said casing being perforated in two intervals, thereby forming a set of first perforations and a set of second perforations and providing communication with said uppermost region, running a tubing into said casing to a depth intermediate between said two sets of perforations, and setting a packer in the annulus formed by said casing and said tubing and intermediate between said two sets of perforations.

3. The method of claim 1 wherein said driving fluid is selected from the group consisting of methane, natural gas, flue gas, ethane, carbon dioxide, nitrogen, air and mixtures thereof.

4. The method of claim 1 wherein said driving fluid is injected above said slug and via a third well penetrating said uppermost region of said liquid hydrocarbon in said reservoir.

5. The method of claim 1 wherein said slug established in-situ is miscible with said hydrocarbons of said reservoir.

6. The method of claim 1 wherein said driving fluid is miscible with said slug.

7. The method of claim 1 wherein a gas cap is present above said uppermost region of said liquid hydrocarbons in said reservoir and said driving fluid is injected into said gas cap.

8. A method for the recovery of hydrocarbons from a subterranean hydrocarbon-bearing reservoir having a liquid hydrocarbon region and a gas-oil transition zone wherein a slug or solvent is driven downwardly thru said reservoir by a driving fluid, thereby displacing said hydrocarbons downwardly thru said reservoir, comprising the steps of:

a. providing an injection well extending into said reservoir adjacent said gas-oil transition zone,

b. completing said injection well by setting casing extending to at least said gas-oil transition zone, said casing having two intervals of perforations forming a first set and a second set of perforations spaced vertically below said first set of perforations, and a tubing extending substantially to said gas-oil transition zone, setting a packer in the annulus formed between said casing and said tubing and at a depth intermediate between said two intervals of said perforations,

c. providing a production well extending into said hydrocarbon-bearing reservoir adjacent the lower horizon of said liquid hydrocarbon region,

d. injecting via said first set of perforations in said injection well a mixture of light constituents of hydrocarbons comprising substantially hydrocarbons having from one to four carbon atoms per molecule,

e. simultaneously injecting via said second set of perforations in said injection well a mixture of heavy constituents of hydrocarbons comprising substantially hydrocarbons having from three to six carbon atoms per molecule,

f. continuing said injections separately and simultaneously for a time sufficient to establish in-situ said slug of solvent in the vicinity of said gas-oil interface,

g. injecting said driving fluid into said reservoir above said gas-oil transition zone thereby displacing said solvent slug and said reservoir hydrocarbons downwardly thru said reservoir,

h. producing said hydrocarbons via said production well.

9. The method of claim **8** wherein said driving fluid is selected from the group consisting of methane, natural gas, flue gas, ethane, carbon dioxide, nitrogen, air and mixtures thereof.

10. The method of claim **8** wherein said reservoir is repressured to substantially its saturation pressure by the injection of a fluid selected from the group consisting of methane, natural gas, carbon dioxide, nitrogen, air, water and mixtures thereof.

11. The method of claim **8** wherein said slug is miscible with said hydrocarbons of said reservoir.

12. The method of claim **8** wherein said driving fluid is miscible with said slug.

13. The method of claim **8** wherein said driving fluid is injected via a well extending to the upper region of said gas-oil interface.

14. The method of claim **2** wherein said first hydrocarbon fluid comprising a mixture of light constituents of hydrocarbons having from one to four carbon atoms per molecule is injected into said reservoir via said set of first perforations and said second hydrocarbon fluid comprising a mixture of heavy constituents of hydrocarbons having from three to six carbon atoms per molecule is injected via said set of second perforations.

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