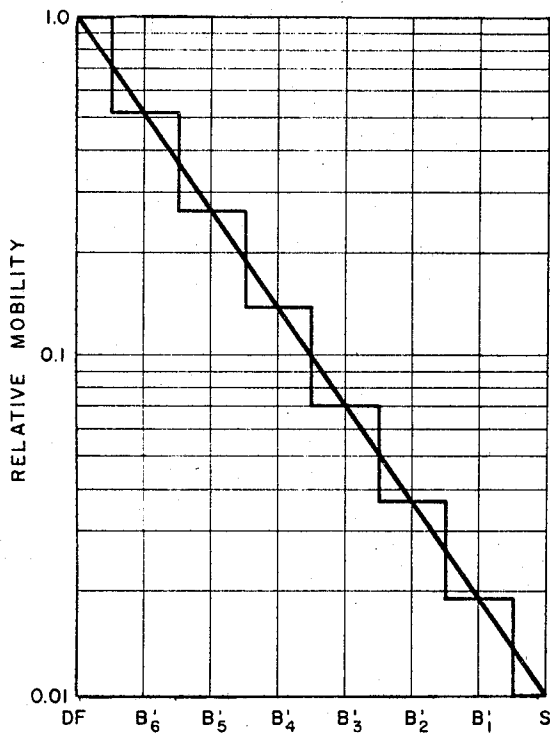
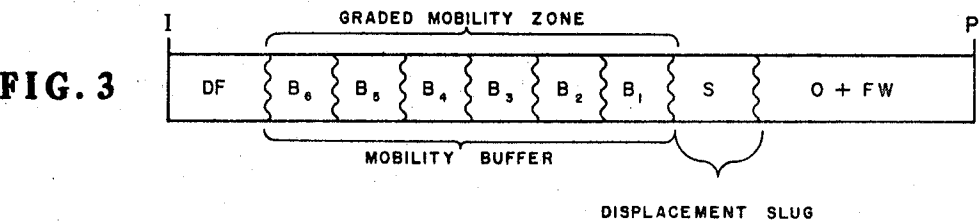
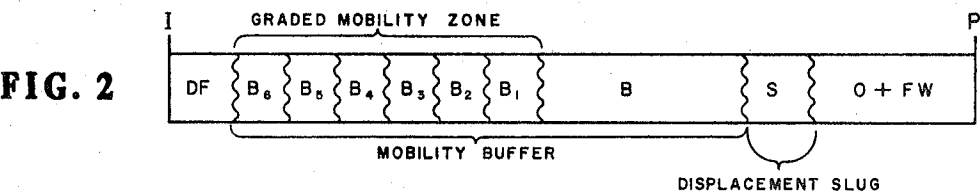
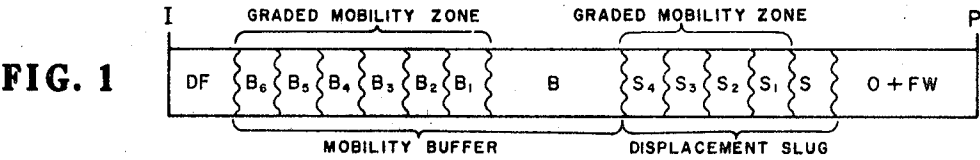


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STABILITY OF A SECONDARY-TYPE CRUDE PETROLEUM
RECOVERY SYSTEM
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STABILITY OF A SECONDARY-TYPE CRUDE PETROLEUM RECOVERY SYSTEM

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ABSTRACT OF THE DISCLOSURE

A process for improving the stability of a crude petroleum recovery process wherein crude petroleum is displaced from a subterranean formation by a displacement slug, a mobility buffer, and finally a drive fluid, the improvement being that the mobilities within at least a portion of the mobility buffer and optionally a portion of the displacement slug from the crude petroleum to the drive fluid are defined with distance by a semi-logarithmic straight-line function.

BACKGROUND OF THE INVENTION

United States Patent No. 3,261,399 to Coppel teaches an efficient oil recovery process wherein a subterranean formation is flooded with an emulsion displaced by a material having a viscosity reduced gradually from that of the emulsion to that of a subsequent water drive.

In the design of a crude petroleum recovery process wherein artificial means (i.e. other than natural displacement) are used to displace the petroleum from the formation, the mobilities of the displacing material are usually increased from a low at the displacement material and crude petroleum interface to a high at the displacement material and drive fluid juncture. Mobility is defined as the ratio of the effective permeability to the particular liquid within the formation divided by the viscosity of the particular liquid. The mobility ratio between adjacent fluids is, of course (the ratio of their respective mobilities as defined herein. In a miscible system, e.g. hydrocarbon displacing hydrocarbon, the effective permeabilities are identical and thus the mobility ratio is equal to the reciprocal of the respective viscosities. The mobility ratios between adjoining fluids, defined as the mobility of the displaced fluid divided by the mobility of the displacing fluid, dictate the relative stability of the process, i.e. as the mobility ratio decreases from 1 the degree of instability of the system increases. For example, a mobility ratio of 0.9 indicates a more stable condition than does 0.09.

A practical example of an unstable secondary recovery process is if the mobilities of the displacement material or a portion thereof are increased from front to back and defined with distance by a straight-line function—displacement at the front portion of the graded mobility zone will be more unstable than the back portion of the graded mobility zone.

Also, if the mobilities of the displacement material are based on viscosities of equal increments of the material being defined with distance by a straight-line function from a high at the crude petroleum interface to a low at the drive fluid, displacement at the back portion of the displacement material will be more unstable than the front portion. This can be illustrated, for example, by grading the displacement material from a high of 101 cps. by nine equal increments each decreased in viscosity by 10 cps. to a low of 1 cp. at the drive fluid. Assuming the process is a miscible displacement wherein the permeabilities are the same, the relative mobility will

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then be proportional to the reciprocal of the viscosity. Thus, the mobility ratio between the front portion of the displacement material and the crude petroleum will be $1/101 \div 1/91$, or 0.89, whereas the mobility ratio between the back portion of the displacement material and the drive water will be $1/11 \div 1/1$, or 0.091. Thus, the mobility ratio at the rear of the displacement material will be $0.091 \div 0.89$ or about 1/10 of that at the front of the displacement material indicating a much more unfavorable stability.

Applicants have discovered that by grading increasingly the mobilities in at least a portion of the mobility buffer and optionally a portion of the displacement slug from the crude petroleum to the drive fluid with distance by a semi-logarithmic straight-line function, that such a system will have a built-in stability and will be more stable than similar systems described above. By this method, the mobility ratios between increments of the graded zone will be equal. As a result, this system will suppress the "fingering" effect of crude petroleum recovery processes.

DESCRIPTION OF THE DRAWING

FIGURE 1 is representative of a secondary or tertiary recovery process wherein O (crude oil) and FW (formation water) are displaced through a formation by S (front portion of a displacement slug) and S_2S_4 (portions of the displacement slug having mobilities graded increasingly with distance by a semi-logarithmic straight-line function). B is part of the mobility buffer and has a mobility equal to the back portion of S_n . B_1-B_6 are the rest of the mobility buffer and their mobilities are graded increasingly with distance by a semi-logarithmic straight-line function. Preferably, the mobility ratios between B and B_1 and between B_6 and DF (drive fluid) are equal. Sufficient amounts of DF are injected into I (injection means) to displace the displacement slug and mobility buffer towards P (production means) and crude petroleum is recovered from P.

FIGURE 2 represents a preferred embodiment of the invention wherein S, B and B_1-B_6 (portions of the mobility buffer having mobilities graded increasingly with distance by a semi-logarithmic straight-line function) are displaced through the formation by sufficient amounts of DF. Preferably, the mobility ratios between B and B_1 and between B_6 and the front portion of DF are equal.

FIGURE 3 is also an embodiment of the invention wherein O and FW are displaced towards P by S followed by B_1-B_6 (having mobilities graded with distance by a semi-logarithmic straight-line function) and sufficient amounts of DF injected into I to effect the displacement. Preferably, the mobility ratios between S and B_1 and between B_6 and the front portion of DF are equal.

FIGURE 4 is a semi-logarithmic graph which illustrates the relative mobilities of the B_1-B_6 fluids within the graded mobility buffer zone of FIGURE 3. The $B'_1-B'_6$ letters represent mobility values for each particular portion of the graded mobility buffer zone. The horizontal lines on the graph are representative of the particular B' portions of the mobility buffer. As the graph illustrates, the mobility ratios between each portion of the mobility buffer including the ratios between the back portion of S and B'_1 and between the front portion of DF and B'_6 are all equal.

It is to be understood that the number of B portions and the number of S portions are relative and these numbers can be increased or decreased.

DESCRIPTION OF THE INVENTION

The displacement slug can be any material which will effectively displace all, a major portion, or an economically attractive portion of the crude oil and/or formation water. Examples of such slugs include liquefied petroleum

gases (herein defined as LPG), alcohols (e.g. isopropanol, tertiary butanol, and the amyl alcohols), aldehydes, ketones, esters, water and oil-external emulsions, water and oil-external micellar solutions, and any like fluid. These slugs can be classified as "miscible" (i.e., they reduce the interfacial tension between the crude oil and formation water and are more phase compatible with the crude oil) and "immiscible" (i.e., these slugs do not greatly affect the reduction of interfacial tension as the "miscible" slugs and are more phase compatible with the formation water).

Examples of "miscible" processes include slugs such as an oil-external micellar solution, isopropanol, and tertiary butanol, followed by a water-like mobility buffer. Where most of the crude oil but little of the formation water is displaced, the slug can be an oil-external emulsion, LPG or an oleophilic alcohol followed by a suitable mobility buffer—also, this system can be effected by an oil-external emulsion or LPG slug followed by LPG as the mobility buffer with natural gas as the drive fluid. Where desirable, the slugs may contain agents to increase their viscosities.

Examples of "immiscible" processes are those wherein the crude oil and formation water are displaced by thickened water, water-external emulsions or water-external micellar solutions. In this process, the displacement slug and the mobility buffer can be identical and utilized to immediately displace the crude oil and formation water—however, a displacement slug followed by mobility buffer can be incorporated.

Preferably, the displacement slug is a micellar solution. The term "micellar solution" as used herein is meant to include "microemulsion" [Schulman & Montagne, *Annals of the Academy of Sciences*, 92, pp. 366-371, (1961)], oleopathic hydro-micelles [Hoar and Schulman, *Nature*, 152, p. 102 (1943)], "transparent emulsion" (Blair, Jr. et al., United States Patent No. 2,356,205) and micellar solutions defined in United States Patent Nos. 3,254,714 and 3,275,075. Such micellar solutions can be generally characterized by their equilibrium tending toward further dispersion or "solubilization" of the internal phase rather than coalescence of this internal phase.

The micellar solution is composed essentially of a hydrocarbon (e.g., sweet and sour crude oils, straight-run gasoline containing lower hydrocarbon fractions equal to or greater than at least pentane and liquefied petroleum gases), an aqueous medium such as water or water-containing bactericides, corrosion inhibitors, etc., and a surfactant sufficient to impart micellar solution characteristics to the mixture. Examples of useful surfactants include alkyl aryl sulfonates, more commonly known in the art as petroleum sulfonates, or as alkyl aryl naphthenic sulfonates. Additional examples of surfactants are found in United States Patent No. 3,254,714. In addition, the micellar solution can contain a co-surfactant such as a semi-polar organic compound selected from the group consisting of alcohols, ketones, esters, amides, etc. Examples of the alcohols include those containing up to about 20 or more carbon atoms, e.g., isopropanol, n- and isobutanol, the amyl alcohols, 1- and 2-hexanol, 1- and 2-octanol and p-nonyl phenol. Electrolytes, such as inorganic acids, inorganic bases, organic bases, and inorganic and organic salts, e.g., sodium hydroxide, sodium chloride, sodium sulfate, sodium nitrate, similar alkali metal salts, etc. can also be added to the micellar solution. Also, brine, i.e. salty water, can be substituted for the water in the micellar solution.

As mentioned previously, the displacement slug is followed by a mobility buffer. The mobility buffer is a fluid having a controllable mobility and is compatible with the displacement slug and the drive fluid. One reason for the latter is to buffer the mobilities of the displaced material (i.e. crude oil and/or formation water) from the drive fluid. Another reason is to protect the rather expensive displacement slug from invasion by the highly mobile drive fluid.

The mobility buffer can be LPG, a lower molecular weight alcohol containing from one up to about 4 carbon atoms, a water-external emulsion, a water-external micellar solution, a thickened water, or any fluid acting similar to these. For displacement slugs requiring mobility buffers exhibiting water-like characteristics, the buffer preferably is composed essentially of two components, i.e., an aqueous medium such as water, and a thickening agent. Examples of thickening agents include sugars, dextrans, carboxyl methylated cellulose, amines, polymers, glycerins, alcohols, and mixtures of these agents. A particularly useful agent is a high molecular weight partially hydrolyzed polyarylamide, e.g., the Pusher products sold by Dow Chemical Company. In addition, the mobility buffer may contain a co-surfactant and/or an electrolyte, such as are identified above.

Where the mobility buffer is composed substantially of hydrocarbon, thickening agents such as high molecular weight polyisobutylene can be used to increase the viscosity.

As illustrated by the drawings, a portion of the displacement slug can have graded mobilities. Preferably, the back portion of the slug is graded. These mobilities can be graded with distance by a straight-line function, or preferably, by a semi-logarithmic straight-line function.

The mobility buffer following the displacement slug is characterized as having mobilities graded with distance by a semi-logarithmic straight-line function. For example, a 2% graded portion is useful where the mobility buffer occupies a large percent pore volume. However, 5%, 10% or larger percents are also useful and preferably the back portion of the mobility buffer is graded. All or a portion of the mobility buffer can be graded. A preferred embodiment is to have equal mobility ratios between various portions of the graded zones including the fluids contiguous to the front and back portions of the graded mobility zones (i.e., the graded portions of the displacement slug and/or the mobility buffer).

For example, from about 1% to about 15% of displacement slug can be followed by from about 10% to about 70% of the mobility buffer, percents based on pore volume. Within these ranges, up to about 75% of the displacement slug can have graded mobilities and from about 2% up to 100% of the mobility buffer can have graded mobilities. A more specific example is to have up to about 10% pore volume of a displacement slug followed by about 55% pore volume of a mobility buffer having graded mobilities within about 20% of the back portion thereof.

Normally from about 1% up to about 15% of the micellar solution is useful to effect efficient removal of the crude petroleum if such percentages are followed by 10% up to about 70% of the mobility buffer, the percents based on formation pore volume. More preferably, the amount of micellar solution can be within the range of from about 1% up to about 10% formation pore volume if the mobility buffer occupies from about 20% up to about 50% formation pore volume with the last 20% of the mobility buffer having graded mobilities as taught by this invention. However, the total amount of micellar solution and mobility buffer required will vary with the particular formation and acreage to be flooded.

The drive fluid can be natural gas, water-containing components to reduce the mobility thereof, water mixed with components to obtain characteristics desirable to the particular formation, or any like fluid. Preferably, the drive fluid is composed substantially of water and can be water containing minor amounts of salts.

It is not intended that this invention be limited by the particular displacement slugs, mobility buffers, graded mobility zones, drive fluid, etc. Rather, it is intended that all equivalents within the broad concept of this invention which are obvious to those skilled in the art be included within the scope of the invention as described herein.

What is claimed is:

1. A process for the recovery of crude petroleum from permeable subterranean formations having at least one injection means and at least one recovery means in fluid communication with said subterranean formation comprising injecting into the formation in the following order:

(1) a displacement slug,

(2) a mobility buffer characterized in that at least a portion thereof has mobilities graded increasingly from front to back with distance by a semi-logarithmic, substantially straight-line function,

(3) sufficient drive fluid to displace the displacement slug and mobility buffer toward the production means, and

recovering crude petroleum from said recovery means.

2. The process of claim 1 wherein a portion of the displacement slug is characterized as having mobilities graded with distance by a semi-logarithmic straight-line function.

3. The process of claim 1 wherein the displacement slug is a micellar solution.

4. The process of claim 1 wherein the mobility buffer is comprised of water and a thickening agent.

5. The process of claim 1 wherein the back portion of the displacement slug is characterized as having mobilities graded with distance by a semi-logarithmic straight-line function.

6. The process of claim 1 wherein substantially all of the mobility buffer is characterized as having mobilities graded with distance by a semi-logarithmic straight-line function.

7. The process of claim 1 wherein the mobility of the back portion of the mobility buffer is about equal to the mobility of the front portion of the drive fluid.

8. A process for the recovery of crude petroleum from permeable subterranean formations having at least one injection means and at least one recovery means in fluid communication with said subterranean formation comprising injecting into the formation in the following order:

(1) a displacement slug characterized in that a portion thereof has mobilities graded increasingly from front to back with distance by a semi-logarithmic substantially straight-line function,

(2) a mobility buffer characterized in that at least about 10% of the back portion has mobilities graded increasingly from front to back with distance by a semi-logarithmic straight-line function,

(3) sufficient drive fluid to displace the displacement slug and mobility buffer toward the recovery means, and

recovering crude petroleum from said recovery means.

9. The process of claim 8 wherein the mobilities of the back portion of the displacement slug and the front portion of the mobility buffer are about equal.

10. The process of claim 8 wherein the mobilities of the back portion of the mobility buffer and the front portion of the drive fluid are about equal.

11. A process for the recovery of crude petroleum from permeable subterranean formations having at least one injection means and at least one recovery means in fluid communication with said subterranean formation comprising injecting into the formation in the following order:

(1) a displacement slug,

(2) a mobility buffer characterized in that at least about 10% of the back portion has mobilities graded increasingly from front to back with distance by a semi-logarithmic, substantially straight-line function,

(3) sufficient drive fluid to displace the displacement slug and mobility buffer toward the recovery means, and

recovering crude petroleum from said recovery means.

12. The process of claim 11 wherein the mobilities of the back portion of the displacement slug and the front portion of the mobility buffer are about equal.

13. The process of claim 11 wherein the mobilities of the back portion of the mobility buffer and the front portion of the drive fluid are about equal.

14. The process of claim 11 wherein the displacement slug is a micellar solution.

15. The process of claim 11 wherein the mobility buffer is comprised of water and a thickening agent.

16. The process of claim 11 wherein the drive fluid is water.

17. A process for the recovery of crude petroleum from permeable subterranean formations having at least one injection means and at least one recovery means in fluid communication with said subterranean formation comprising injecting into the formation in the following order:

(1) a mobility buffer characterized in that at least a portion thereof has mobilities graded increasingly from front to back with distance by a semi-logarithmic, substantially straight-line function,

(2) sufficient drive fluid to displace the mobility buffer toward the production means, and

recovering crude petroleum from said recovery means.

18. The process of claim 17 wherein the mobility buffer is comprised of water and a thickening agent.

19. The process of claim 17 wherein the mobilities of the crude petroleum in the formation and the front portion of the mobility buffer are about equal.

20. The process of claim 17 wherein the mobilities of the back portion of the mobility buffer and the front portion of the drive fluid are about equal.

21. The process of claim 17 wherein substantially all of the mobility buffer is graded increasingly from front to back with distance by a semi-logarithmic straight-line function.

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