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June 29, 1965 R. E. GILCHRIST 3,191,675
RECOVERY OF OIL
Filed June 30, 1961 2 Sheets-Sheet 1

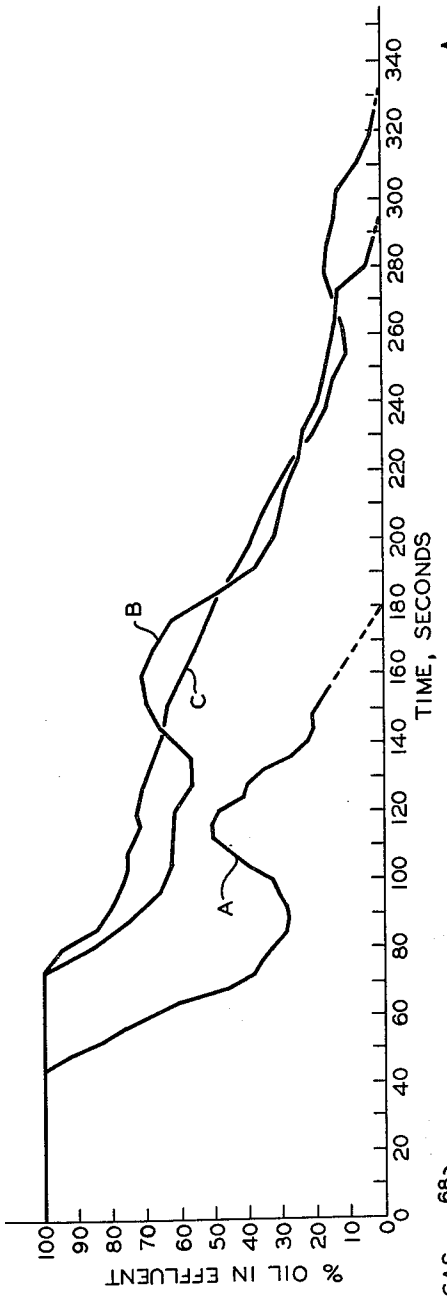


FIG. 1

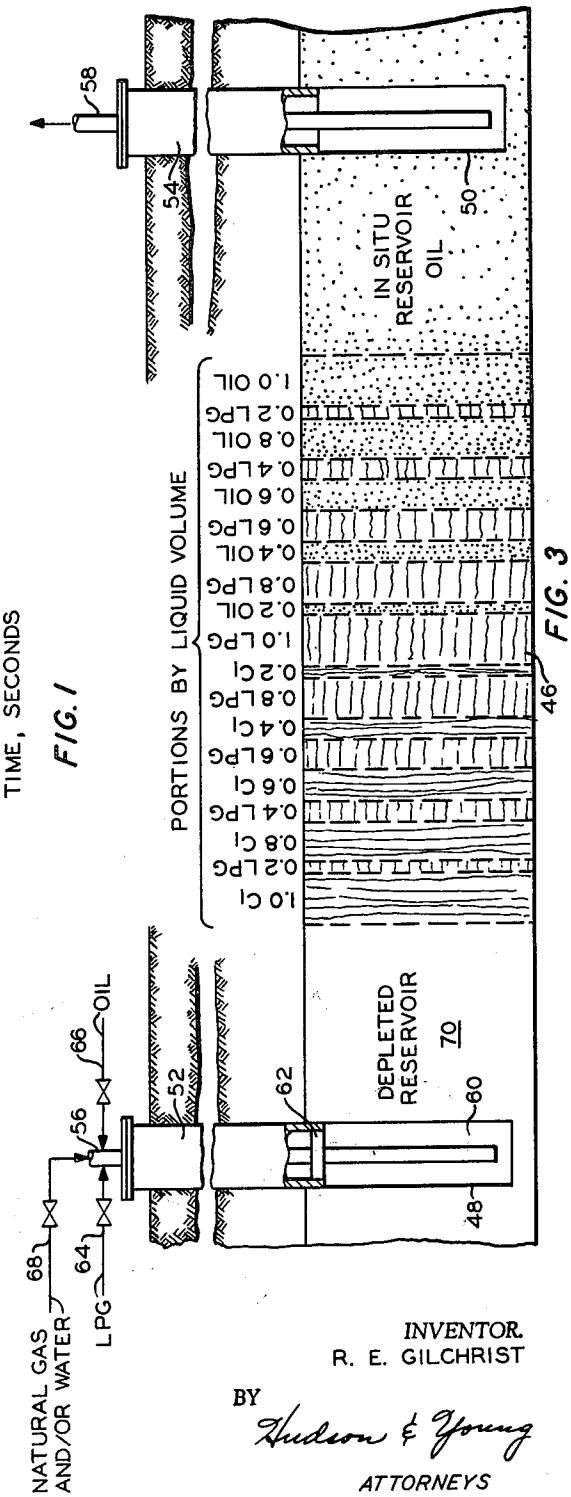


FIG. 3

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RECOVERY OF OIL

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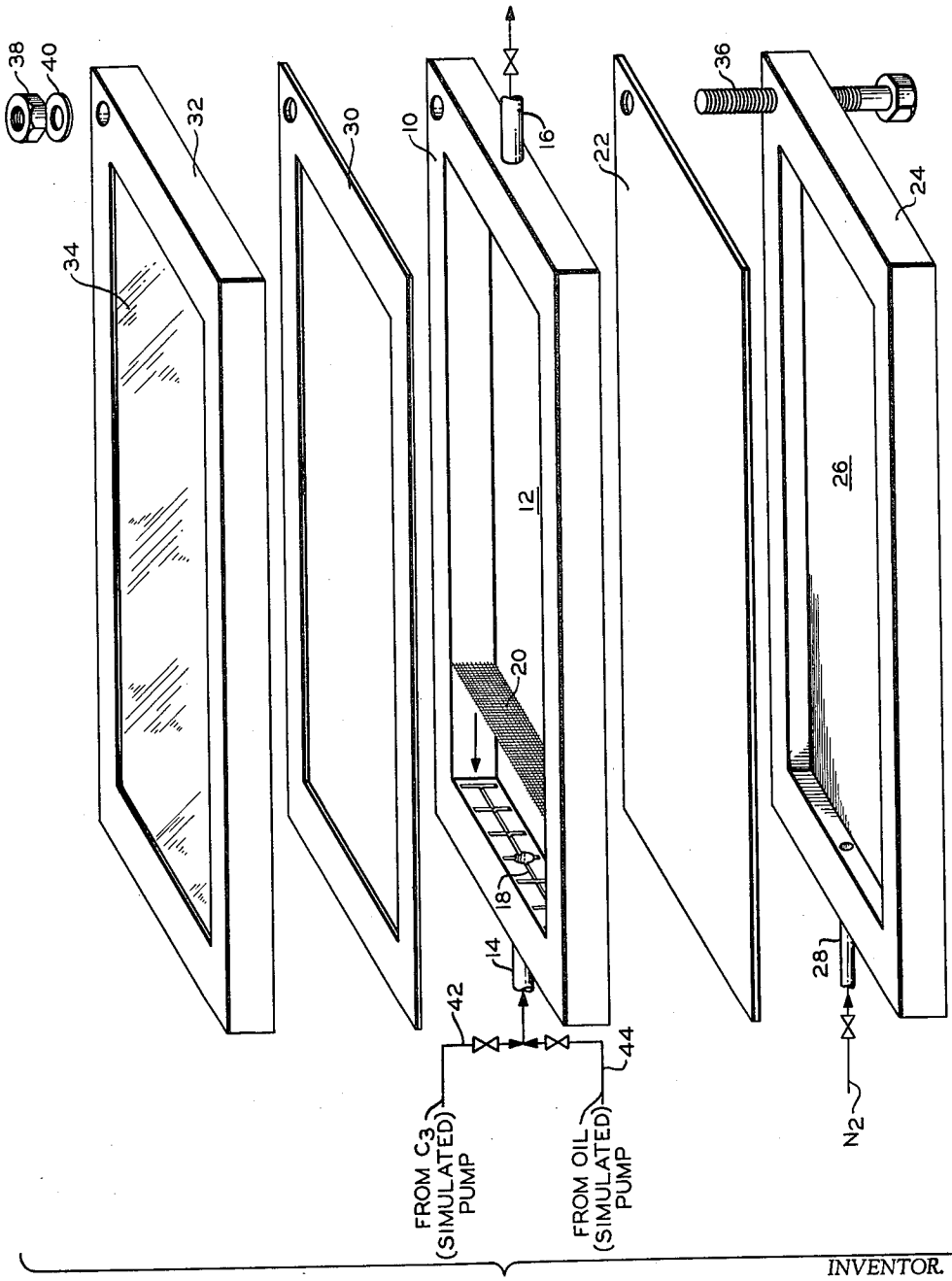


FIG. 2

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3,191,675

RECOVERY OF OIL

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13 Claims. (Cl. 166—9)

This invention relates to a process for recovering oil from an oil-bearing reservoir by miscible phase displacement. A specific aspect of the invention pertains to a method of establishing a transition zone between a viscosity reducer and the reservoir oil.

The recovery of oil by miscible phase displacement is becoming more important in the oil industry. This process involves establishing a transition zone in the reservoir between the oil and a viscosity reducer, the transition phase of the drive being forced through the reservoir by the viscosity reducer, usually with the aid of a driving fluid injected behind the viscosity reducer and transition phase. The problem of "fingering" arises when the viscosity reducer is forced thru the reservoir structure to displace and produce the reservoir oil. The term "fingering" is used to designate the flow of driving fluid (viscosity reducer) more rapidly thru certain sections of the reservoir toward the production well where it is produced prematurely. This is due at least in part to too much and too sharp a difference in viscosity between the displacing fluid and the reservoir oil. This signifies improper formation of the transition zone.

Two different methods of establishing transistion zones in miscible flooding or fluid drive processes have been practiced. One of these, illustrated in U.S. Patent 2,742,-089, involves injecting a single miscible liquid hydrocarbon slug, such as L.P.G., into the reservoir with the resultant transition zone forming some distance away from the injection well. The effect of this transition zone on production is illustrated in FIGURE 1, curve A, of the drawing referred to hereinafter. The early breakthrough plus uneven transition zone, indicates the severity of the fingering.

U.S. Patent 2,867,277 illustrates a second method of establishing a transition zone in a miscible phase displacement process. The process of this patent involves premixing the hydrocarbon fluids in variable proportions at the well head to establish a broad transition zone in the injection stream, itself, before it passes into the stratum. The effect on production by this method of establishing the transition zone is represented by curve B. It should be noted that the transition zone breakthrough occurs later than in the process of the aforesaid patent, and a longer transition zone results. However, the uneven transition zone still reflects the severity of the fingering.

This invention is concerned with a method of establishing a transition zone which is more effective in eliminating the problem of fingering and producing higher yields of oil from the reservoir.

Accordingly, it is an object of the invention to provide an improved process for producing oil from an oil-bearing reservoir, utilizing miscible fluid displacement or drive. Another object is to provide a method of establishing a transition zone between the reservoir oil and the displacing medium. A further object is to provide a process for recovering oil by miscible fluid displacement which decreases fingering. Other objects of the invention will become apparent to one skilled in the art upon consideration of the accompanying disclosure.

A broad aspect of the invention comprises establishing the transition zone between the reservoir oil and the miscible fluid used in the process by alternately injecting separate portions of heavy oil, compatible with the reservoir oil and with the miscible fluid, and miscible fluid or viscosity reducer, whereby the initial laminar flow stream of the miscible viscosity reducer and oil mixes the constituents as it is moved through the reservoir to form the transition zone of substantially gradually diminishing viscosity upstream of flow. A preferred embodiment of the invention comprises determining the volume of the miscible viscosity reducer to be injected and dividing this volume into separate portions of gradually diminishing volume and injecting these separate portions in order, from the smallest to the largest, alternately with separate gradually decreasing portions of heavy oil. The total volume of oil and viscosity reducer are preferably about the same but may vary somewhat. The heavy oil is preferably crude oil from the reservoir being produced; however, other heavy oil or crude oil from another reservoir may be utilized providing the oil is compatible with the crude of the reservoir being produced and with the viscosity reducer with which it is being associated. The term "compatible" is understood to mean that mixing of the oil with the viscosity reducer and with reservoir oil forms a solution and does not cause a precipitate.

The volume of miscible viscosity reducer to be utilized in the method or process is determined in relation to the character of the reservoir and reservoir oil to be produced. This volume usually is in the range of 0.5 to 10% of the effective pore volume of the reservoir in the displacement flow path. In reservoirs containing oil of high API gravity, greater well spacing is permissible and the volume of viscosity reducer will generally be in the lower portion of the range of pore volume given; whereas, in reservoirs containing oil of low API gravity, the volume of viscosity reducer is generally in the upper portion of the range.

Commonly used viscosity reducers comprise low boiling hydrocarbons such as C_2–C_5 hydrocarbons, L.P.G. (including principally ethane, propane and butane), kerosene, and mixtures or blends of normally liquid hydrocarbons of substantially lower viscosity than the viscosity of the reservoir oil to be produced.

After calculating the volume of viscosity reducer to be injected into the reservoir, the number of separate portions into which the total volume is to be divided is determined. This number should be infinite for the best theoretical results, but is limited by economics and practicality. Usually at least 4 or 5 portions are separately injected alternately with the heavy oil and the injection of a greater number of portions is advantageous in most reservoirs. The use of 20 or more portions of gradually increasing volume is advantageous.

A similar second transition zone is established in a similar manner between the miscible viscosity reducer and the driving fluid injected behind same when such a driving fluid is used. Natural gas or methane functions as an effective driving fluid for L.P.G., and L.P.G. functions as an effective driving fluid for heavier liquid hydrocarbons such as kerosene, Soltrol, and Stoddard solvent. The second transition zone is formed by injecting separate slugs or portions of the driving fluid alternately with separate portions of the miscible viscosity reducer in similar manner to the injection of the constituents of the first transition zone, using increasingly larger portions of driving fluid and gradually decreasing portions of viscosity reducer.

A more complete understanding of the invention may be had by reference to the accompanying schematic drawing of which FIGURE 1 is a graph showing curves obtained by plotting percent of oil in the effluent against the time in seconds for production of fluids, utilizing a simulated oil sand described hereinafter, with 3 different techniques for establishing the transition zone; FIGURE 2 is an exploded view of the apparatus used in the tests on which the graphs are based; and FIGURE 3 is a vertical

partial section through a reservoir illustrating the process and method of the invention.

In FIGURE 1, curve A illustrates the results obtained by injecting the entire slug or propane so that there is an instantaneous change from 100% oil and 0% propane to 100% propane and 0% oil, as practiced in U.S. Patent 2,742,089.

Curve B represents the results obtained when operating in accordance with U.S. Patent 2,867,277. With this method, there is a gradual change in composition from two pumps (in 5% increments), with each change being held the same number of time units (in this case 480 seconds). The mixing schedule is presented below:

Time, sec.	Propane, percent of stream	Oil, percent of stream
0	0	100
480	5	95
960	10	90
1,440	15	85
1,920	20	80
2,400	25	75
2,380	30	70
3,360	35	65
3,840	40	60
4,320	45	55
4,800	50	50
5,280	55	45
5,760	60	40
6,240	65	35
6,720	70	30
7,200	75	25
7,680	80	20
8,160	85	15
8,640	90	10
9,120	95	5
9,600	100	0
10,080		

Curve C represents operation in accordance with the invention. In this process there is a gradual change in composition from two pumps with one pump off while the other pump is running. The change in time units is the same as in the operation associated with curve B, i.e., 480 seconds. The time that each pump runs varies in 5% increments. The total rate of flow of both pumps is the same as used in connection with curves A and B. The schedule of operation of the pumps is given below:

Time, sec.	Propane, sec.	Oil, sec.
0	0	480(1.00×480)
480	24(0.05×480)	456(0.95×480)
960	48(0.10×480)	432(0.90×480)
1,440	72(0.15×480)	408(0.85×480)
1,920	96(0.20×480)	384(0.80×480)
2,400	120(0.25×480)	360(0.75×480)
2,880	144(0.30×480)	336(0.70×480)
3,360	168(0.35×480)	312(0.65×480)
3,840	192(0.40×480)	288(0.60×480)
4,320	216(0.45×480)	264(0.55×480)
4,800	240(0.50×480)	240(0.50×480)
5,280	264(0.55×480)	216(0.45×480)
5,760	288(0.60×480)	192(0.40×480)
6,240	312(0.65×480)	168(0.35×480)
6,720	336(0.70×480)	144(0.30×480)
7,200	360(0.75×480)	120(0.25×480)
7,680	384(0.80×480)	96(0.20×480)
8,160	408(0.85×480)	72(0.15×480)
8,640	432(0.90×480)	48(0.10×480)
9,120	456(0.95×480)	24(0.05×480)
9,600	480(1.00×480)	0
10,080		

FIGURE 2 shows the apparatus utilized in obtaining the data for curves A, B, and C of FIGURE 1. The device comprises a metal frame **10**, 1" in thickness and having a cutout section **12** for a sand compartment which is 3" wide and 9" long and is provided with an inlet **14** at one end and an outlet **16** at the opposite end. Both the inlet and outlet surfaces of frame **10** adjacent space **12** are provided with grooves **18** leading along the inner face of the end of the frame for distribution of fluid over the entire end and pickup of fluid over the entire opposite end adjacent outlet **16**. A screen **20** is placed over the inlet end, and a similar screen (not shown) is placed over the outlet end of the frame. Space **12** is filled with sand after placing rubber gasket **22** on top of bottom plate **24** which is provided with a space **26**, ¼" deep, for exerting pressure on the rubber gasket **22** by injecting nitrogen or other pressurizing gas into space **26** through conduit **28**. A rubber gasket **30** is placed around the top surface of plate **10** and coverplate **32** having a window **34** therein is positioned on the gasket **30**. A series of 24 bolts **36** (only one being shown), with matching nuts and washers **38** and **40**, respectively, bolt the assembly together to simulate a section of sand. Valved line **42** connects inlet **14** with the propane pump and valve line **44** connects line **14** with the oil pump. Before simulated starting of formation of the transition zone, the sand in space **12** is saturated with crude oil. The pumps are then operated in accordance with the schedules for curves A, B, and C for the different tests or runs, and the effluent in line **16** is periodically analyzed for composition to obtain oil and propane concentration. Variations in the oil concentration in the effluent clearly show the result of fingering of the miscible transition zone, particularly with respect to curves A and B. Curve C shows much less fluctuation in the oil content of the produced effluent and, therefore, less fingering of the displacing fluid and a more efficient transition zone.

Referring to FIGURE 3, an oil stratum or reservoir **46** is penetrated by an injection well **48** and a production well **50**. Wells **48** and **50** are provided with casings **52** and **54**, respectively, and with tubing strings **56** and **58**, respectively. The annulus in well **48** within reservoir **46** is packed with sand or gravel **60** and a packer **62** is set around tubing **56** in the lower end of the casing. The packing of sand or gravel **60** in the well around the tubing string assures mixing of the injected fluids within the reservoir sand face surrounding well **48**. The section of tubing **60** below packer **62** may be perforated to provide better distribution of fluids in the gravel. Also, casing **52** may extend to the bottom of the hole, being perforated below packer **62** before packing the hole.

Lines **64**, **66**, and **68** connect with tubing **56** and with suitable pumps to provide for injection of L.P.G., oil, and natural gas, respectively.

An illustration of the laminar nature of the transition zone is shown between the depleted reservoir **70** and the oil-filled reservoir intermediate the transition zone and the production well **50**. This illustration assumes that the injected constituents of the transition zone remain in their respective positions without mixing in order to better demonstrate the size and the order of the portions injected. Actually, the portions of oil and L.P.G. first injected thru well **48** begin to mix as they are forced deeper into the formation, as do the later injected portions, so that there is a substantially gradual decrease in viscosity upstream of flow in the reservoir or toward the injection well.

In the case illustrated in FIGURE 3, the total volume of the L.P.G. slug to be injected is calculated and this amount is divided into 3 units, 0.2 unit being injected as the first portion, 0.4 unit as the second portion, 0.6 unit as the third portion, 0.8 unit as the fourth portion, and 1.0 unit as the fifth portion. A similar volume of crude oil is divided into 3 units and injected in portions alternately with the L.P.G. and in reverse order of the size of the portions, beginning with the largest (1.0) and ending with the smallest (0.2). Following the injection of the crude oil and L.P.G. slugs forming the first transition zone, the methane (or natural gas) and L.P.G. slugs forming the second transition zone are injected in similar order and manner.

Variations in the technique illustrated are within the scope of the invention, it being feasible to inject slugs of propane of equal volume interspersed or alternated with oil slugs of substantially decreasing volume. It is also feasible to inject slugs of oil of equal volume and to progressively increase the volume of the injected slugs of L.P.G. The same variations apply to the formation of the second transition zone. It should be realized that

if the portions of injected fluids are extremely small, the technique really amounts to injecting the viscosity reducer and reservoir oil simultaneously at different rates, one fluid at gradually increasing rates and the other at gradually decreasing rates. With this technique, the fluids are simultaneously injected into the tubing string thru a connection or mixing chamber at the well head.

In the disclosure thus far it has been assumed that the first slug injected consists of heavy oil or crude oil from the reservoir being produced. This practice of injecting the oil, first, is advisable when the pores of the reservoir are not substantially filled with oil at the beginning of the production process. In the event the process is being applied to a virgin reservoir or to one in which the reservoir pores are substantially filled with crude, particularly around the injection well, it is feasible to inject the small slug of L.P.G. first, followed by the alternate injection of oil and L.P.G. as described hereinbefore.

Certain modifications of the invention will become apparent to those skilled in the art and the illustrative details disclosed are not to be construed as imposing unnecessary limitations on the invention.

I claim:

1. In a miscible phase displacement process for producing oil from an oil-bearing reservoir penetrated by an injection well and a production well wherein a quantity of viscosity reducer miscible with the reservoir oil is injected thru said injection well into said reservoir to establish a transition zone between the oil and said viscosity reducer and driving fluid is injected thru said injection well behind said viscosity reducer to drive same, along with oil, thru said reservoir toward said production well, the improvement comprising establishing said transition zone by injecting said quantity of viscosity reducer in separate portions alternately with separate portions of heavy oil compatible with the reservoir oil and with said viscosity reducer, said portion of viscosity reducer increasing gradually in volume from a portion less than 0.25 of the volume of the first portion of oil and the portions of oil gradually decreasing in volume until the last portion of oil is less than 0.25 of the volume of the adjacent portion of viscosity reducer.

2. The process of claim **1** wherein said viscosity reducer comprises liquid hydrocarbon of substantially lower viscosity than said reservoir oil and the injected oil is said reservoir oil.

3. The process of claim **2** wherein said hydrocarbon is liquefied gas.

4. The process of claim **1** wherein the volume of said viscosity reducer is in the range of 0.5 to 10% of the effective pore volume of the reservoir in the displacement flow path.

5. The process of claim **1** including the steps of establishing a second transition zone between said viscosity reducer and said driving fluid comprising injecting said driving fluid in separate portions alternately with additional separate portions of said viscosity reducer.

6. The process of claim **1** wherein said viscosity reducer consists essentially of liquid hydrocarbon of substantially lower viscosity than said reservoir oil, the injected oil consists essentially of reservoir oil and said driving fluid consists essentially of normally gaseous hydrocarbons.

7. The process of claim **6** wherein a second transition zone between said liquid hydrocarbon and said normally gaseous hydrocarbon is established by injecting said gaseous hydrocarbon in separate portions alternately with separate additional portions of said liquid hydrocarbon, the portions of said normally gaseous hydrocarbon increasing gradually in volume from less than 0.25 of the volume of the adjacent portion of liquid hydrocarbon and the additional portions of liquid hydrocarbon decreasing gradually in volume until the last portion thereof is less than 0.25 of the volume of the last portion of said normally gaseous hydrocarbon.

8. The process of claim **7** wherein the volume of said liquid hydrocarbon in each transition zone is in the range of 0.5 to 10% of the effective pore volume of the reservoir within the displacement flow path.

9. In the production of oil from an oil-bearing reservoir by miscible phase displacement, the method of establishing a transition zone between the reservoir oil and a viscosity reducer comprising injecting into said reservoir thru an injection well therein separate portions of said viscosity reducer alternately with separate portions of crude oil compatible with the reservoir oil and with said viscosity reducer, said portions of viscosity reducer successively increasing in volume and said portions of oil successively decreasing in volume, whereby the initial laminar flow stream of viscosity reducer and oil mixes these constituents as it is moved thru said reservoir to form a transition zone of gradually diminishing viscosity upstream of flow.

10. The method of claim **9** wherein the portions of viscosity reducer gradually increase in volume from a portion less than 0.25 of the volume of the first portion of oil and the portions of oil gradually decrease until the last portion of oil is less than 0.25 volume of the adjacent portion of viscosity reducer, the total volume of viscosity reducer being in the range of 0.5 to 10% of the effective pore volume of the reservoir in the displacement flow path.

11. In a miscible phase displacement process for producing oil from an oil-bearing reservoir penetrated by an injection well and a production well wherein a quantity of viscosity reducer miscible with the reservoir oil is injected thru said injection well into said reservoir to establish a transition zone between the oil and said viscosity reducer and driving fluid is injected thru said injection well behind said viscosity reducer to drive same, along with reservoir oil, thru said reservoir toward said production well, the improvement comprising establishing said transition zone by injecting said quantity of viscosity reducer in separate portions alternately with separate portions of heavy oil compatible with the reservoir oil and with said viscosity reducer, said separate portions of viscosity reducer successively increasing in volume and said separate portions of oil successively decreasing in volume.

12. In a miscible phase displacement process for producing oil from an oil-bearing reservoir penetrated by an injection well and a production well wherein a quantity of viscosity reducer miscible with the reservoir oil is injected thru said injection well into said reservoir to establish a transition zone between the oil and said viscosity reducer and driving fluid is injected thru said injection well behind said viscosity reducer to drive same, along with reservoir oil, thru said reservoir toward said production well, the improvement comprising establishing said transition zone by dividing said quantity of viscosity reducer into separate portions of gradually diminishing volume and injecting these separate portions in order, from the smallest to the largest, alternately with separate gradually decreasing portions of heavy oil.

13. The process of claim **12** wherein the total volumes of injected viscosity reducer and heavy oil are approximately equal.

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