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"SECONDARY VS. TERTIARY OIL RECOVERY FROM A TWO-DIMENSIONAL POROUS MEDIA BY MICROEMULSION FLOODING"

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ABSTRACT

The objective of this research was to study the application of microemulsion flooding in a visual, two-dimensional sandpack for the purpose of investigating the efficiency of oil displacement during secondary and tertiary stage. The associated variations in relative permeabilities to oleic and aqueous phases were determined.

The same ultimate oil recovery was obtained in the secondary process with one fourth of the pore volumes injected in the tertiary flooding process. Hence the injection of microemulsion solutions during the water flooding stage is much better then their injection after plain water flooding (i.e. tertiary process). The oil-water relative permeability ratio was found to be a function of the process used.

The results of this work will help plan a field test of the process, that will be more economical. The two-dimensional studies will help in the selection of a suitable pattern.

INTRODUCTION

After a successful water or gas injection project, as much as 50% of the initial oil in place remains entrapped in the pores of the reservoir rock [1]. This remaining residual oil needs a very high pressure gradient to be mobilized owing to the capillary forces needed to drive the isolated oil bubbles through the narrow necks of the porous medium [2]. To recover this residual oil under the usually applied field presure gradients, the interfacial tension between the oil and the displacing fluid must be either greatly reduced or completely eliminated. This can be done chemically by injectiing completely or partially miscible solutions in both oil and water phases. Since these solutions are usually very expensive, slugs of these solutions are driven by water. Mobility control can be achieved by injecting a buffer zone of polymers [3].

Displacement by microemulsion solutions is one of the important tertiary recovery processes by chemical solutions. This process is known in the petroleum industry by several names. Hill et al. [4], Larson et al. [5], Shah et al. [6], and Van Pollen [7] name the process as surfactant flooding. The term micellar flooding was used by Davis et al. [8], Gogarty et al. [9–12], Farouq Ali et al. [13], Gupta et al. [14], Sayyouh et al. [15] and Trushenaki et al. [16]. Based on interfacial tension criteria, Foster [17] and Bleakley [18] named the process low tension water flooding. The term microemulsion flooding was introduced by Healy et al. [19–22]. Holm [23] used the term soluble oil flooding. Bleakley [18] and Danielson [24] named the process Maraflood process. The Mara-flood process was first interoduced by Gogarty and Tosch [25].

Displacement of oil by microemulsion solutions involves the injection into the reservoir of a small volume of a solvent slug [suitable surfactant solution). Subsequently, the slug is driven by a polymer slug followed by brine. The microemulsion solutions are composed of hydrocarbons, water, a surfactant, and cosurfactant. In this manner the microemulsion slug displaces the oil and water in the reservoir more or less like a piston, and theoretically, 100% oil recovery can be obtained. However, the surfactant slug tends to dissipate in the formation through mixing or dispersion and/or adsorption [26–30].

All investigations of microemulsion flooding reported to date have been concerned with displacement of residual oil after secondary processes i.e. tertiary recovery. No studies of microemulsion flooding in the secondary stage have been conducted.

Our understanding of the mechanism by which microemulsion solutions mobilize residual oil under tertiary and secondary conditions is needed in order to design rationally for field flooding. In addition to economic considerations related to the cost of the surface active agents and polymer additives and the operational costs, the high salinity condition for some fields places some restrictions on the use of microemulsion-type flood. To ensure optimal displacement efficiency and minimum microemulsion loss, the injected microemulsion fluid should have the salinity giving minimum residual oil left. In order to prevent fingering and ensure significant tertiary oil recovery it is important that mobility control be maintained from the stable oilwater bank through the microemulsion displacing fluid to the polymer thickened drive water. Specifically mobility control means that the relative mobility of the stablized oil-water bank must be less than or equal to the relative mobility of the microemulsion slug which in turn must be less than or equal to the relative mobility of the polymer drive water.

The main objectives of this research were to perform enhanced oil displacement tests to investigate oil recovery behavior under both tertiary and secondary conditions to find the optimum economical design for both processes.

CRUDE OIL DISPLACEMENT TESTS:

The experimental apparatus used in this work is schematically shown in Figure 1. It consists of a quadrant of five-spot model which is made of transparent prespex. It is a parallelepiped having inner dismensions of 30 x 30 x 2.5 cm, and containing one injector and one producer on the same diagonal (of 8 mm inner diameter for each).

The model was packed homogeneously with a mixture composed of 20% silica powder and 80% sand whose complete analysis is given in Table 1. The vaccuum pump was used to evacuate the sandpack model.

Complete water (or brine 1% NaCl) saturation of the sandpack was obtained when two pore volumes of brine were injected and passed through the sandpack model. Porosity of the sandpacks was then measured (about 26%). The absolute permeability was calculated by measuring the flow rate of water and the pressure drop across the core by using the following equation:

$$Q = [\ 3.54\ kh\ (\ P_i - P_p\ )\ ]\ /\ \mu\ [\ r_w\ (\ d/r_w\ ) - 0.619\ ]$$

where,

Q = flow rate (bbl/day)
h = core thickness (ft)
$(P_i - P_p)$ = pressure difference between injector and producer (psi)
d = [distance between injector and producer (ft)
r_w = radius of the well (ft)
μ = viscosity (cp)
k = the sabsolute permeability (darcy)

In the secondary recovery process, initial oil was displaced by injecting the microemulsion slug. The slug was then driven by 50% PV (pore volume) polymer solution (500 ppm – Pusher 500) followed by 1% NaCl brine.

In the tertiary recovery process, initial oil was displaced by injecting two pore volumes of brine (1% NaCl. solution), until the residual oil was established. A tertiary process was started by injecting a microemulsion slug having the same size as in the secondary process. The microemulsion slug was then driven by 50% PV polymer solution (500 ppm – Pusher 500) followed by 1% NaCl brine.

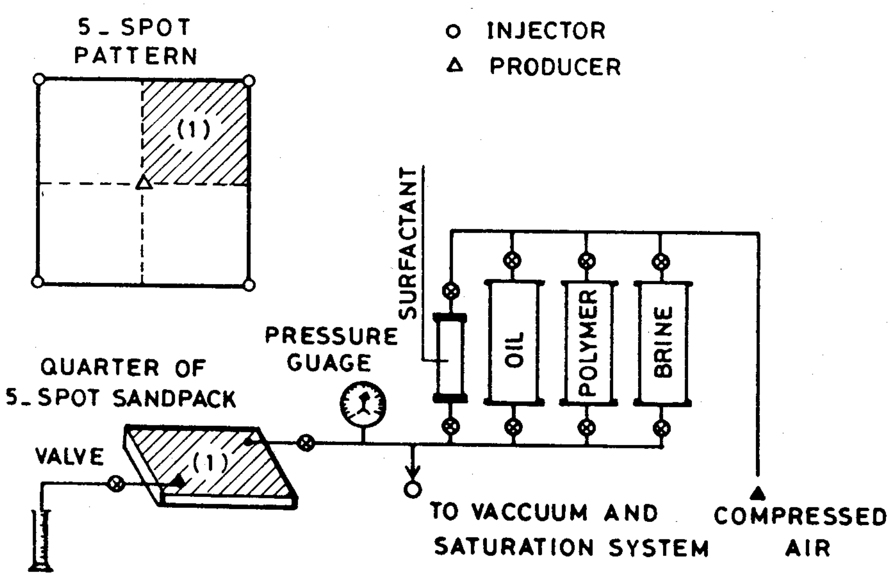

Fig. (1) : Schematic Representation of Displacement Apparatus.

DISCUSSION OF THE EXPERIMENTAL RESULTS:

Figure 2 shows the relationship between both tertiary and secondary recovery and the pore volumes of liquids injected for 5, 10 and 20% PV (sandpack pore volume) slug sizes. It is evident from this figure that for a secondary microemulsion solution flood (slug size = 5% PV), 81.0% oil recovery was obtained by injecting 1.6 pore volumes, whereas for a tertiary microemulsion flood, the same value of oil recovery was obtained by injecting 4.0 pore volumes of liquids. The distinct feature of this figure is that secondary recovery without ›using a microemulsion slug resulted in producing about 64.3% oil, which is very low as compared with the obtained value by secondary flood. Similar behavior is observed using 10 and 20% PV slug sizes as seen from the same figure, the only difference being that the same oil recovery value was obtained at 1.2 pore volumes in secondary microemulsion flood and 4.0 pore volumes in tertiary microemulsion flood.

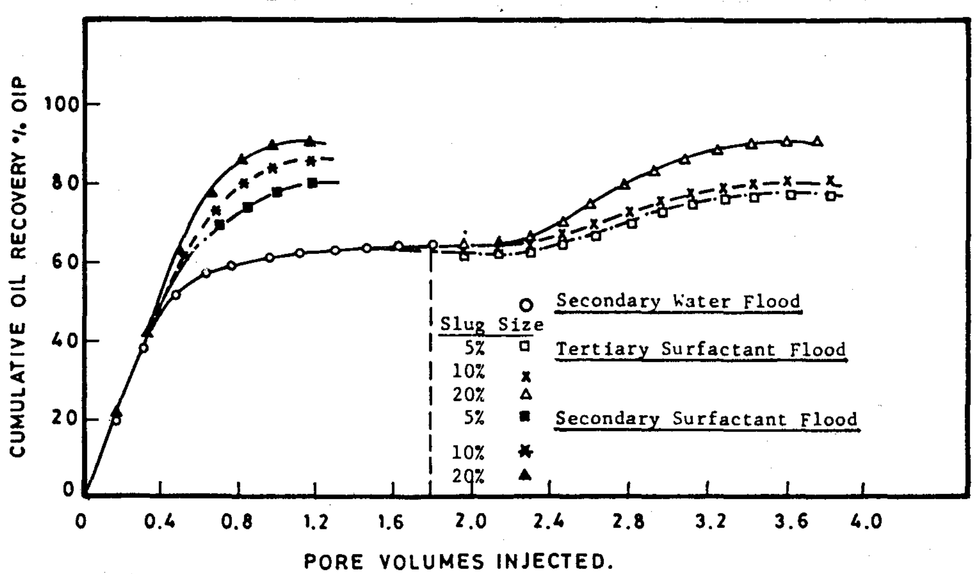

Fig. (2) : Cumulative Oil Recovery and Pore Volumes Injected.

In the oil displacement by microemulsion slug in secondary and tertiary process, the above results show that (i) although the same results were obtained, the pore volumes injected in the secondary process were one fourth the pore volumes injected in the tertiary process and this is very valuable in evaluating the two processes economically; and (ii) the oil-water bank is more stabilized in the secondary slug process, and this which implies a favorable mobility ratio.

These results provide important information on the behavior and mechanistic features of the different processes. From the economical point of view, it can be said that for a given slug size the injection of a microemulsion slug during secondary recovery is better than its injection during the tertiary recovery process. This means that when an engineer plans to apply a microemulsion slug to produce oil from any reservoir suitable for EOR process, it is more economical to inject the slug during the secondary stage.

MEASUREMENT OF RELATIVE PERMEABILITY IN MICROEMULSION SECONDARY AND TERTIARY DISPLACEMENT PROCESSES:

Relative permeability calculations were made for aqueous and oleic phases. The data from displacement tests were used to calculate relative permeability ratios of oleic and aqueous phases by Welge technique [30].

Effect of microemulsion slug size on oil/water relative permeability ratio in the secondary flood was calculated and plotted in Figure 3. As expected, increasing slug size increases the relative permeability ratio. This means higher oil flow for higher slug size. Figure 4, is for the change of relative permeability ratio during the teriary microemulsion-polymer floods for all the slug sizes used. In the initial time period only water is produced. During this period the stabilized oil-water bank propagates through the porous medium, and the oil-water relative permeability ratio decreases as indicated by the dashed line shown in Figure 4. At break through, production of both oil and water at a more less constant ratio starts. When the stabilized oil-water bank breaks out of the core, the oil cut jumps from zero to a higher value, and thereafter, in most of the tests, the k_{rw}/k_{ro} increases with increasing water saturation. This behavior was the same for all slug sizes used (5, 10 and 20% pore volumes). Also, it is clear from Figure 4 that increasing the slug size improves k_{ro}/k_{rw} in the tertiary process. Tertiary relative permeability vs secondary relative permeabilities is shown in Figure 3. This figure shows that, oil-water relative permeability ratios are much higher in the case of injecting the microemulsion slug during the secondary process than in tertiary process for all slug sizes used.

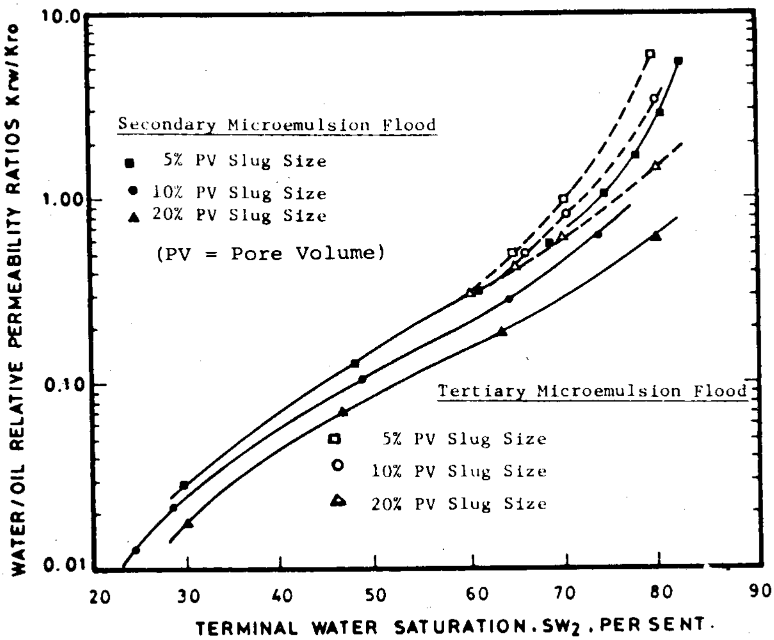

Fig. (3) : Water/Oil Relative Permeability Ratios Versus Terminal Water Saturation.

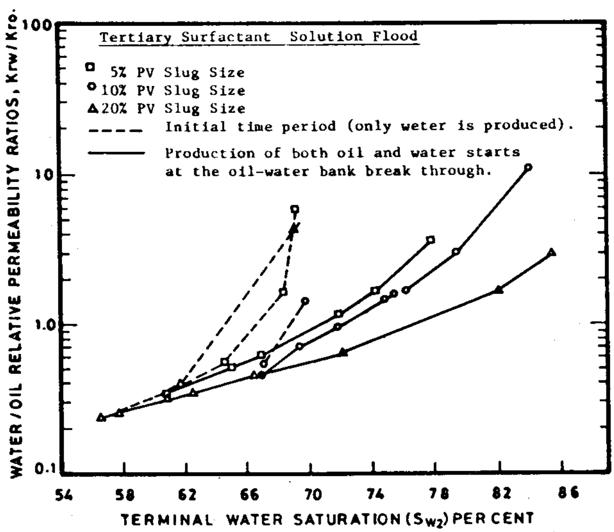

Fig. (4) : Water/Oil Relative Permeability Ratios Versus Terminal Water Saturation.

MEASUREMENT OF WATER-CUT (F_w) IN EFFLUENT:

Water-cut ratios (F_w) in effluent were calculated. Figures 5 and 6 show the water-cut (F_w) versus terminal water saturation (S_w) for all runs. Effect of microemulsion solution slug size on F_w in secondary flood is shown in Figure 5. Increasing slug size decreases F_w. This means, as indicated before, higher expected oil recovery for higher slug size. Figure 6 is for the change of water-cut during the tertiary flood by different slug sizes. Water cut decreases as slug size increases which means that oil recovery increases as slug size increases. In general, these conclusions agree, completely with that of oil/water relative permeability ratios.

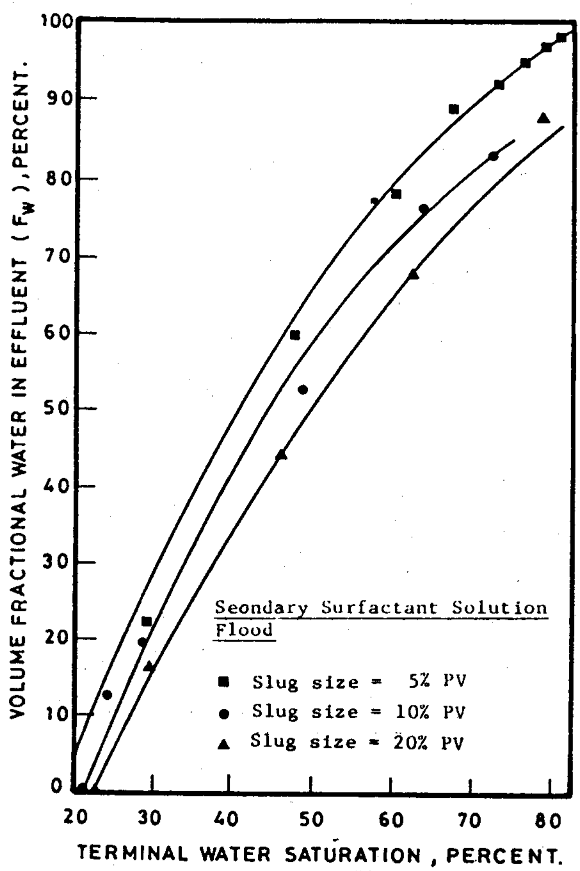

Fig. (5) : Water-Cut Cersus Terminal Water Saturation for Secondary Surfactant Flood.

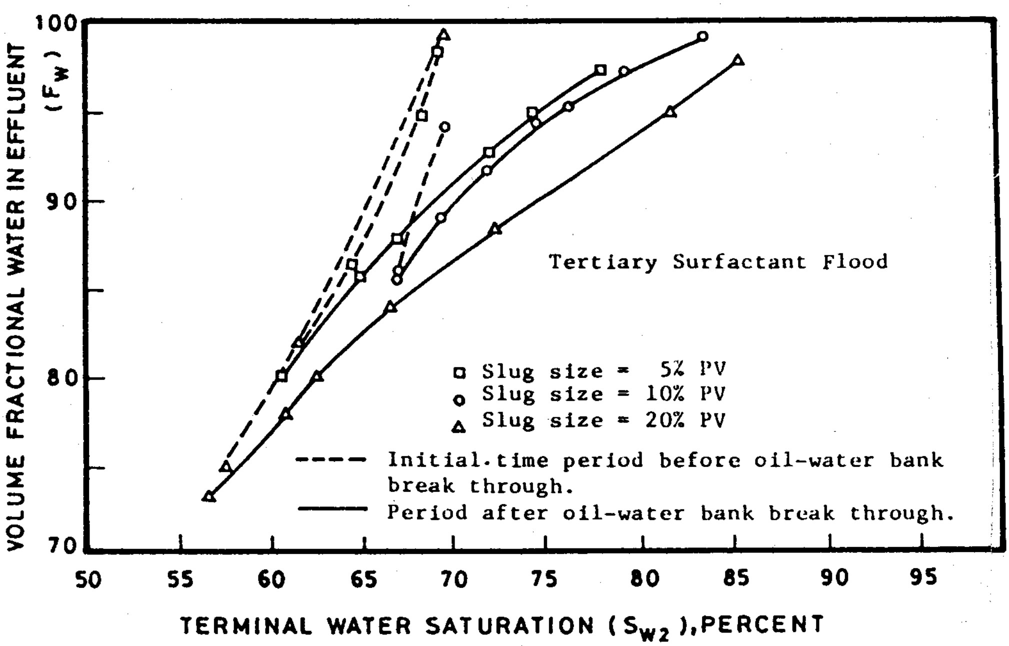

Fig. (6) : **Water-Cut in Effluent Versus Terminal Water Saturation Tertiary Surfactant Flood.**

SUMMARY AND CONCLUSIONS:

The objective of this research was to investigate the displacement process under secondary and tertiary conditions by microemulsion solutions. This study consisted in carrying out tertiary and secondary displacements in a quadrant of five-spot sandpack model of 30 x 30 x 2.5 cm, using the designed microemulsion solution, the slug sizes being 5, 10 and 20% PV.

Based on the displacement runs made, it was found that:

1. Increasing microemulsion slug size increases oil recovery, in both secondary and tertiary process. Oil recovery shows a small increase with further increase in slug size.

2. For a secondary microemulsion flood (for all slug sizes) ultimate oil recovery was obtained by injecting about 1.5 pore volumes of fluids, whereas for a tertiary surfactant process, the same ultimate recovery was obtained by injecting about 4.0 pore volumes of fluids.

3. The oil-water bank is more stabilized in secondary microemulsion slug processes which implies a favorable mobility.

4. Water/oil relative permeability ratio decreased when microemulsion slug size increased. Injection of microemulsion slug during the secondary stage increases the oil-water relative permeability ratio and hence improving the displacement efficiency.

Table (1) : Size Analysis of the Used Sand*

Mesh size of the sieve	Wt. of the sand retained on the the sieve	Wt. % of the sand retained	Mesh diameter (mm)	Cummulative wt. %
30	33.7	10.4	0.59	10.4
40	62.9	19.4	0.42	29.8
50	118.3	36.4	0.297	66.2
60	33.7	10.4	0.25	76.6
100	58.2	17.9	0.149	94.5
—	18.0	5.5	Less than 0.149	100.0

The mixture used was as follows :

80 % sand*

20 % silica powder (or flour) obtained by crushing sand grains

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