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Surfactant - Polymer Interaction for Improved Oil Recovery

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"SURFACTANT - POLYMER INTERACTION FOR IMPROVED OIL RECOVERY"

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"SURFACTANT - POLYMER INTERACTION FOR IMPROVED OIL RECOVERY"

INTRODUCTION

The primary and secondary oil recovery methods only recovered between 30 and 40 % of the oil in place. The rest is left in the reservoir. This untouched reserved creates a target of approximately 280 billion barrels of oil. Tertiary oil methods are required to recover part of this oil. Several methods are not economically feasible under the present market conditions. New research is needed, especially in chemical flooding methods, to reduce the operation cost. The two main forces that oppose oil recovery are, capillary and viscous forces. These "resistances" to the oil recovery can be overcome by polymer flooding methods that improve areal sweep by mobility reduction and surfactant methods that reduce the influence of capillary forces and also improve mobility control.

A vast amount of proven domestic oil deposit is stranded in reservoirs too shallow for miscible flooding, yet this oil is too light for thermal techniques. Surfactant-polymer flooding is the only method to unlock this vast resource. The integrity of the surfactant slug is critical to the economic success of a surfactant-polymer flood.

The goal of the proposed research is to use the interaction between a surfactant and a polymer for efficient displacement of tertiary oil by improving slug integrity, adsorption and mobility control. Surfactant - polymer flooding has been shown to be highly effective in laboratory-scale linear floods. Field tests have demonstrated that preflushes to remove excessive salinity are mostly ineffective and both surfactant and polymers need to be compatible with the reservoir brine. It has also been shown that the effective and timely oil recovery from surfactant - polymer field tests correlates well with maintaining good integrity of both surfactant slug and polymer buffer during passage through the reservoir. Surfactant slugs break down in the reservoirs due to adsorption, phase trapping, dispersion, and viscous/heterogeneity fingering. The mobility ratio across surfactant - oil bank flood front is often unfavorable, but can be stabilized by the addition of polymers. The focus of this proposal is to **design an inexpensive surfactant-polymer mixture that can efficiently recover tertiary oil** by avoiding surfactant slug degradation, high adsorption and viscous/heterogeneity fingering.

The strategy of the proposed research is to use a scaled physical areal model to **monitor surfactant - polymer slug movement** in well-defined laboratory-scale surfactant-polymer floods. Suitable surfactant and polymer systems will be identified

from phase behavior and coreflood experiments. Polymers and surfactant concentrations will be varied and the stability of the surfactant movement will be measured in the scaled physical areal model. **Vertical and horizontal injection** will be studied. The scaled model, fluids and all rock-fluid properties will be adequately characterized. Mechanistic simulations will be made to capture the mechanisms of fluid flow. This simulations will be used for process scale-up and optimization. The proposed research will supply experimental data and mechanistic principles for optimum surfactant-polymer slug design.

This project will be carried out by a team involving, Dr. Kishore Mohanty from the University of Houston (UH), Dr. Jorge Gabitto from Prairie View A&M University (PVAMU) and an industrial partner, BDM Petroleum Technologies (BDM-PT). Dr. Mohanty will perform the experimental work at UH; Dr. Gabitto will conduct numerical simulation and theoretical studies; and BDM-PT will perform experiments and provide data concerning the selection of a suitable oil-surfactant-polymer system to be used in the experiments and numerical simulations.

EXPERIMENTAL PROGRAM

The strategy consists of experimentally observing movements of surfactant - oil bank flood fronts in well-characterized cores and quarter 5-spot model, developing mechanistic simulation for their movements and using the mechanistic simulation for field scale-up and optimization. The displacement in a low heterogeneity core will be one-dimensional when appropriate flow rate is used. The results of these experiments should provide the mobility of all the fluid banks and help conform the mechanistic model in one-dimension. The floods in a quarter 5-spot model will provide experimental data on movement of surfactant-oil bank in multi-dimensions. In some cases, surfactant-oil bank front will be stable and in some, it will be unstable. The effect of surfactant slug composition on movement of this front will be studied.

The corefloods will be conducted with three types of chemical systems: (1) alcohols, (2) surfactants without polymers and (3) surfactants with polymers. Alcohol systems are analogous to surfactants systems, but are easier to study because of low adsorptions and simpler phase behavior. Alcohol systems will be used to validate the numerical models in the absence of adsorption and complex phase trapping. Surfactant systems with and without polymers will be used to study the effect of polymers. Polymer and surfactant concentrations will be varied to study the effect of surfactant composition on the nature of displacement.

The research group at BDM-PT will select reservoir fluids and surfactant and polymer formulations to study chemical IOR system transport in the 1/4 5-spot pattern porous media model. The idea is to design a low-tension surfactant/polymer chemical system that:

- 1) maintain good integrity of both surfactant slug and polymer buffer during oil recovery,
- 2) try to overcome adverse effects such as phase trapping, dispersion, and viscous/heterogeneity fingering,
- 3) provide data for simulation studies of oil movement during chemical IOR studies.

Fluid evaluation techniques include phase behavior studies, interfacial tension measurements, and viscosity measurements.

The quarter 5 spot model characteristics are listed in Table I. In order to prepare the equipment for the experiments several runs using water and a typical oil were done. Values of the fluids physical properties are listed in Table II. The quarter 5 spots model was filled with glass beads with a diameter range between 0.706 - 0.15 mm. The average packing diameter was 0.419 mm

TABLE I. QUARTER 5 -SPOT CHARACTERISTICS

Thickness (m)	0.0254
Width (m)	0.419
Area (m ²)	1754.8
Pore Volume (ml)	1630
Porosity	0.365
Permeability (darcys)	15

TABLE II. IMMISCIBLES DISPLACEMENTS

Displacement	Drainage	Imbibition
Displacing fluid	Oil 1	Water 1
ρ (g/cc)	0.747	1
μ (cp)	1.3	1
Displaced fluid	Water 2	0.419
ρ (g/cc)	1.21	0.869
μ (cp)	60.1	62.5
$\Delta\rho$ (gm/cc)	0.463	-0.131
Viscosity ratio	46	62.5
Initial Sw	1	0.155
End point Mobility Ratio	25	64
Average Mobility Ratio	2.3	3
Breakthrough (% PV)	0.2	3
Recovery (% PV) at 1 PV injection	20	30

The experimental procedure involved the following steps:

- 1). Fill quarter 5-spot with water
- 2). Displace using glycerol-water
- 3). Displace using light oil (drainage)
- 4). Inject a heavy oil up to residual water saturation
- 5). Inject low viscosity water (imbibition).

Figures 1 and 2 show some typical results. Steady-state relative permeability curves are shown in Fig. 1. These experiments involved a primary drainage, a primary imbibition and a secondary drainage. Typical recovery results are shown in Fig. 2 for unstable immiscible displacements.

Fig. 1- Steady-state relative permeability of the porous media.

Fig. 2- Recovery of the displaced fluid in unstable immiscible displacements.

THEORETICAL PROGRAM

The theoretical program involves two different goals: First, we want to be able to simulate the UH experiments in order to understand the different mechanisms involved. Second, we would like to study the stability of the system to fingering in order to provide practitioners with tools to design surfactant-polymer processes with improved recovery.

Two different computer codes will be used in the numerical simulations, UTCHEM, a chemical flooding simulator developed at the University of Texas at Austin and a custom made simulator. The custom made simulator will be used primarily to study the fingering aspects related to stability while UTCHEM will be used to simulate the process itself. The input data for the simulations will be provided by the UH and by the BDM-PT research groups. A brief description of the custom made simulator including some preliminary results are shown below.

Custom Made Simulator

An IMPES like formulation was used in order to solve the required flow equations for a wetting (w) and a non-wetting (nw) phase. The flow equations are shown below.

$$\frac{\partial}{\partial t}(\phi S_k) = \nabla \cdot [\lambda_k \nabla \Phi_k] + Q_k, k = w, nw \quad (1)$$

S_k is the phase saturation, λ_k is the phase mobility, Q_k is the rate of injection of phase k into the system. We use the fact that the saturations are related through

$$S_w + S_{nw} = 1 \quad (2),$$

and the capillary pressure is defined by,

$$P_{cwnw} = P_{nw} - P_w \quad (3).$$

The gravity potential is defined by,

$$\Phi_k = p_k - \gamma_k d, k = w, nw \quad (4).$$

The simulator is still under validation against analytical and other numerical solutions obtained from the BEST-GEL simulator. Typical velocity and saturation contours are shown in Figs. 3 and 4. The results represent water flooding of an oil saturated porous media. Water is injected at the upper left corner and a production well is located at the lower right corner. Figs. 3 and 4 represent results at breakthrough.

Fig. 3. Water velocity contour at breakthrough.

Fig. 4. Water saturation contour at breakthrough.

Stability Analysis in 2-D

The goal of this task is to determine stability ranges for the main physical properties. This information can then be used in designing optimal surfactant-polymer sweeps. The system is described by eqns. (1). We introduced a transformation that leads to,

$$\nabla \cdot [M \nabla P] + \nabla \cdot [M \nabla R] + Q_w + Q_{nw} = 0 \quad (5), \text{ and}$$

$$-2 \frac{\partial}{\partial t} (\phi S_k) = \nabla \cdot [N \nabla P] + \nabla \cdot [M \nabla R] + Q_{nw} - Q_w \quad (6),$$

where $P = \{ \Phi_{nw} + \Phi_w \}/2$ and $R = \{ \Phi_{nw} - \Phi_w \}/2$.

The derivation procedure involves defining perturbations to P and R given by,

$$P^* = P(x,y,t) + \varepsilon G(x,y,t-tp), \text{ and } R^*(x,y,t) + \varepsilon H(x,y,t-tp) \quad (7).$$

Eqns. (7) are introduced into (5) and (6) to yield,

$$\Lambda_1 H_x + B_1 \nabla^2 H + C_1 G_x + D_1 \nabla^2 G + E_1 G = 0 \quad (8)$$

$$\frac{\partial G}{\partial t} = A_2 H_x + B_2 \nabla^2 H + C_2 G_x + D_2 \nabla^2 G + E_2 G \quad (9),$$

where the letter coefficients are functions of the system properties.

We proposed a Fourier series solutions for H and G given by,

$$H = H_0 \exp[\alpha (t - tp)] \sum_{j=1}^{\infty} \exp[i (\frac{j \pi x}{L_x})] \sum_{k=1}^{\infty} \exp[i (\frac{j \pi y}{L_y})] \quad (10),$$

$$G = G_0 \exp[\beta (t - tp)] \sum_{j=1}^{\infty} \exp[i (\frac{j \pi x}{L_x})] \sum_{k=1}^{\infty} \exp[i (\frac{j \pi y}{L_y})] \quad (11).$$

Eqns. (10) and (11) are introduced into (8) and (9) and system of equations results which depends upon α , β . The growth or decay of the perturbations is analyzed through the sign of α and β . α , $\beta < 0$ implies stability.

The analysis is repeated for different values of physical properties that will change the values of the letter coefficients in eqns. (8) and (9). Maps involving the different stability regions then can be prepared in this way.

Conclusions

The property selection task is in under way. The experimental equipment is ready to be used. Once the surfactant-polymer system has been selected experiments can start immediately. A custom made simulator has been developed. Validation of this simulator

is under way. A commercial simulator (UTCHEM) has been obtained. A graduate student is presently being trained in the use of the simulator. The equations for stability analysis have been derived and a computer code is being written to implement the procedure described above.

FUTURE WORK

Future work will involve the following steps:

- 1). Completion of experimental program including WAG experiments
- 2). Complete numerical simulations using custom made simulator
- 3). Numerical simulations using UTCHEM
- 4). Stability analysis for 2 and 3 - D
- 5). Phase maps for physical properties parameter ranges