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Simultaneous HPAM/SDS Injection in Heterogeneous/Layered Models

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Abstract**—**Although lots of experiments have been done in enhanced oil recovery, the number of experiments which consider the effects of local and global heterogeneity on efficiency of enhanced oil recovery based on the polymer-surfactant flooding is low and rarely done. In this research, we have done numerous experiments of water flooding and polymer-surfactant flooding on a five spot glass micromodel in different conditions such as different positions of layers. In these experiments, five different micromodels with three different pore structures are designed. Three models with different layer orientation, one homogenous model and one heterogeneous model are designed. In order to import the effect of heterogeneity of porous media, three types of pore structures are distributed accidentally and with equal ratio throughout heterogeneous micromodel network according to random normal distribution. The results show that maximum EOR recovery factor will happen in a situation where the layers are orthogonal to the path of mainstream and the minimum EOR recovery factor will happen in a situation where the model is heterogeneous. This experiments show that in polymer-surfactant flooding, with increase of angles of layers the EOR recovery factor will increase and this recovery factor is strongly affected by local heterogeneity around the injection zone.

Keywords**—**Layered Reservoir, Micromodel, Local Heterogeneity, Polymer-Surfactant Flooding, Enhanced Oil Recovery.

I. Introduction

AFTER flooding the reservoir with water, due to capillary forces, oil will remain in reservoir as oil drops which sometimes will reach 70% of initial oil in place. The low recovery of oil by water flooding is due to significant difference between oil and water viscosity and heterogeneity of reservoir [1].

Despite of mobility ratio, capillary forces will reduce oil production. In order to consider these forces, capillary number is used. In flooding, capillary number is the ratio of viscous to capillary forces which varies from 10^{-7} to 10^{-8}. The amount of remaining oil corresponding to this range is between 30 to 40% [2]. The maximum amount of oil recovered from viscous oil reservoirs equals 20% which shows the importance of EOR methods to increase the recovery. Recently, tertiary oil extraction technologies are widely developed. One of these methods is Polymer flooding. The main purpose of this method is to increase the sweep efficiency in order to reduce the remaining oil saturation and the mobility ratio. Through this method it is possible to enhance oil recovery up to 20% of initial oil in place.

The main concept is the effect of polymer flooding on the sweep efficiency. Sweep efficiency is defined as the ratio of oil volume contacted by displacing agent to initial volume of oil in place. Sweep efficiency is influenced by mobility ratio, pore structure, reservoir rock wettability, reservoir heterogeneity and properties of fractures [3].

In 1982, Argabright et al. showed that hydrolyzed solution of polyacrylamide enhanced oil recovery by controlling the water mobility and increasing the sweep efficiency due to increasing the water viscosity and reducing its relative permeability as well [4]. Generally, polymer solution increases oil recovery in three ways: (1) by affecting fractional flow, (2) by reduction of water-oil mobility ratio, (3) by diversion of injected water toward swept zones [5].

In order to enhance water flooding, aqueous polymers are used to increase water viscosity, the higher molecular weight of polymers the higher water viscosity. Also, some polymers reduce water relative permeability without affecting oil relative permeability. These effects increase the efficiency of injected water [6], [7]. In 2007, Tabary and Bazin showed that after water flooding, 50-70% oil remained in the reservoir and this amount could be reduced by injection of hydrolyzed polyacrylamide (HPAM) as tertiary recovery [8]. However, they did not investigate the effect of other polymer types on recovery efficiency.

One of the most simple and inexpensive EOR methods is dilute surfactant flooding. Decrease in capillary forces, that is the main reason of oil trapping, is the essential concept in this method of EOR. The combination of polymer and surfactant,

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Polymer-Surfactant (PS) flooding increases oil recovery considerably.

Emami Meybodi et al. have done many works on this type of chemical EOR. They were the first ones who investigated many roles during polymer flooding in layered reservoirs [9]. In this work we investigate the role of heterogeneity and layer orientation during Polymer-Surfactant Flooding in layered/heterogeneous reservoirs using micromodel apparatus.

II. Experimental

The micromodel setup was used in this research. Fig. 1 is a schematic diagram of the experimental setup [10]

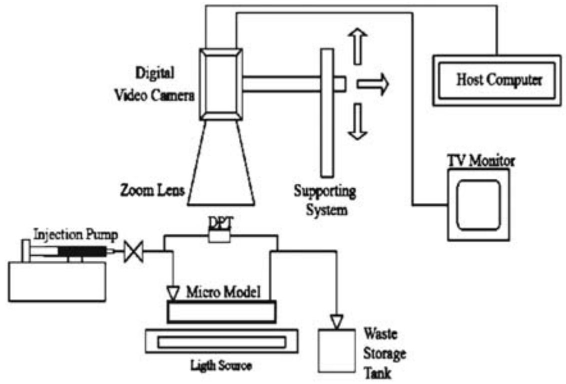

Fig. 1 Schematic diagram of displacement experimental model

A. Micromodels

As it is obvious in Fig. 2, for showing heterogeneity of porous media, three different pore structures are used. These entire pore structures have the same pore size diameters but the opening diameters differ.

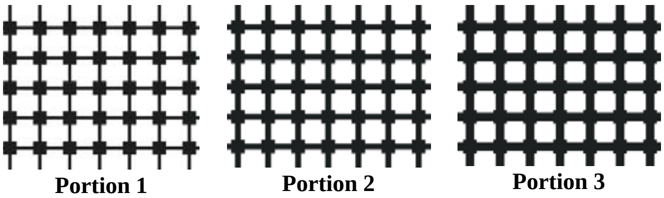

Fig. 2 Three kind of pore morphology having different aspect ratios

TABLE I

Glass Type Micromodel Physical and Hydraulic Properties

Micromodel	A	B	C	D	E
Length(mm)	60	60	60.2	60.15	60.1
Width(mm)	60	60	60.1	60.2	60.2
Average Etch Depth(mm)	0.095	0.09	0.1	0.095	1.05
Coordinate Number	4	4	4	4	4
Aspect Ratio	2.35	2.35 4.44 1.60	2.35 4.44 1.60	2.35 4.44 1.60	1.60- 2.35
Number of Pore	1156	1156	1156	1156	1156
Number of Grain	1087	1087	1087	1087	1087
1 PV (cm3)	0.149	0.149	0.154	0.154	0.167
Porosity (%)	43.4	45.9	42.8	44.9	44.1
Absolute Permeability (D)	2.73	2.05 2.81 3.52	2.21 2.99 3.67	2.01 2.88 3.41	1.76- 3.51

B. Test Fluids

The oil used in this experiment is a heavy and dead oil of an Iranian Oil field which has API degree of 16 in 25ºC. HPAM with 30% of hydrolysis, at the concentration of 1200ppm and SDS in 2000 ppm are consequently used as the polymer and surfactant types.

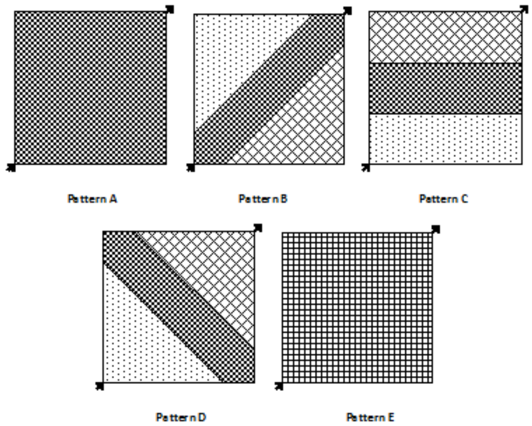

Fig. 3 Different patterns designed for micromodel experiments

III. Procedure

The micromodel is cleaned by toluene and distilled water. Prepared micromodels are saturated by crude oil. All experiments are done in a water wet porous media and in ambience temperature and horizontal state. “A” and “E” patterns are used for studying effect of heterogeneity and “B”, “C” and “D” patterns are used for studying the effect of layer heterogeneity of porous media. Operation of Polymer-Surfactant and water flooding on crude oil in homo- and heterogeneous environments are measured and compared.

TABLE II
EXPERIMENTAL DATA RELATED TO ALL RUNS IN WATER AND POLYMER-SURFACTANT FLOODING

Test No.	Temperature (°C)	Pattern Type (Injection Port)	Fluid Type
1	21.5	{A}	Brine
2	22	{B}	Brine
3	21.4	{C} (from high-perm layer)	Brine
4	21.1	{C} (from low-perm layer)	Brine
5	21.5	{D} (from high-perm layer)	Brine
6	22.1	{D} (from high-perm layer)	Brine
7	21	{E}(Injection from port A)	Brine
8	21.1	{E}(Injection from port B)	Brine
9	21	{A}	PS
10	21.6	{B}	PS
11	21.5	{C} (from high-perm layer)	PS
12	21.8	{C} (from low-perm layer)	PS
13	22	{D} (from high-perm layer)	PS
14	21.1	{D} (from high-perm layer)	PS
15	21.3	{E}(Injection from port A)	PS
16	22.1	{E}(Injection from port B)	PS

IV. RESULTS AND DISCUSSION

A. Role of Heterogeneity

The heterogeneous pattern E is generated by different throat diameter sizes where randomly are speared through the model. But in homogenous model all through sizes are the same.

Figs. 4, 5 show the recovery of both homogenous and heterogeneous models with time where are scaled in order of pore volume injection. Note that there are two cases where are tested in heterogeneous model because the model is generated randomly, injection from each port is a specific case.

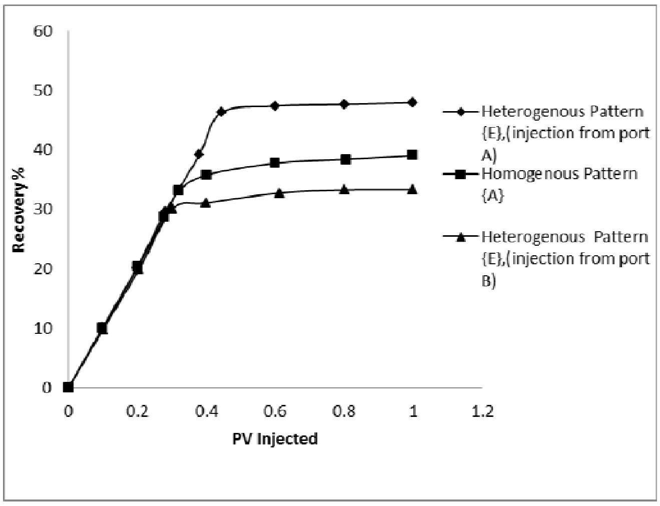

Fig. 4 Water flooding in homogeneous and heterogeneous porous medium (patterns {A} and {E})

As all this graphs show, oil recovery of Polymer-Surfactant flooding is much higher than water flooding. The reason is the effect of polymer which increases mobility ratio by increasing viscosity and surfactant reduces IFT. As this figure shows, the oil recovery of heterogonous model will be higher or lower from the homogenous one. It means that recovery is very depended to local heterogeneity near the injection zone. Thus selection of injection port is an important parameter in chemical flooding.

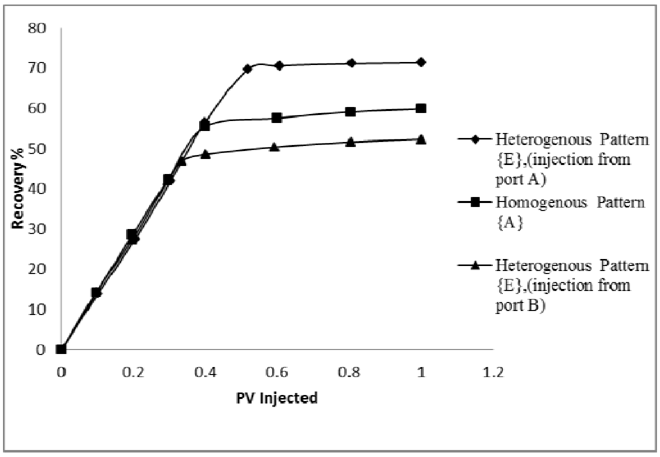

Fig. 5 Polymer-Surfactant flooding in homogeneous and heterogeneous porous medium (patterns {A} and {E})

B. Roles of Layer Orientation and Injection Port

3 models named B, C, D are created in 3 orientation of layers to observe the effect of layer orientation in water and Polymer-Surfactant flooding. Also each pattern can run on test with to kind of injection port selection. Port A from high permeable to low permeable layers and port B from low permeable to high permeable layers. Recovery vs. pore volume of each orientation for water flooding and Polymer-Surfactant flooding is illustrated in Figs. 6, 7.

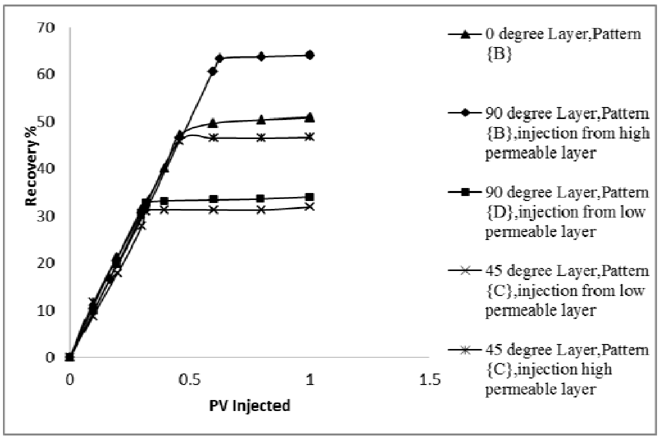

Fig. 6 Water flooding for different layer orientation (patterns {B}, {C}, and {D})

It is shown that in pattern D when water flooding is run from its port where is in high permeable layer where make pattern layer sequences as high permeable to low permeable layer has the highest recovery among other patterns in water flooding. Also this case has highest recovery in Polymer flooding where recovery is exceeded to 50%. The highest oil recovery of water and also Polymer flooding is in 90 degree layer orientation when injection is done from high permeable port. In this case polymer and water can spread in high permeable zone and wide front contact between oil and injection fluid leads to later breakthrough and increases recovery.

From Fig. 7 in polymer flooding injection in high permeable port by increasing layer orientation from 0 to 90,the recovery increases and the higher recovery is in layer sequences with 90 degree orientation when injection is done from that port where is in high permeable port.

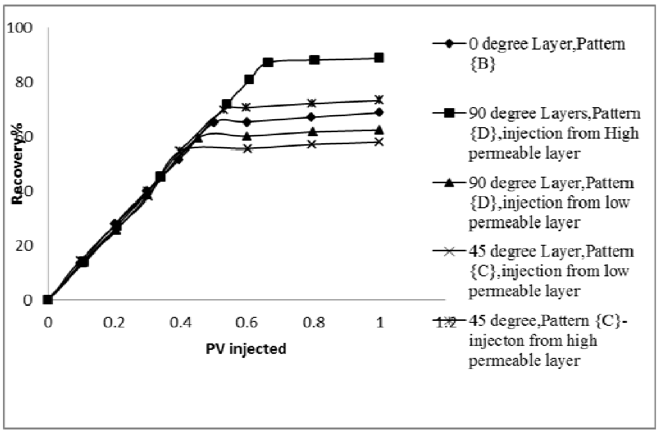

Fig. 7 Polymer-Surfactant flooding for different layer orientation (pattern {B}, {C}, and {D})

Improvement of recovery in polymer-surfactant flooding from 0 degree to 90 degree angle in high permeable injection port is around 25 % and also change from low permeable to high permeable port as injection port increases recovery around 40%. The reason of this improvement is expansion in area of high permeable in flooding path. In low permeable portions the contact of polymer-Surfactant solution and medium is more than this contact in high permeable portions, and also the pores are water wet, so the capillary forces have positive effect on recovery.

But when the injection is done from the low permeable layer and fluid passes low to high permeable races, the recovery vs. pore volume increases with decreasing the orientation angle of layers i.e. the recovery of 0 degree orientation is higher than 45 degree and 90 degree layer orientations.

Also, the figures show that the breakthrough time increases in polymer-surfactant flooding in comparison to water flooding.

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