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# Effects of Polymers and Alkaline on Recovery Improvement from Fractured Models

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***Abstract*—**In this work, several ASP solutions were flooded into fractured models initially saturated with heavy oil at a constant flow rate and different geometrical characteristics of fracture. The ASP solutions are constituted from 2 polymers i.e. a synthetic polymer, hydrolyzed polyacrylamide as well as a biopolymer, a surfactant and 2types of alkaline. The results showed that using synthetic hydrolyzed polyacrylamide polymer increases ultimate oil recovery; however, type of alkaline does not play a significant rule on oil recovery. In addition, position of the injection well respect to the fracture system has remarkable effects on ASP flooding. For instance increasing angle of fractures with mean flow direction causes more oil recovery and delays breakthrough time. This work can be accounted as a comprehensive survey on ASP flooding which considers most of effective factors in this chemical EOR method.

***Keywords*—**ASP Flooding, Fractured System, Displacement, Heavy Oil.



## I. Introduction

SURFACTANT flooding is a commercial EOR method which improves oil recovery because of its remarkable effect on decreasing IFT (interfacial tension) even in dilute solutions; however, it does not show a good sweep efficiency. The alkaline flooding method relies on chemical reactions between chemicals such as sodium carbonate and sodium hydroxide and organic acids in crude oil to produce in situ surfactants that lowers the interfacial tension. The main concept of polymer flooding is influencing the sweep efficiency. Sweep efficiency is defined as the ratio of oil volume contacted by displacing agent to initial volume of oil in place. Since much residual oil remains cohesive to tiny and dead end pores, using an IFT reduction agent is essential. This IFT reduction agent is surfactant; however, they may not be economical singularly. So, adding alkaline to polymer and surfactant solution increases recovery by applying all displacement mechanisms of polymer flooding, surfactant flooding and alkaline flooding, all together. Surfactants whether synthetic or in situ surfactants generated by alkaline reaction with crude oil's acids, reduce IFT between water and oil [1]. Reduction in interfacial tension can result in capillary number which reduces residual oil to a low value in swept regions [2]. In addition to use of alkaline and surfactant, polymers should be used to provide mobility control to the displacement process [3]. So, ASP flooding can increase oil recovery considerably.

In this work, several ASP solutions constitute from 2 polymers, a surfactant and 2 alkaline types at different level of concentrations were used in the flooding tests. And the effects of chemical material types as well as effects of fracture characteristics such as fracture length and orientation on heavy oil recovery have been investigated.

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## II. Experimental Set up

### *A. Model*

The micromodel setup is composed of a micromodel holder placed on a platform includes: a camera supplied with a video recording system, a precise pressure transducer and a pump that is used to control the flow rate of fluids through micromodel. Fig. 1 is a schematic diagram of the experimental setup [4].Schematic samples of used micromodels are shown in Fig. 2. Also, Physical properties of models are shown in Table I.

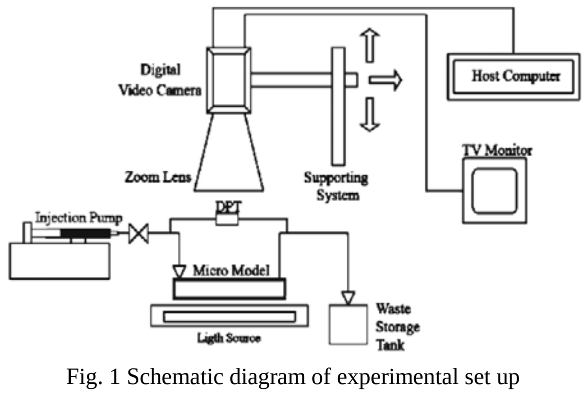


Fig. 1 Schematic diagram of experimental set up

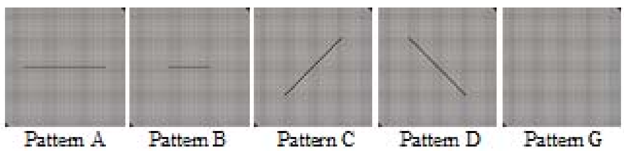


Fig. 2 Glass micromodels used as porous media

TABLE I
PHYSICAL AND HYDRAULIC PROPERTIES OF MICROMODELS

| Pattern | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Length (mm) | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| Width (mm) | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| Average depth (mm) | 0.1 | 0.095 | 0.085 | 0.1 | 0.080 | 0.085 | 0.09 |
| Coordinate Number | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Pore Volume ($cm^3$) | 0.096 | 0.092 | 0.085 | 0.096 | 0.078 | 0.083 | 0.086 |
| Porosity | 52.29 | 52.2 | 52.47 | 52.47 | 52.29 | 52.29 | 50.08 |
| Permeability (mD) | 1800 | 1700 | 2000 | 1800 | 2100 | 2000 | 1600 |
| Number of fractures | 1 | 1 | 1 | 1 | 3 | 3 | - |
| Fracture Orientation | 45 | 45 | 0 | 90 | 45 | 45 | - |

*B. Wettability*

Because of long time contact of these models with the toluene, they are completely oil-wet. This is due to toluene effect as an oily solvent to change wettability of glasses from water-wet to oil wet.

*C. Test Fluids*

The oil used in this experiment is heavy oil which has API degree of 20.1 and viscosity of 60cp at 20ºC. In addition, 10 ASP solutions were generated to do the tests. These solutions are shown in Table II. They are prepared by a surfactant, Sodium Dodecyl Sulfate (SDS), two polymers, HPAM 3330, and Xanthan as well as two alkaline, KOH and $Na_2CO_3$.

The experiments were done in ambient temperature and horizontal stage by injection of ASP solutions in constant rate of 0.0008 ml/sec.

TABLE II
SDS/OIL IFT AT DIFFERENT SDS CONCENTRATIONS IN 22 °C

| Concentration (ppm) | IFT (dyne/cm) |
|---|---|
| 2000 | 0.065 |
| 1000 | 0.114 |

SDS surfactant solutions were used at concentrations of 2000 ppm, near its critical micelle concentration. To prepare surfactant solution, specific amount of surfactant powder is added to a specific amount of water in order to produce a solution with a specific weight fraction. It dissolves just by stirring. The solutions are shown in Table III.

*D. Experimental Procedure*

Before each experiment, the micromodel is cleaned by toluene and methylene chloride and acetone and distilled water. Prepared micromodels are saturated by crude oil to reach to the connate water condition. All experiments were done in oil wet porous media and at ambient temperature and for horizontal displacement.

TABLE III
PROPERTIES OF ASP SOLUTIONS

| ASP Type | $Na_2CO_3$ ppm | KOH ppm | SDS ppm | HPAM ppm | Xanthan ppm |
|---|---|---|---|---|---|
| ASP 1 | 10000 | - | 2000 | 1200 | - |
| ASP 2 | 10000 | - | 2000 | 600 | - |
| ASP 3 | 10000 | - | 2000 | 300 | - |
| ASP 4 | 10000 | - | 1500 | 1200 | - |
| ASP 5 | 10000 | - | 1000 | 1200 | - |
| ASP 6 | 10000 | - | 2000 | - | - |
| ASP 7 | 10000 | - | 2000 | - | 1200 |
| ASP 8 | 15000 | - | 2000 | 1200 | - |
| ASP 9 | 5000 | - | 2000 | 1200 | - |
| ASP 10 | - | 10000 | 2000 | 1200 | - |

## III. RESULTS AND DISCUSSIONS

In this section, effects of polymer/surfactant/alkaline type and concentration, as well as fracture characteristics such as fracture orientation and length of fractures were surveyed and compared with water injection.

*A. Effects of Fracture Geometrical Properties*

*1. Effect of Fracture Length*

Fig. 3 shows oil recovery of ASP 1 solution during injection of 2 PV in patterns “A” and “B” with different fracture length. In pattern “B”, injected fluid sweeps fracture due to shorter length of fracture and reaches to output sooner.

However, in pattern “A” it takes more time to sweep fracture due to longer length of fracture, but transfer of fluid from fracture to matrix occurs better and more efficient than pattern “B”. So, in pattern “A”, breakthrough occurs later than “B” and oil recovery after breakthrough, has a larger value; however, this increase is not too tangible.

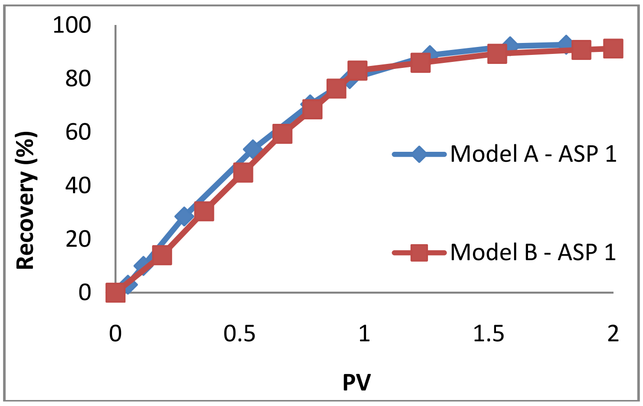


Fig. 3 Role of fracture length on efficiency of ASP flooding

*2. Effect of Fracture Orientation*

In Fig. 4, due to presence of fracture along flow direction which transfers injected fluid toward producing port directly, breakthrough time and recovery in pattern C is less than D and A. In pattern C, initially, injected fluid flows through fracture. This causes low oil recovery at breakthrough time, but after that, fluid flows in matrix and sweeps a vast area of porous media. In pattern D, presence of fracture perpendicular to flow direction causes diffusion of ASP solution in a large area of porous media which leads to higher oil recovery with its higher sweep efficiency and later breakthrough because of the delay resulted from fluid movement perpendicular to flow direction.

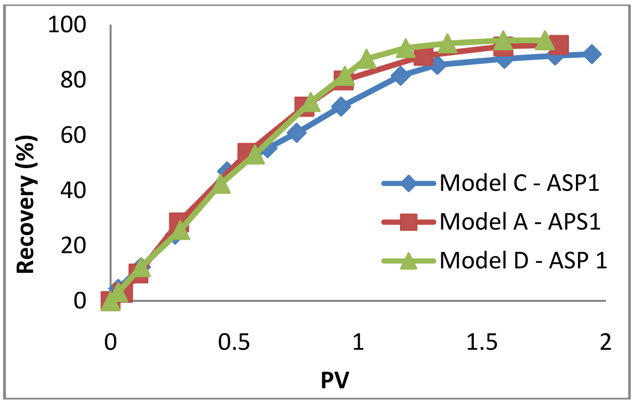


Fig. 4 Role of fracture orientation in ASP flooding

*B. Effects of ASP Solution Type*

*1. Effect of polymer*

Fig. 5 shows oil recovery verses pore-volume injection of ASP 1, ASP 2 and ASP 3 solutions in homogenous pattern G. Oil recovery increases with increase in polymer concentration of ASP solutions from 300 ppm to 1200 ppm due to increase in fluid viscosity. In addition, breakthrough time increases with increase in polymer concentration of ASP solution that increases ASP viscosity.

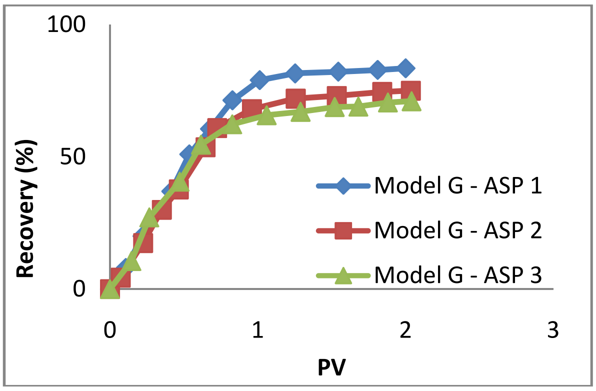


Fig. 5 Role of polymer concentration in ASP flooding in pattern G

Fig. 6 shows oil recovery verses pore-volume injection of ASP 1 and ASP 7 solutions in homogenous pattern G. As it is obvious, polymer type of ASP solution has a significant effect on oil recovery. Fig. 6 shows that synthetic polyacrylamide polymers i.e. HPAM 3330, cause higher recovery than Xanthan biopolymer in ASP solutions. This is due to higher viscosity of mentioned synthetic polymers and their severe visco-elastic behavior. This is because of increase in injected ASP solution viscosity by using 30% hydrolyzed polyacrylamide which is due to hydrolysis effect on polymer's chains.

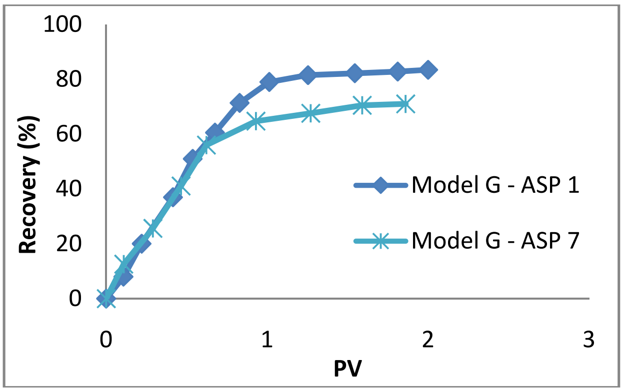


Fig. 6 Role of polymer type in ASP flooding in pattern G

*2. Effect of Surfactant*

Fig. 7 shows oil recovery verses injected pore-volume of solutions ASP 1, ASP 4 and ASP 5 in pattern G. As it is obvious, Increase in SDS concentration in ASP solution has a significant effect on oil recovery. It increases oil recovery and postpones breakthrough due to its effect on reducing of IFT.

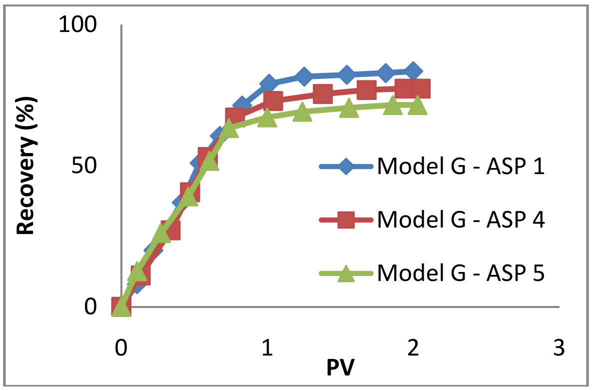


Fig. 7 Role of surfactant concentration in ASP flooding in pattern G

*3. Effect of Alkaline*

Fig. 8 shows oil recovery verses injected pore-volume of solutions ASP 1, ASP 8 and ASP 9 in pattern G. As it is obvious, increase in $Na_2CO_3$ concentration in ASP solution has a significant effect on oil recovery. Increase in alkaline concentration, intensifies its reaction with acids of heavy oil and increases in situ surfactant. Higher concentrations of alkaline in ASP flooding lead to decrease in IFT because of increase in generated surfactant. In addition, higher concentrations of alkaline disperse injection front and cause higher sweep efficiency by improving alkaline diffusion and dispersed droplets mechanisms. Thus, this increase results in increasing in oil recovery and delaying the breakthrough.

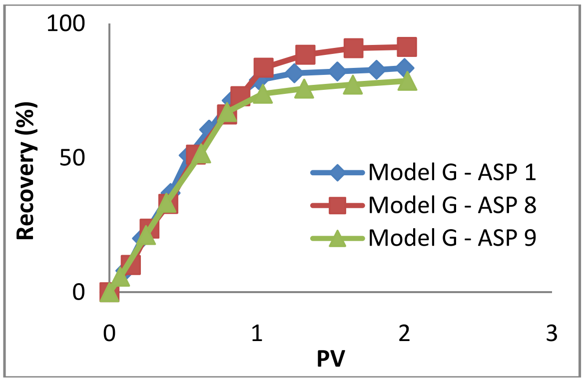


Fig. 8 Role of alkaline concentration on ASP flooding in pattern G

Fig. 9 shows oil recovery verses pore-volume injection of ASP 1 and ASP 10 solutions in homogenous pattern G. As it is obvious, $Na_2CO_3$ and KOH have similar results. This is due to their close pH in concentration of 10000 ppm which is shown in Table III. Because of rapid increase in pH and rapid emulsification, $Na_2CO_3$ is more recommended.

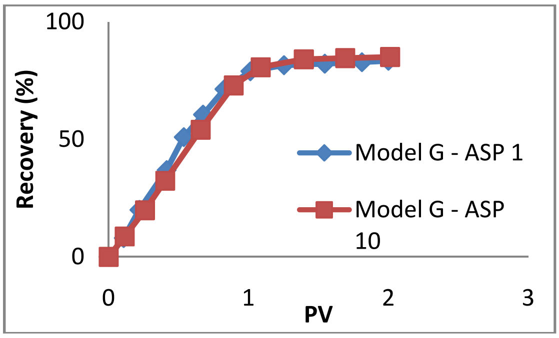


Fig. 9 Investigation of alkaline type in ASP flooding in pattern G

## IV. Conclusion

In this work 10 ASP solutions with different polymer/surfactant/alkaline type and concentration were tested on 5 fractured micromodels with different fracture properties. Based on the obtained results the following conclusions can be drawn:

- In ASP injection in all fractured models with different fracture geometric properties, using HPAM polymer solutions causes higher oil recovery rather than using P and Xanthan biopolymer.
- Increasing polymer concentration from 300 ppm to 1200 ppm in ASP solution increases ultimate oil recovery and postpones breakthrough.
- Regardless of fracture direction, presence of fracture increases final oil recovery, but orthogonal-to-flow fractures delay breakthrough while parallel-to-flow fractures speed-up breakthrough. Oil recovery in fractured models is much more than non-fractured models after breakthrough. Oil recovery in parallel-to-flow fractured model is more than other models. Generally, increasing angle of fractures with flow direction causes more oil recovery and delays breakthrough time.
- Longer fractures due to better distribution of ASP solution in matrix causes more increase in oil recovery. Also due to better flowing of ASP in longer fractures which is not in flow direction, breakthrough postpones. It should be noticed that in ASP injection, this increase in oil recovery and in breakthrough time in longer fractures is not significant.
- Alkaline concentration plays a considerable role in increase in oil recovery; however, alkaline type does not play such remarkable role.

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