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Aspects of Alkaline Flooding: Oil Recovery Improvement and Displacement Mechanisms

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Abstract: Alkaline flooding is one of the newest chemical enhanced oil recovery (EOR) methods. Alkaline generates in situ surfactants when in reacts with acid content of the oil. This economic surfactant generated in oil-water interface, reduces interfacial tension (IFT) significantly that leads to increase in oil recovery by extracting oil from tiny pores. In this study, three alkaline i.e. Na_2CO_3, NaOH and KOH in various concentrations were flooded in a glassy micromodel to detect displacement mechanisms and compare oil recovery. According to the results, increase in alkaline concentration leads to increase in recovery. However, in this case, alkaline type does not play a significant role. In addition, the microscopic pictures showed that water droplet mechanism, emulsification, viscosity intensification and diffusion are playing significant roles during alkaline flooding.

Key words: Alkaline Flooding · Sweep Efficiency · Displacement Mechanism · Chemical EOR · Experimental

INTRODUCTION

One of the most practical enhanced oil recovery techniques for recovering the residual oil left in the reservoir after water flooding is chemical flooding methods which play a significant role for those reservoirs where high-water-oil ratios have been reached as well.

Chemical flooding methods aid a more desirable mobility ratio and capillary number by adjusting the mobility ratio of the displacing flood and reducing the interfacial tension between the displacing and the displaced phases in sequence. Wettability changes, relative permeability shifts, formation of precipitates and formation of macro- and micro emulsions are also other effects of these EOR techniques that must be carefully investigated in chemical and petroleum researches. Macro-emulsions may enhance the mobility ratio through drop entertainment and entrapment while adsorption of chemical compounds may occur at the rock surface contemporaneously. This is the principal limitation of most chemical flooding methods that can be improved by a very successful modification of the micellar/polymer technology in which a simple substitution with cost effective materials, such as alkaline agents for the majority of surfactants is implemented [1].

With alkaline agents, such as sodium carbonates, sodium hydroxide and various silicates, surfactant concentrations as low as 0.1 wt % can be used. This is less than 5 % of the concentration used in micellar solutions for the micellar/polymer technology. Another cost saving modification is the replacement of costly cosurfactants used for viscosity control in a micellar solution with water – soluble polymers. Moreover reducing the chemical adsorption of surfactant and polymer, which is the cause of alkaline agent reaction with the rock, leads to a more effective displacement of oil by chemical system.

Through investigating the effect of sodium hydroxide (NaOH) and sodium orthosilicate (Na_4SiO_4) for the improved oil recovery of the Garzan and Raman oils of Turkey, Turksoy and Bagci in 2001 [2] noticed that the salinity of the alkaline solution has an important impact on the Garzan crude oil recovery. According to the experimental results presented in this study, the

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concentration loss of alkaline reached up to 50 % of the original concentration during some displacement tests which shows a significant consumption of alkaline from alkaline solution in limestone porous medium and to the oil.

Bertaux and Lemanczyk in 1987 [3] demonstrated that with NaOH a crystalline zeolite precipitate becomes visible at the tested temperatures (90 and 150°C) while if KOH is used, amorphous precipitates would be present at these temperatures. Based on these observations, the solubility in alkaline solutions of minerals commonly found in sandstones indicates the possible use of alkalis as matrix treatment fluids for carbonate cemented sandstones.

From Labrid and Bazin in 1989 [4] experiments with sand packs containing homogeneous disaggregated rock powder, calcite played a minor role in the conversion of clays, probably because the slow decrease in pH during the flooding and the presence of significant amount of divalent ions in the injected water limit its dissolution. Osman *et al*. [5] have shown that the shale content is a major factor in the overall recovery efficiency within a reservoir due to the large surface area and highly reactive ionic characteristics of the clay particles. A small amount of clay may has a very little effect on porosity but it would significantly reduce permeability. An alkaline solution of 2 % by weight NaOH concentration and 20 % pore volume slug size, driven by seawater, was used to flood sandstone cores of different shale content. The less the percentage of shale content, the more the value of oil recovery. Further increase in shale content yields a decrease of oil recovery at different pore volumes injected. The hydration of the shale reduced the pore sizes and trapped more oil when shale content value exceeded 1 %.

Holm and Robertson in 1978 [6] conducted a number of batch contacting tests using sodium orthosilicate solution and some common reservoir minerals including calcite, dolomite, siderite, mangano – siderite and three clay samples namely kaolinite, illite and montmorillonite. The medium of sand packs and Berea sandstones were prepared for conducting the tests. They observed that the permeability to high pH silicate solutions was 75 to 85 % of the brine permeability in the porous system investigated and that alkaline agents are consumed by reaction with reservoir brine, clays, carbonate and calcium sulfate minerals.

Strong Alkalis (NaOH, KOH and Na_4SiO_4) are very promising for mobilizing residual oil in laboratory core floods but imply higher reactivity effects with reservoir rocks (clays – basically kaolinite), resulting in chemical consumption and aluminosilicates and a decrease in permeability.

Although according to the literature review many researchers involved in experimens on alkaline flooding, just a few ones worked on displacement mechanisms during this EOR process. In this work three alkaline solutions in various concentrations are flooded in a model to detect macroscopic and microscopic aspects in displacement mechanisms and ultimate oil recovery.

Experimental Setup: Figure 1 shows the designed and fabricated model for this study. The micromodel was designed by Corel Draw Software and the laser beam was used to engrave the drawing on the glass surface. Once the paths were engraved and cleaned, the glass has been stuck to another glass part by sintering them in a furnace. Physical properties of the model can be seen in Table 1.

A very high accuracy pump fabricated by Quizix was used to inject fluids in high accuracy. The precision of this computer-controlled pump is 0.0001cc/min. The pump was equipped with two cylinders placed in parallel with respect to each other and providing continuous injection. Also, a high pressures container is used to keep injected fluid. The fluid is poured into this container continuously during the experiments. The pumped fluid pushes the piston and the piston drives the displacing fluid out of the cylinder into the model. Figure 2 provides a schematic of the micromodel set up.

Test Fluids: In this investigation, Na_2CO_3, NaOH and KOHwere used to preparealkaline solutions with concentrations 5000, 10000 and 15000 ppm. Characteristics of these chemical solutions are presented in Table 2. Also, the characteristics of the crude oil are given in Table 3.

Experimental Procedure: The water and alkaline solutions were injected at constant rate) 0.0002 cc/min (in the micromodel initially saturated with oil. For complete saturation of micromodel with the oil, appropriate vacuum has been employed. To calculate recovery, a high quality camera connected to a computer that took pictures in definite time intervals was used and the pictures were processed by Photoshop software. The software calculated the recovery by counting the black pixels in each picture.

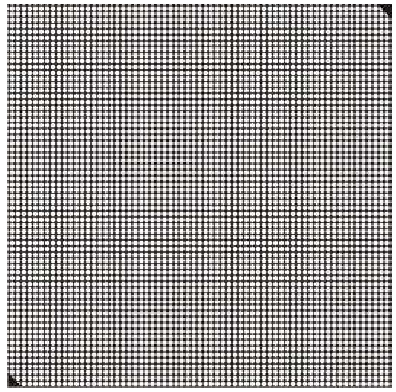


Fig. 1: Designed micromodel

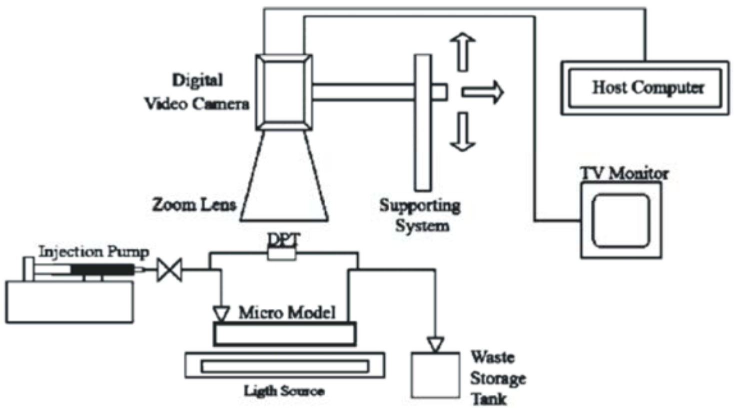


Fig. 2: Schematic of micromodel set up

Table 1: Physical properties of micromodel

Parameter	Value
Length (mm)	60
With (mm)	60
Average depth (mm)	0.085
Coordinate Number	4
Pore Volume (cm^3)	0.082
Porosity	52.48
Permeability (mD)	1600

Table 2: Characteristics of chemical solutions

Chemical	Molecular Weight (g/mol)	Concentration (ppm)
Na_2CO_3	105.96	5000,10000,15000
NaOH	39.98	10000
KOH	56.09	10000

Table 3: Specifications of used oil

Density	API
0.8696	31.2

RESULTS AND DISCUSSIONS

The solutions were tested on homogenous model. In addition, displacement mechanisms of alkaline flooding were surveyed in this investigation.

Macroscopic Results: Figure 3 shows oil recovery verses pore-volume injection of Na_2CO_3 alkaline solution with three concentrations of 5000, 10000 and 15000 ppm. As it is obvious, by increasing alkaline concentration, oil recovery increases. This increase is because of increase in viscosity due to emulsification. When alkaline concentration increases, the concentration of generated in situ surfactant increases. As a result, IFT decreases and more residual oil releases in a miscible flow. So, increase in fluid viscosity due to presence of discrete droplets of water and decrease in IFT increase ultimate oil recovery. However, increase in alkaline concentration in this range, does not increase breakthrough time significantly.

Figure 4 shows recovery during 2 pore volume injection of three different alkaline types in a constant concentration of 10000 ppm. As it is obvious, change in alkaline type does not lead to a significant change in the results. It is because of somehow equal pH in these three various solutions. Table 4 shows pH in each solution. So, in this case, alkaline type is not as sensitive as alkaline concentration.

Table 4: pH of the various solutions

Chemical	Concentration (ppm)	pH
Na_2CO_3	5000	11.9
Na_2CO_3	10000	12.1
Na_2CO_3	15000	12.2
NAOH	10000	13.1
KOH	10000	13.1

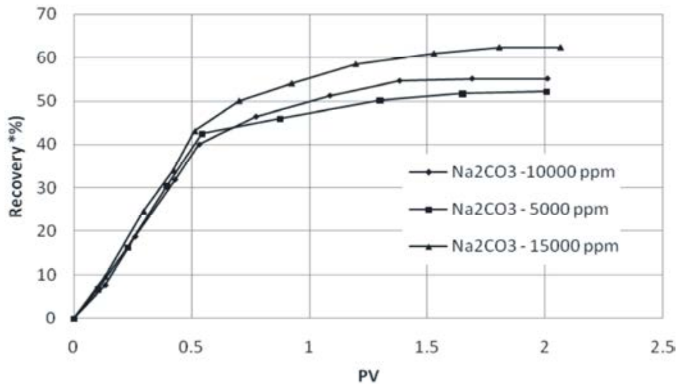


Fig. 3: Effect of alkaline concentration on oil recovery

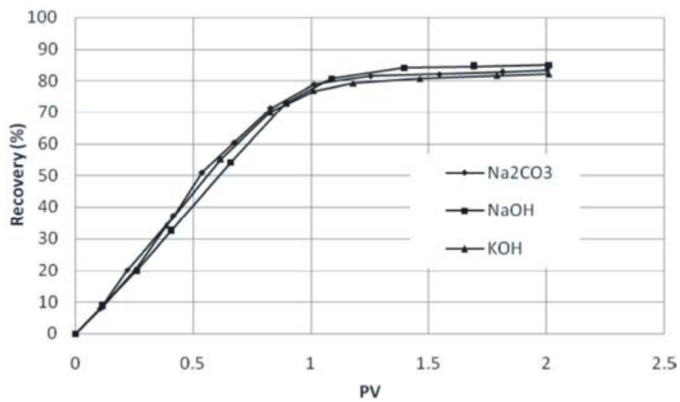


Fig. 4: Effect of alkaline typeon oil recovery

Displacement Mechanisms

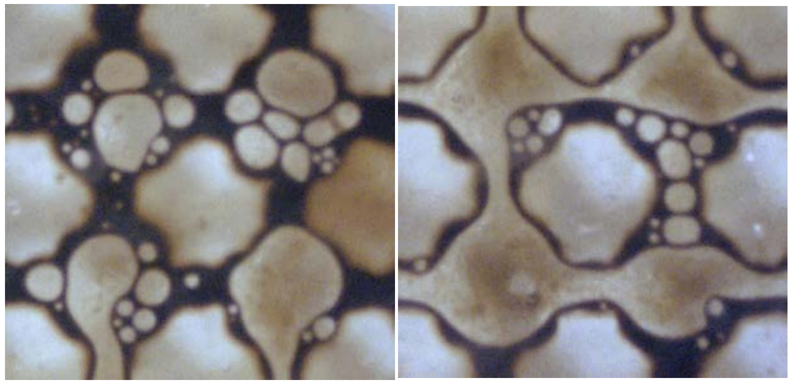
Water Droplets Mechanism: While alkaline flooding, generation of water droplets in oil hastwo steps. First, diffusion of alkaline into oil and generation of brownish water columns and second, discretization of this column to droplets which flow toward production port.

Both steps are because of interfacial reactions of alkaline with oil which causes not only serious decrease in IFT, but also heterogeneous improvement in generated in situ surfactants. Decrease in IFT leads to intensification of alkaline diffusion; however, heterogeneous distribution of in situ surfactant results in water droplets discretization and dispersion. When in situ surfactant concentration is low, IFT is higher and water phase is more discretized and dispersed. As it is obvious in Figure 5a and 5b, in comparison with ASP flooding [7], the bulk flow of alkaline flooding is more dispersed because of lower concentration of surfactant.

Viscosity Improvement: Figure 6 shows a glassy micromodel after waterflooding. It can be shown that water passes the pattern with low sweep efficiency and fingering occurs. So, much residual oil remain in the model.

Figure 7 shows the micromodel after injection of 2 pore-volumes of alkaline solution of Na_2CO_3 with concentration of10000 ppm.

It is apparent that alkaline solution have diffused in crude oil and generated brownish columns of water. After alkaline solution entrance to porous media, aqueous phase front becomes dispersed emulsion of water in oil. Due to applied viscosity of this emulsion because of Jamin effect, front becomes more uniformed and continuous and decreases fingering in comparison with waterflooding. Thus, using alkaline increases sweep efficiency. This mechanism is effective especially in heavy oil reservoirs which fingering is common and have high



(a) (b)

Fig. 5: Residual oil distribution after (a) alkaline flooding and (b) ASP flooding

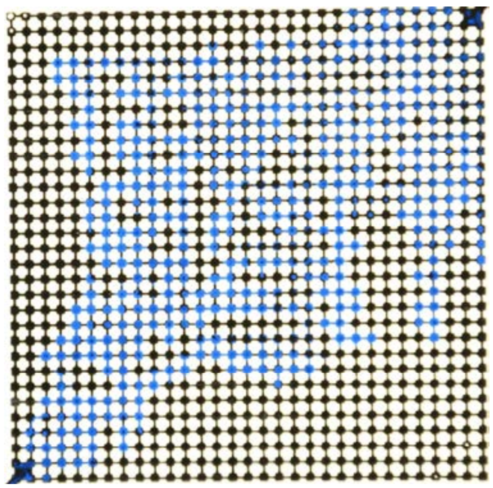


Fig. 6: Residual oil distribution after waterflooding

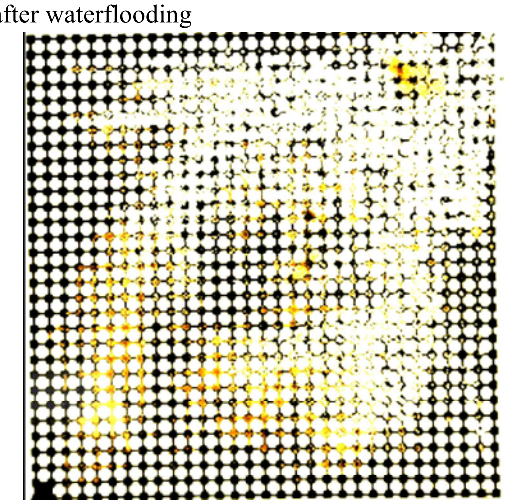
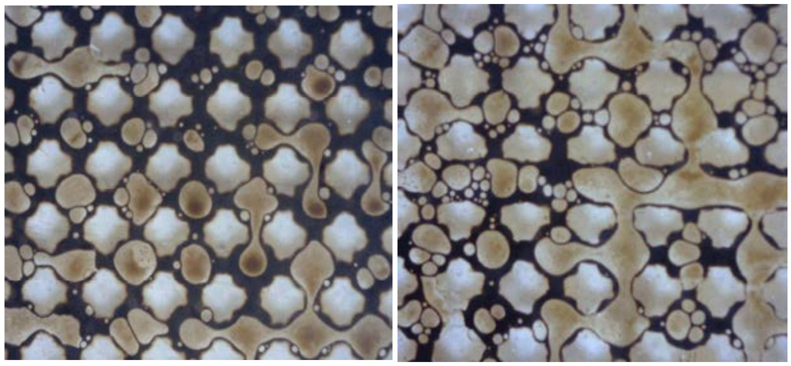


Fig. 7: Residual oil distribution after alkaline flooding

acid content. Figure 8a and 8.b illustrate micromodel after alkaline flooding of Na_2CO_3 with concentrations of 15000 and 10000 ppm. According to Figure 8, by increasing alkaline concentration alkaline diffusion and emulsification are intensified and sweep efficiency increases.



(a) (b)

Fig. 8: Residual oil distribution after alkaline flooding with concentration of (a) 10000 ppm and (b) 15000 ppm

CONCLUSION

Three alkalines in three concentrations were flooded in a micromodel saturated by oil and microscopic pictures have been taken during the process. Analysis of the pictures got the following conclusion:

- Increase in alkaline concentration results in decrease in IFT that leads to increase in oil recovery.
- In constant concentration, Na_2CO_3, NaOH and KOH lead to equal results.
- Water droplet mechanism plays a significant role in oil displacement.
- Viscosity intensification due to emulsification makes the displacing front uniform and significantly improves sweep efficiency.

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