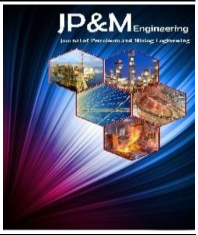
JP&M Engineering

Journal of Petroleum and Mining Engineering



Visco-Elastic Surfactant Improves Sweep Efficiency and Interfacial Tension in Chemical Flooding

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Abstract

Enhanced oil recovery methods hold promise for recovering oil remaining after conventional waterflood. High demands for oil and high oil prices are driving more research in chemical EOR in particular. The total world oil production from EOR has remained relatively level over the years, contributing about 3 million barrels of oil per day, compared to around 85 million barrels of daily production, or nearly 3.5% of the daily production. Visco-Elastic surfactant (VES), has many applications in oil industry as friction reducer, improves carrying capacity and finally in acid diversion. VES can reduce the interfacial tension (IFT) and can build viscosity with saline water, through the reaction between the di-valent cation within the formation water and the active group of the VES. The VES gel can be broken upon contacting hydrocarbon phase or flushing with mutual solvent; this feature will help to reduce the formation damage. Mixing of 2 vol% VES with 2 wt% $CaCl_2$ can build a moderate viscosity that can sweep the oil ahead. Formation water will help to sustain the VES viscosity and reduce the gel degradation effect, on contrary to polymers. On the other hand, the VES will help to improve the interfacial tension (IFT). Berea Sand Stone standard cores of different permeabilities and 20-22% porosity range were used to conduct core flooding experiments using a mixture of 2 vol % VES with 2 wt % of $CaCl_2$ to form a 25 cp VES solution. The core flooding was done at ambient condition. The cores were initially saturated with brine, then de-saturated using 29^o API crude oil of 20 cp viscosity. The cores were undergone water flooding to produce the max oil recovery before the water breakthrough, then the VES solution was pumped at 2cc/hr to maximize sweeping of the remaining oil. The VES flooding resulted in producing additional 33% of the oil remained after water flooding. About 11% of the produced oil from VES flooding was at mobility ratio less than unity. The water breakthrough was delayed until 24% of the remaining oil was recovered by VES flooding. Above results indicate the possible application of VES in tertiary recovery to improve the oil productivity through improving the mobility ratio while reducing the IFT.

Keywords

Visco-Elastic Surfactant; Sweep Efficiency; Interfacial Tension; Chemical Flooding

Introduction

The two most general polymer types used in the EOR process are a synthetic material, Polyacrylamides, in its partially hydrolyzed form (HPAM) and the biopolymer, xanthenes. These kinds of polymers are extensively used in several industries as the thickening agents or as the parts of the manufacturing process [1].

The Polyacrylamides used in polymer flood application is in its hydrolyzed form (HPA M) [2]. HPAM is a straight-chain polymer that has the acryl amide molecule as the monomer. This partial hydrolysis can occur in some of these monomers. Typical degrees of hydrolysis are 25% - 35% that are chosen to optimize the specie properties of the polymer solutions. If the degree of hydrolysis is too small, the polymer will not be water soluble. If it is too large, its properties are overly sensitive to salinity and hardness. The typical molecular weight of HPAM used in polymer flood is within the range of 2 - 20 X 10^6 g/mole. The viscosity increasing feature is derived the repulsion between polymer molecules and between the segments of the same molecule. This repulsion causes the molecule to lengthen and snag on other molecule. This increase in viscosity causes the lower mobility of the polymer solution [3].

A lot of tests were run at different shear rates, the viscosity of HPAM co-polymer was examined in presence of different concentrations of NaCl salt. 0, 0.01, 0.05, 0.2, 1.4 and 8.2 wt% concentrations were tested. This test was run at a fixed polymer concentration of 1000 ppm. The result obtained, indicated that NaCl decreases the viscosity of the polymer [13] as shown in Figure 1 [4].

At high polymer concentration the viscosity decreased with NaCl concentration increase to a certain limit then the polymer viscosity remained at the same value in spite of increasing NaCl salt concentration. The lower polymer concentration recoded lower viscosity at low shear rate [5].

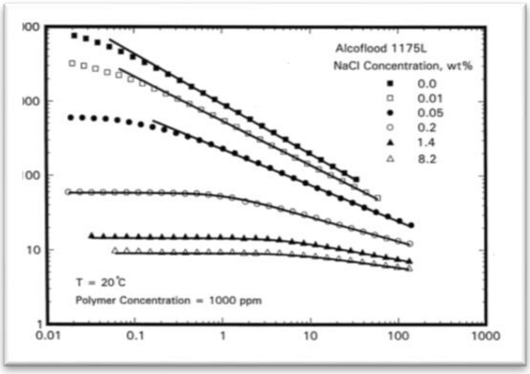

Figure 1 Effect of NaCl on HPAM viscosity, after Taylor, 1994.

Calcium ion is heavier than sodium. With fixed polymer concentration 1000 ppm, the calcium salt caused a decrease in polymer viscosity higher than that caused by NaCl [6] as shown in Figure 2.

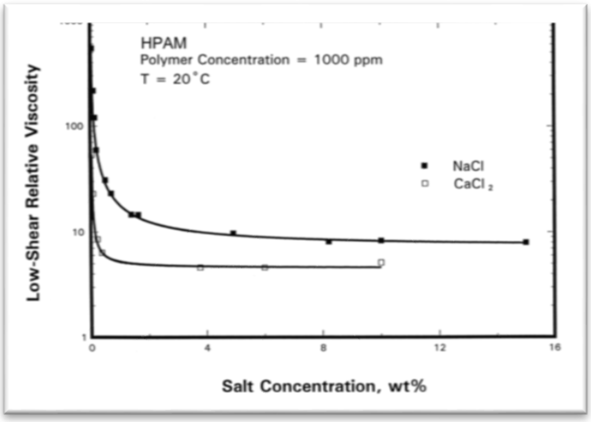

Figure 2 Effect of cation on low-shear HPAM viscosity after Taylor, 1994.

Viscoelastic Surfactant Solutions The term viscoelastic refers to those viscous fluids having elastic properties, i.e., the liquid at least partially returns to its original form when an applied stress is released. Viscoelasticity is caused by a different type of micelle formation than the spherical micelles formed by most surfactants. Viscoelastic surfactant fluids form worm-like, rod-like, or cylindrical micelles in solution Figure 3. The formation of long, cylindrical micelles creates useful rheological properties [7]. A viscoelastic surfactant solution exhibits shear thinning behavior, and remains stable despite repeated high shear applications. Viscoelastic surfactants usually require higher concentrations of surfactant than a polymeric gelling agent system to develop equivalent viscosity [8]. Amphoteric surfactant contains both a positively and a negatively charged moieties over a certain pH range, only a negatively charged moiety over a certain pH range, and only a positively charged moiety at a different pH range.

Effect of salts on the chemical flooding is a problem facing the application of the Polyacrylamides co-polymer in EOR. It is known that formation water contains high concentrations of NaCl and CaCl2, both of which have a negative effect on the Polyacrylamides viscosity behavior in oil industry application, as it causes a rapid degradation of the formed gel. Multi cation has a higher degrading effect on the polymers than the mono-cations. So, Examine the salts effect on the VES behavior is essential to understand the behavior of the VES solution while flooding and when it comes into contact with formation water.

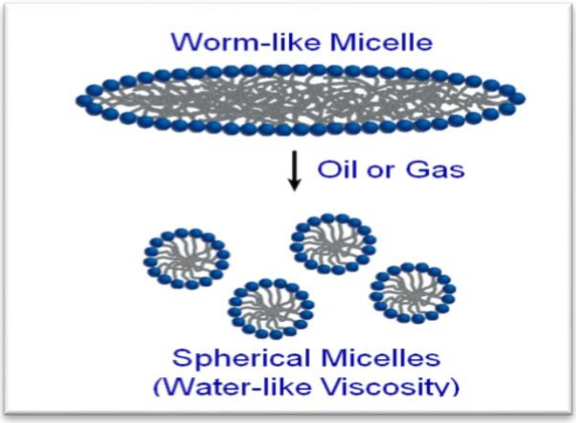

Figure 3 VES worm-like Micelle.

The test was done at 40 sec^{-1} shear rate applied on the VES after mixing with three different $CaCl_2$ concentrations 3, 5, 15% by weight.

The test result shows in figure 4 that the VES viscosity increased with salt concentration. The behavior characteristics of VES are in contrary to Polyacrylamides co-polymers.

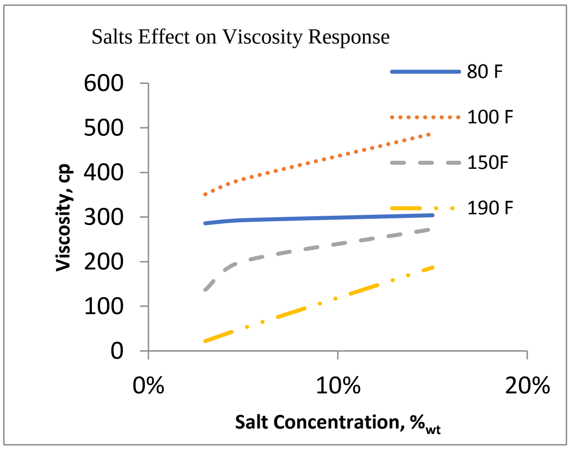

Figure 4 Viscosity response with salts concentration.

Core Flooding Experiments

A Core flooding test was done on four cores to compare the Polyacrylamides flooding with the VES flooding.

The four cores underwent the same procedures and steps in order to have a fair comparison between the polymer flooding and VES.

Experiment procedure can be summarized as follows:

1. Core cleaning: all cores were soaked in toluene and Xylene, in order to dissolve any hydrocarbon residual within the cores.
2. Drying: Figure 5 shows the drying apparatus.
3. Cores properties measurements.
4. Brine Saturation.
5. Permeability measurements [9].
6. De-Saturation with 29° API oil to have S_o & $S_{wi.}$
7. Water flooding: to produce the maximum oil recovery before the water breakthrough.
8. VES Chemical flooding for two plugs No. 2&4 and the other two plugs 1&3 were flooded with Hydrolyzed Polyacrylamides Co-Polymer.

Figure 5 Vacuum pump.

Results and Discussion

Core Properties

Table 1 shows the core properties in regard to the dimensions, pore volume, porosity & permeability.

Plug No.	Length (cm)	Dia. (cm)	BV. (cc)	Wt. (gm)	Gv. (cc)	Pv. (cc)	Porosity %	Brine Permeability, (md)
1	7.5	3.8	85	178.5	67.48	17.5	20.6	146
2	7.5	3.8	85	182.2	68.89	18.0	20.7	175
3	7.5	3.8	85	179.2	67.74	17.3	20.3	116
4	7.5	3.8	85	178.4	67.44	17.6	20.7	104

Water Flooding Results

Natural recovery mechanisms leave unrecovered 60 to 90 percent of the original oil in place. Secondary oil recovery processes have been developed in efforts to recover all or part of this oil. Of these, water flooding -an artificial form of water drive-has been the most successful. It is applicable principally to many reservoirs where the primary oil-recovery mechanisms have not and will not produce more than about 20 to 30 percent of the original oil in place. Water-flooding practices have assumed various forms in efforts to increase oil-recovery efficiency and decrease cost [10].

All core were water flooded at 2cc/hr to displace the oil ahead in order to produce the max oil capacity from the cores before the water breakthrough take place, the optimum mobility ratio always remain below unity in order to have higher oil productivity over water, once the M (Mobility ratio) jumped above unity, the water cut starts to increase rapidly until the breakthrough occurs.

Table 2 shows the water flooding results carried on the four core plugs.

Table 1 Water flooding results.

Plugs	Plug No. 1	Plug No. 2	Plug No. 3	Plug No. 4	Npwf/N, %
So Initial	0.68	0.67	0.63	0.61	37.7
Sw Initial	0.32	0.33	0.37	0.39	44
Sowf, after WF	0.42	0.37	0.35	0.35	44
Swwf, after WF	0.58	0.63	0.65	0.65	42

Chemical Flooding Results

After the initial water flooding, it was intended to maximize the oil productivity from the four cores through chemical flooding depending on improving the mobility ratio, the water flooding ended at a mobility ratio value of 8 and at which the water breakthrough occurred, higher viscosity fluid flooding is required to drag back the mobility ratio and improve the sweep efficiency.

Mobility ratio [11] represents the displacing fluid to the displaced fluid relative permeability

$$M= (K_{rw}/M_w)/ (K_{ro}/M_o)$$

Table 3 & Figures 6, 7, 8 & 9 below summarize the results of the chemical flooding process of the VES compared to polymer flooding. In Figure 6, a comparison between the four plugs in the cumulative oil produced. Plugs 2&4 were flooded with VES showed higher recovery values compared to plugs 1&3 that were flooded with hydrolyzed Co-polymer , also the oil recovery last longer at high mobility ratio values in plugs 2&4 with delayed water breakthrough which reflects the IFT effect of the VES.

In Figure 7, it showed the total injected water versus the oil recovery from the flooding process. The injected volume of the flooding fluid was almost the same equals 2 pore volumes, the plugs flooded with VES consumed the same amount of flooding fluid to produce higher volume of oil compared the plugs flooded with polymer.

Water cut is a real problem to the oil production as it causes a lot of associated problems such as corrosion, scales and other problems. Figures 8&9; show that the water cut resulted from the VES flooding is less than the water cut from the polymer flooding, that supports the financial impacts of the VES application in chemical flooding.

Table 2 Chemical flooding results.

Description	Plug No.1 Polymer Flooding	Plug No. 2 VES Flooding	Plug No.3 Polymer Flooding	Plug No. 4 VES Flooding
Np/N-Npwf	25%	33%	26%	44%
Soi	0.31	0.22	0.26	0.20
Sw Final	0.69	0.78	0.74	0.80

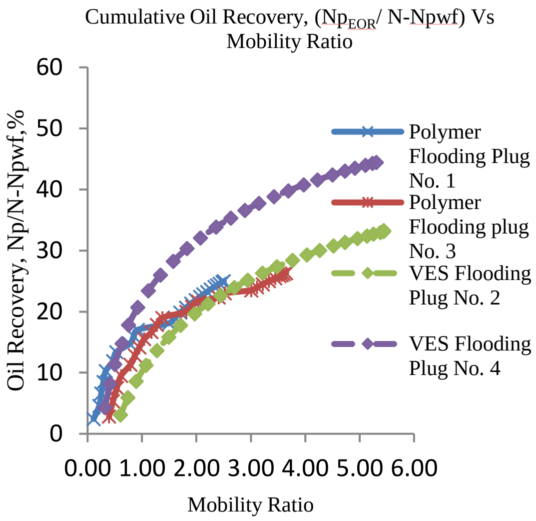

Figure 6 VES & polymer recovery mobility ratio.

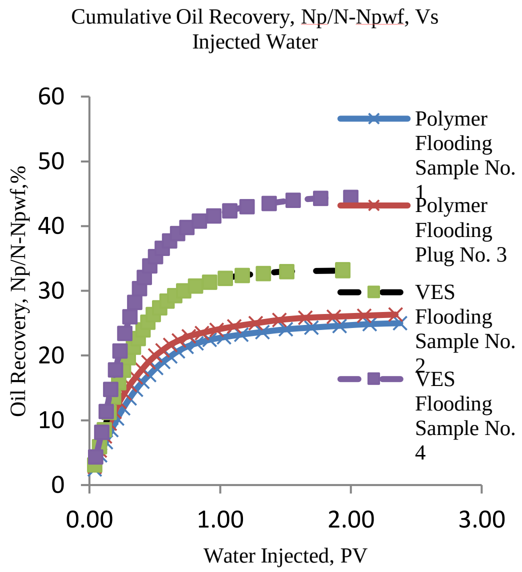

Figure 7 VES & polymer recovery mobility ratio.

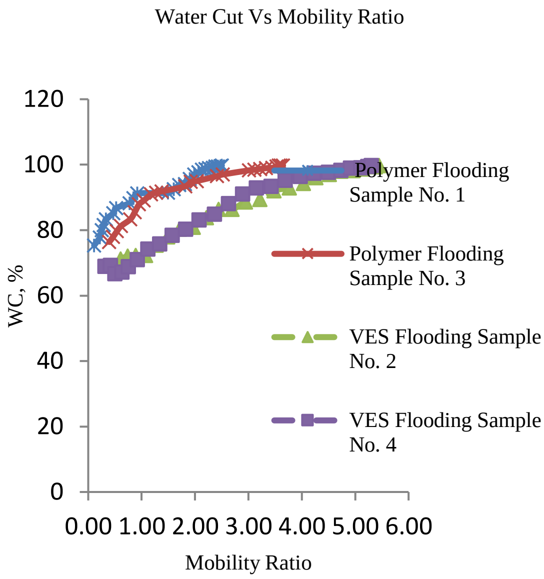

Figure 8 VES & polymer water cut vs mobility ratio.

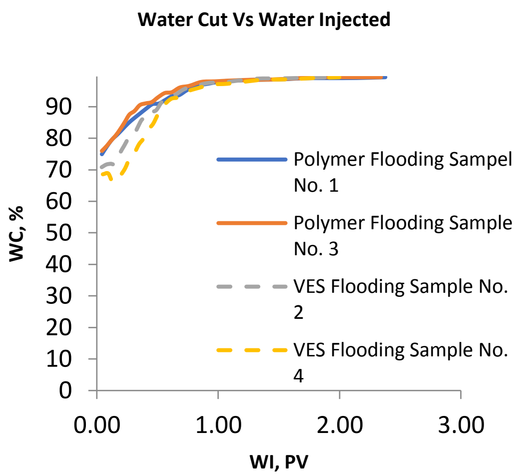

Figure 9 VES & polymer water cut vs injected water.

Conclusions

Based on the results from the experimental and core flooding works, we can summarize the conclusion in the following points:

- Salts increase the VES solution viscosity, which help improving the mobility ratio over the traveled distance within the reservoir when it came into contact with formation water.
- Visco-Elastic Surfactant flooding can improve the mobility ratio and hence enhance the oil productivity.
- Visco-Elastic Surfactant core flooding resulted in improving the oil productivity compared to the polymer flooding, as the two-core flooded with VES has a higher oil recovery compared the oil recovery from the polymer flooding. VES flooding reduces

the water cut, which has an important impact on economics of the VES application in chemical flooding compared to polymers.

Acknowledgements

The authors wish to acknowledge the Suez University for granting permission to present and publish this paper. The authors would like to thank the department of the Petroleum Engineering for their full support and guidance.

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