

Surfactant and Surfactant-Polymer Flooding for Enhanced Oil Recovery

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Abstract

Investigation has been made to characterize the surfactant solution in terms of its ability to reduce the surface tension and the interaction between surfactant and polymer in its aqueous solution. A series of flooding experiments have been carried out to find the additional recovery using surfactant and surfactant polymer slug. Approximately 0.5 pore volume (PV) surfactant (Sodium dodecylsulfate) slug was injected in surfactant flooding, while 0.3 PV surfactant slug and 0.2 PV polymer (partially hydrolyzed polyacrylamide) slug were injected for surfactant-polymer flooding. In each case chase water was used to maintain the pressure gradient. The additional recovery in surfactant and polymer augmented surfactant flooding were found around 20% and 23% respectively.

Key words: Enhanced oil recovery; Surfactant; Polymer; Surface tension; Flooding

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Nomenclature

CAC	Critical aggregation concentration
CMC	Critical micelle concentration
EOR	Enhanced oil recovery
k	Absolute permeability, Darcy
k_o	Effective permeability to oil, Darcy
k_w	Effective permeability to water, Darcy
OOIP	Original oil in place
P	Polymer
PHPA	Partially hydrolyzed polyacrylamide
PSP	Polymer saturation point
PV	Pore volume
S	Surfactant
SDS	Sodium dodecyl sulfate
S_{or}	Residual oil saturation
SP	Surfactant-Polymer
S_{wi}	Irreducible water saturation

INTRODUCTION

Chemical flooding methods are classified into a special branch of enhanced oil recovery (EOR) processes to produce residual oil after water flooding. These methods are utilized in order to reduce the interfacial tension, to increase brine viscosity for mobility control and to increase sweep efficiency in tertiary recovery. Surfactants are considered as good enhanced oil recovery agents since 1970s^[1] because it can significantly lower the interfacial tensions and alter wetting properties. Displacement by surfactant solutions is one of the important tertiary recovery processes by chemical solutions. The addition of surfactant decreases the interfacial tension between crude oil and formation water, lowers the capillary forces, facilitates oil mobilization, and enhances oil recovery. The surfactant is dissolved in either water or oil to form microemulsion^[2] which in turn forms an oil bank. The formation of oil bank and subsequent maintenance of sweep efficiency and pressure gradient by injection of polymer and chase water increase the oil recovery

significantly^[3-5]. The idea of injecting surfactant solution to improve imbibitions recovery was proposed for fractured reservoirs^[6-8] and carbonaceous oil fields in the United States^[9-11]. The effects of capillary imbibitions and lowering of IFT using surfactant slug have been reported by many researchers^[12-16].

It is well known that use of polymer increases the viscosity of the injected water and reduces permeability of the porous media, allowing for an increase in the vertical and areal sweep efficiencies, and consequently, higher oil recovery^[17-20]. The main objective of polymer injection is for mobility control, by reducing the mobility ratio between water and oil. The reduction of the mobility ratio is achieved by increasing the viscosity of the aqueous phase. Another main accepted mechanism of mobile residual oil after water flooding is that there must be a rather large viscous force perpendicular to the oil-water interface to push the residual oil. This force must overcome the capillary forces retaining the residual oil, move it, mobilize it, and recover it^[21]. The injection of polymer helps to propagate the oil bank formed by surfactant injection by increasing the sweep efficiency. Austad et al.^[22] reported that significant improvements can be obtained by co-injecting surfactant and polymer at a rather low chemical concentration.

In the present study, the investigation has been made to characterize the surfactant solution in terms of its ability to reduce the surface tension and the interaction between surfactant and polymer in its aqueous solution. A series of flooding experiments have been carried out to find the additional recovery using surfactant and surfactant polymer slug.

1. EXPERIMENTAL

1.1 Materials Used

Sodium Dodecyl Sulfate (SDS) (approximately 99% purity) was used as surfactant and commercial grade Partially Hydrolyzed Polyacrylamide (PHPA) used as polymer. SDS ($C_{12}H_{24}SO_4Na$, M.W. = 288.38) was purchased from Central Drug House (P) Ltd., India and PHPA (Av. Mol. Wt. = 3000000) from SNF Floerger, France. NaCl were purchased from Qualigens Fine Chemicals.

The aqueous solutions with different concentrations of surfactant and polymer were always freshly prepared to avoid degradation, and then stirred with the help of Remi Magnetic Stirrer. The appropriate quantity of anionic surfactant and polymer were mixed carefully for about 15 minutes. A wide range of concentrations around the

critical micellization concentration of SDS (0.1 – 0.3 wt %) and PHPA concentrations (1500, 2000, 2500 and 5000 ppm) were chosen for the present study).

1.2 Flooding Procedure

All the experiments have been completed by using sand packs in the laboratory. The experimental apparatus is composed of a sand pack holder, cylinders for chemical slugs and crude oil, positive displacement pump, measuring cylinders for collecting the samples. The detail of the apparatus is shown in Figure 1. The displacement pump is one set of Teledyne Isco syringe pump. Control and measuring system is composed of different pressure transducer and a Pentium IV computer. The physical model is homogeneous sand packing model vertically positive rhythm. The model geometry size is $L=35$ cm and $r=3.5$ cm.

Sandpack flood tests were employed by (i) preparing uniform sandpicks, 60–100 mesh sand was cleaned and washed with 1% brine. Then the sands were poured in to the core holder which was vertically mounted on a vibrator and filled with 1.0 wt% brine. The core holder was fully filled at a time and was vibrated for one hour. (ii) The wet packed sandpack was flooded with brine, the absolute permeability (k_w) is calculated. (iii) Then sand pack was flooded with the Crude oil at 800 psig to irreducible water saturation. The initial water saturation was determined on the basis of mass balance. (iv) Water flooding was conducted horizontally at a constant injection flow rate. The same injection flow rate was used for all the displacement tests of this study. (v) After water flooding, ~ 0.5 PV polymer or surfactant in case of (polymer surfactant flooding) and ~ 0.3 PV surfactant followed by ~ 0.2 PV polymer buffer (surfactant-polymer flooding) was injected followed by ~ 2.0 PV water injection as chase water flooding.

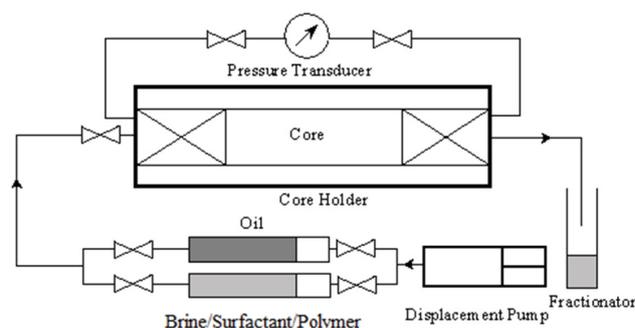


Figure 1
Schematic of Experimental Set-Up for Flooding Experiments Through Sandpicks

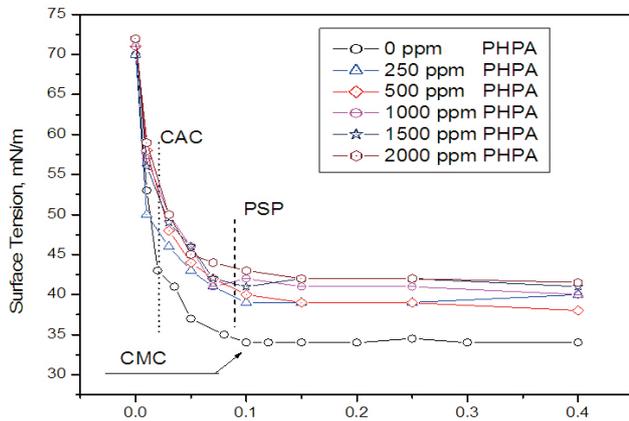


Figure 2
Effect of Partially Hydrolyzed Polyacrylamide PHPA on Surface Tension of SDS

2. RESULTS AND DISCUSSION

2.1 Influence of Polymer of Surface Tension

It is well known that the surfactants reduce the surface tension of water by getting adsorbed on the liquid-gas interface. The critical micelle concentration CMC, one of the main parameters for surfactants, is the concentration at which surfactant solutions begin to form micelles in large amount^[23]. Surface tensions of the aqueous solution of SDS at different concentrations were measured and plotted as a function of concentration Figure 2. The concentration at the turning point of the curve is CMC.

The interaction of water-soluble polymers with anionic surfactants should be considered while injecting surfactant and polymer slugs for enhanced oil recovery. To observe the effect of polymer on the surface properties, surface tension of aqueous solution of surfactant were measured in presence of polymer (PHPA) as shown in Figure 2. The surface tension of the surfactant solutions increases in presence of polymers. Hongyan et al.^[24] reported that because of elevation of system viscosity upon the addition of polymers, the diffusion of surfactant from water phase towards oil/water interface slows down, extending the time for IFT to reach the super low level. The surface tension vs. surfactant concentration plots in presence of polymer shows three distinct zones. Above the critical aggregation concentration (CAC), the interaction between the water-soluble polymer and surfactants is started. Dynamic equilibrium between surfactant-saturated-polymer and the regular aqueous micelles coexist just above the polymer saturation point (PSP). With further increase in surfactant concentration, surface tension remains constant and normal surfactant micelles start to form.

2.2 Polymer Viscosity

Polymer plays an important role to improve the mobility ratio in chemical flooding by increasing the solution viscosity. The details of rheology of PHPA have been discussed in our earlier paper^[25]. Polymer viscosity decreases with increase in shear stress and temperature. In surfactant flooding, one the oil bank is formed propagated through the expansion of swept volume by polymer^[26]. Mobility control is needed to prevent the chemical slug from fingering into the oil/water bank where it would dissipate by dispersive mixing^[27].

2.3 Surfactant and Surfactant Polymer Flooding

In the present study two sets of surfactant flooding scheme have been conducted. In the first set, enhanced recovery over water flooding has been studied using different concentrations of surfactants. In other set a combined surfactant and polymer has been injected after water flooding. Approximately 0.5PV surfactant slug were injected in surfactant flooding, while in surfactant-polymer flooding, ~0.3PV surfactant slug were injected after water flooding followed by injection of ~0.2 PV polymer slug.

To determine the effects of surfactant concentration on the additional oil recovery, three sets of sandpack flooding (Sample S1, S2 and S3) were conducted using different surfactant concentrations, viz. 0.1, 0.2, and 0.3 wt%. The concentrations of the surfactant were kept above CMC considering the surfactant loss by adsorption during flooding^[28]. Surfactant slugs were injected when water cut reached ~95% during water flooding. The oil recovery and water cut as function of pore volume injected of surfactant slugs have been plotted in Figure 3. Use of surfactant shows significant additional recovery after water flooding due to reduction of interfacial tension between oil and displacing fluid and consequent formation of oil bank. The additional recovery after the water flooding increases with increase in surfactant concentration. A relationship between the surfactant concentrations and the flow rate across the sand pack is shown in Figure 4. The three runs had almost the same flow rate for the initial waterflood stage. However, during surfactant injection the flow rate was found to decrease drastically though the injection pressure was maintained constant. The decrease in injection rate may be due to the formation of oil bank and consequent displacement of oil with lower mobility. The higher drop in flow rate was observed for higher concentration of surfactant which results higher recovery at higher concentration. The additional recoveries by surfactant flooding over conventional water flooding have been summarized in Table 1. Residual oil saturations have been calculated by material balance equation.

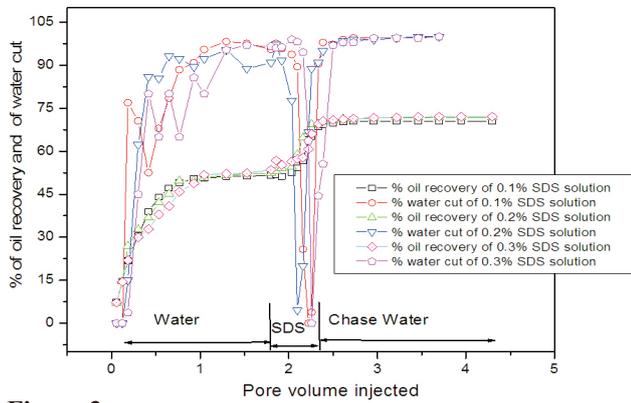


Figure 3
Production Performance of Surfactant Flooding

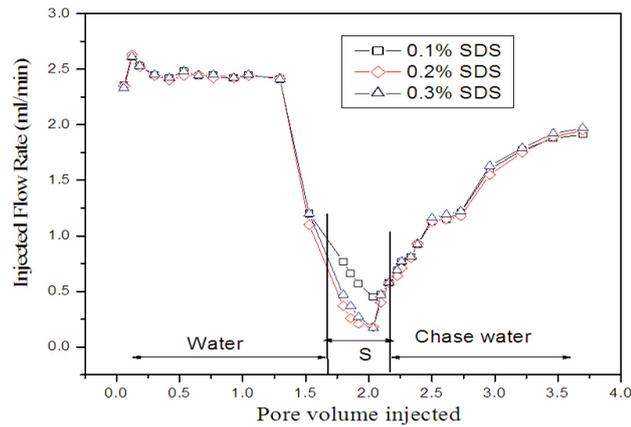


Figure 4
Effect of Produce Pore Volume on Injected Flow Rate in Surfactant Flooding

The production performance of polymer augmented surfactant flooding is shown in Fig. 5 and the results are summarized in Table 2. In case of surfactant flooding 17.955%, 20.29% and 21.565% OOIP (Fig 3 and Table 1) additional oil recovered after water injection were observed for three different concentrations of surfactant. While in case of surfactant-polymer flooding the additional oil recovery is 20.997%, 23.068% and 23.15%

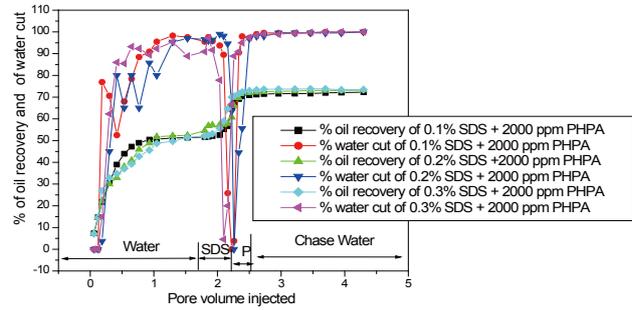


Figure 5
Production Performance of Surfactant-Polymer Flooding

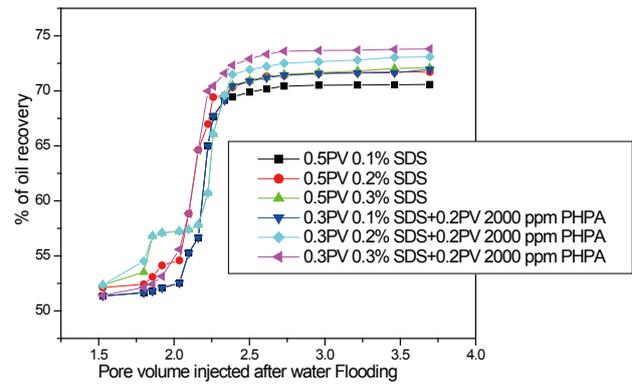


Figure 6
Production Performance of Surfactant and Surfactant-Polymer Flooding

OOIP (Fig 5 and Table 2). Therefore the additional recovery for surfactant-polymer flooding is effectively higher than only surfactant flooding. This is due to the synergic effects of reduction of interfacial tension by surfactant and improvement of mobility ratio by polymer solution. A comparative picture of the flooding performances by surfactant and surfactant-polymer flooding is shown in Figure 6.

Table 1
Recovery of Oil by Surfactant Flooding for Three Different Systems

Exp. No.	Porosity (%)	Permeability, $k_w (S_w=1)$	Permeability, $k_o (S_w)$	Design of chemical slug for flooding	Oil recovery after water flooding (%OOIP)	Additional recovery (% OOIP)	Saturation, S_{wi}	S_{oi}	PV S_{or}
S1	38.665	1.234	0.212	0.5PV SDS (0.1%) + Chase water	51.652	17.955	19.0	80.9	20.2
S2	39.586	1.235	0.212	0.5PV SDS (0.2%) + Chase water	52.42	20.29	19.8	80.2	19.1
S3	38.665	1.233	0.213	0.5PV SDS (0.3%) + Chase water	52.522	21.565	17.9	82.1	18.3

Table 2
Recovery of Oil By Surfactant-Polymer Flooding for Three Different Systems

Exp. No.	Porosity (%)	Permeability, $k_w (S_w=1)$	Permeability, $k_o (S_w)$	Design of chemical slug for flooding	Oil recovery after water flooding (%OOIP)	Additional recovery (% OOIP)	Saturation, S_{wi}	S_{oi}	PV S_{or}
SP1	36.805	1.224	0.213	0.3 PV 0.1% SDS+ 0.2 PV 2000 ppm PHPA+ Chase water	51.353	20.997	15.0	85.0	22.9

To be continued

Continued

Exp. No.	Porosity (%)	Permeability, k (Darcy)		Design of chemical slug for flooding	Oil recovery after water flooding (%OOIP)	Additional recovery (% OOIP)	% Saturation		
		$k_w(S_w=1)$	$k_o(S_w)$				S_{wi}	S_{oi}	S_{or}
SP2	37.725	1.236	0.213	0.3 PV 0.2% SDS+ 0.2 PV 2000 ppm PHPA+ Chase water	51.362	23.068	17.1	82.9	21.7
SP3	37.725	1.245	0.212	0.3 PV 0.3% SDS+ 0.2 PV 2000 ppm PHPA+ Chase water	51.41	23.15	18.5	81.5	21.3

CONCLUSION

In the present study a series of flooding experiments have been conducted to observe the additional oil recovery after water flooding using surfactant and surfactant-polymer slug. Based on the experimental results the following conclusion may be drawn:

1. Use of very small quantity of surfactant reduces the surface tension of displacing fluid (water) significantly, which in turn increases the recovery by forming an oil bank. On the other hand use of polymer increases sweep efficiency by decreasing the mobility ratio.

2. Injection of 0.5 pore volume surfactant increased recovery by approximately 20% OOIP.

3. S-P process increased the recovery by 2.78% OOIP compared to the surfactant flood by injecting same pore volume SP slug.

REFERENCES

- [1] Healy, R. N., & Reed, R. L. (1974). Physicochemical Aspects of Micro Emulsion Flooding. *Soc. Per. Eng. J.*, 14, 491-501.
- [2] Bera, A., Ojha, K., Mandal, A., & Kumar, T. (2011). Interfacial Tension and Phase Behavior of Surfactant-Brine-Oil System. *Coll. Surf. A*, 383, 114-119.
- [3] Hill, H. J., Reisberg, H., & Stegemeier, G. L. (1973). Aqueous Surfactant System for Oil Recovery. *J. Pet. Tech.*, 25, 186-194.
- [4] Larson, R.G., & Hirasaki, G. (1978). Analysis of Physical Mechanisms in Surfactant Flooding. *Soc. Pet. Eng. J.*, 8, 42-58.
- [5] Shah, D.O., & Schechter, R.S. (1977). Improved Oil Recovery by Surfactant and Polymer Flooding. New York: Academic Press Inc..
- [6] Michels, A.M., Djojoseparto, R.S., Haas, H., Mattern, R.B., Van Der Weg, P.B., & Schulle, W.M. (1996). Enhanced Waterflooding Design with Dilute Surfactant Concentrations for North Sea Conditions. *SPE Reservoir Engineering*, 11, 189-195.
- [7] Miller, J., & Austad, T. (1996). Chemical Flooding of Oil Reservoirs 6. Evaluation of the Mechanisms for Oil Expulsion by Spontaneous Imbibition of Brine with and Without Surfactant in Water-Wet, Low Permeability, Chalk Material. *Coll. Surf. A*, 113, 269-278.
- [8] Austad, T., & Milter, J. (1997). *Spontaneous Imbibition of Water into Low Permeable Chalk at Different Wettabilities Using Surfactants*. Paper presented at the SPE International Symposium on Oilfield Chemistry, Houston.
- [9] Flumerfelt, R.W., Li, X., Cox, J.C., & Hsu W.F. (1993). *A Cyclic Surfactant-Based Imbibition/Solution Gas Drive Process for Low Permeability, Fractured Reservoirs*. Paper presented at Annu. Tech. Conf. and Exh., Houston, Tx.
- [10] Spinler, E.A., Baldwin, B., & Graue, A. (2000). *Experimental Artefacts Caused by Wettability Variation in Chalk*. Paper presented at the 6th Symposium on Reservoir Wettability, Socorro, NM, US.
- [11] Chen, H.L., Lucas, L.R., Nogaret, L.A.D., Yang H.D., & Kenyon D.E. (2000). *Laboratory Monitoring of Surfactant Imbibition Using Computerized Tomography*. Proceedings of 2000 SPE International Petroleum Conference and Exhibition in Mexico, Villahermosa, Mexico.
- [12] Keijzer, P.P.M., & De Vries, A.S. (1990). Imbibitions of Surfactant Solutions. Paper presented at SPE/DOE 7th Symp. On Enhanced Oil Recovery, Tulsa, OK.
- [13] Schechter, D.S., Zhou, D., & Jr. Orr, F.M. (1994). Low IFT Drainage and Imbibitions. *J. Pet. Sci. & Eng.*, 11, 283-300.
- [14] Cuiec, L., Bourbiaux, B., & Kalaydjian, F. (1994). *Oil Recovery by Imbibitions in Low-Permeability Chalk*. *SPEFE* 200-208.
- [15] Babadagli, T., Al-Bemani, A., & Boukadi, F. (1999). Analysis of Capillary Imbibition Recovery Considering the Simultaneous Effects of Gravity, Low IFT, and Boundary Conditions. Paper presented at SPE Asia Pacific Improved Oil Recovery Conference, Kuala Lumpur, Malaysia, Oct. 25-26.
- [16] Yu, H., Wang, Y., Zhang, Y., Zhang, P., & Chen, W. (2011). Effects of Displacement Efficiency of Surfactant Flooding in High Salinity Reservoir: Interfacial Tension, Emulsification, Adsorption. *Advances in Petroleum Exploration and Development*, 1(1), 32-39.
- [17] Needhan, R. B., & Peter, H. D. (1987). Polymer flooding review. *J. Pet. Technol.*, 12, 1503-1507.
- [18] Daripa, P. (1987). *Instability and Its Control in Oil Recovery Problems*. Proceedings of 6th IMACS Int. Symp. on Computer Methods for Part. Diff. Eq.-VI; Vichnevetsky, R., Ed. Bethlehem, PA, 411-418.
- [19] Daripa, P., Glimm, J., Lindquist, B., & McBryan, O. (1988a). Polymer Floods: A Case Study of Nonlinear Wave Analysis and of Instability Control In Tertiary Oil Recovery. *SIAM J. Appl. Math.*, 48, 353-373.
- [20] Daripa, P., Glimm, J., Lindquist, B., Maesumi, M., & McBryan, O. (1988b). On The Simulation of Heterogeneous Petroleum Reservoirs, Numerical Simulation in Oil

- Recovery. *IMA Vol. Math. Appl.*, 11, 89-103.
- [21] Guo, S. P., & Huang, Y. Z. (1990). *Physical Chemistry Microscopic Seepage Flow Mechanism* (pp. 100–102). Beijing: Science Press.
- [22] Austad, T., Fjelde, I., Veggeland, K., & Taugbøl K. (1994). Physicochemical Principles of Low Tension Polymer Flood. *J. Pet. Sci. Eng.*, 10, 255-269.
- [23] Hoff, E., Nystrom, B., & Lindman, B. (2001). Polymer-Surfactant Interactions in Dilute Mixtures of a Nonionic Cellulose Derivative and an Anionic Surfactant. *Langmuir*, 17, 28-34.
- [24] Hongyan, W., Xulong C., Jichao, Z., & Aimei, Z. (2009). Development and Application of Dilute Surfactant-Polymer Flooding System for Shengli Oilfield. *J. Pet. Sci. Eng.*, 65, 45-50.
- [25] Samanta, A., Bera, A., Ojha, K., & Mandal, A. 2010. Effects of Alkali, Salts and Surfactant on Rheological Behaviour of Partially Hydrolyzed Polyacrylamide Solutions. *Journal Chemical & Engineering Data*, 55, 4315-4322.
- [26] Cao, X., Jiang, S., Sun, H., Jiang, X., & Li, F. (2002). Interactions of Polymers and Surfactants. *Appl. Chem.*, 19, 866–869.
- [27] Reppert, T.R., Bragg, J.R., Wilkinson, J.R., Snow, T.M., Maer Jr., N.K., & Gale, W.W. (1990). *Second Ripley Surfactant Flood Pilot Test*. Paper presented at the SPE/DOE Symposium on Enhanced Oil Recovery, Tulsa, April 22-25.
- [28] Mannhardt, K., Schramm, L.L., & Novosad, J.J. (1993). Effect of Rock Type and Brine Composition on Adsorption of Two Foam-Forming Surfactants. *SPE Advanced Technology Series*, 1, 212-218.