International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 23 (2015) pp 43801-43806
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Effect of Ethylene Oxide Groups on The Performance of Anionic Extended Surfactants in Light Oil Reservoir

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Abstract

This paper investigates the role of Ethylene Oxide (EO) Groups in the performance of anionic extended surfactant, where Propylene Oxide (PO) groups is absent. Anionic extended surfactant (AES) used in this study is ethoxy carboxylate which has variation on intermediate polar (EO 3, 5, 7, 9) and hydrophobic chain between C11-C13. AES was tested with several laboratory testing using a very light oil sample taken from Tempino Field, Indonesia, that has API gravity 42 and viscosity 0.9 cP. While reservoir brine salinity is 8670 ppm, the surfactants were also tested for wide range of salinity, i.e. 500 ppm-30000 ppm of monovalent ion Na+ and 500 ppm-10000 ppm of divalent ion Ca2+. With the addition of EO groups, the polarity difference between the hydrophilic and hydrophobic group will be smoothed, so the interaction of water and oil at the interface will be much longer and also the formation of micro emulsions can be easily done. The addition of EO groups is also need to be exercised to obtain the optimum one to be compatible with the fluids sample. Based on laboratory test results, AES with EO number between 5 and 7 is optimum showing good performance at Tempino light oil sample by giving low IFT (~10^{-3}) in the salinity range of study with monovalent ion Na^+ and divalent ion Ca^{2+} present, good aqueous stability, good thermal stability (at 68 ^oC for 3 months). Furthermore, AES with EO number 7 yields potentially good incremental oil recovery on core flooding with relatively quick response.

Keywords: Anionic Extended Surfactant, Surfactant Flooding, Light Oil, Ethoxy Carboxylate.

Introduction

Surfactant injection technology is one of promising EOR method to mobilize residual oil saturation [1]. The ability of surfactant to reach an ultralow IFT (≤10^{-2} mN/m) is the main role of surfactant performance [2]. Another mechanism to enhance residual oil saturation is by forming an oil-in-water micro emulsion in the interphase [3].

According to several previous studies, there are so many types of surfactants that are used in researches on surfactant injection for EOR application. One of the latest surfactant used is extended surfactant. This surfactant was firstly introduced in 1995 by Minana-Perez et.al [4]. It is a surfactant that has an intermediate polar groups between the hydrophilic group and hydrophobic group [2,4]. Due to the presence of intermediate-polar group, extended surfactant not only increases the tail length but also offers a smoother interfacial transition from a polar aqueous to non-polar oil region [2,4,5]. In this study, intermediate polar used is EO. It is aimed to improve the interaction of surfactant head groups with water. As the result, extended surfactants are able to form a middle phase of micro emulsion, a high solubilization in aqueous stability test and an ultra-low IFT in a wide range of oil types, for example is a long chains alkanes, triglycerides, and vegetable oils [2,4,5,6,7,8]. Adkins et.al [9] has synthesized Guerbet alkoxy sulfates compound, but this surfactant is not chemically stable in a neutral solution (pH~7) and at a temperature approximately above 60 ^oC. Its stability will increase when pH of the solution range between 10 and 11. To improve the performance of the previous extended surfactant, they developed the surfactant by synthesizing a Guerbet alkoxy carboxylates with a bulk group of hydrophobic, branched hydrophobic group and wide range of Prophylene Oxyde (PO) and Etylene Oxyde (EO) groups added [9]. In 2014, Jun lu [9] showed good results in oil recovery by using Guerbet alkoxy carboxylate surfactants with a wider range of parameter tested, such as a light to viscous oils by using a mixture of dead oil and synthetic oil (surrogate oils), active to inactive oils, low to high temperature, and also sandstone and carbonate rocks.

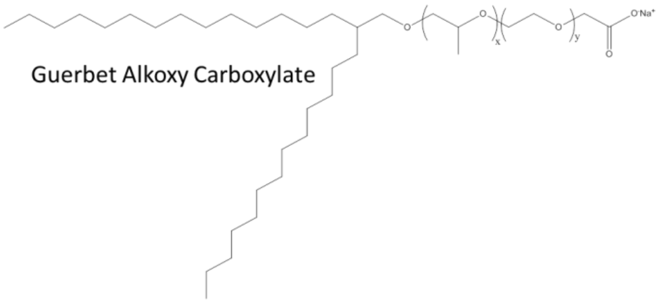


Fig.1. Molecule Structure of Guerbet Alkoxy Carboxylate

In this study, the extended surfactant has been modified in its hydrophobic groups with a linear alkyl (C11-C13), the variations of intermediate polar (EO number 3, 5, 7, and 9) and the hydrophilic group with carboxylate. This chemical structure of anionic extended surfactant has been tested for its compatibility at Tempino fluids characteristic. The oil characteristic are EACN around 8.29 and API gravity at 43.45. The reservoir temperature is 68 ^{o}C. Although the previous work has demonstrated that extended surfactants can provide an ultra-low IFT and a high solubilization capacity in a harsh condition [9], but an information about the effect of chemical structure in extended surfactant for its ability to lower the interfacial tension, to form a micro emulsion in a very light oil and to overbear with divalent ion in brine is still limited especially for enhance oil recovery application. So this study is conducted to evaluate the effect of EO group number in extended surfactants structure on micro emulsions phase behavior, IFT values, CMC, thermal stability, salinity scan with a variation of divalent ion concentrations, and oil recovery enhancement in light oil reservoir.

Experimental Procedure

Surfactant used in this study is anionic extended surfactant (ethoxy carboxylate surfactant [CnH2n+1-(EO)x-COO-] with variation of EO repetition: 3, 5, 7, and 9. Crude oil samples originating from Tempino Field, Indonesia is used for phase behavior, IFT, CMC, thermal stability, and coreflood tests. The surfactants are provided by Rakhara Chemical Technology. The crude oil characteristics are shown in Table 1. Brine is also from Tempino Field, with characteristic shown in Table 2. In core flood experiment, Berea Sandstones is used, which composition is shown in Table 3. The experiment was performed to study the relationship between the structures of surfactant (variation of EO) and its phase behavior, salinity scan, thermal stability. It is also to study their influence on the oil recovery during core flood experiment.

TABLE.1. Characteristics of Oil from Tempino Field

Parameters	Value
Saturated	72.60%
Aromatics	25.49%
Resins	2.14%
Asphaltenes	0.78%
EACN (Equivalent Alkane Carbon Number)	8.29
TAN (Total Acid Number)	1.23
Viscosity	0.90 cP (at 66 ^{o}C)
API Gravity	42

TABLE.2. Characteristics of Brine from Tempino field

Parameters	Value
TDS	15540 ppm
Salinity	8670 ppm
pH	8.6
Na^+	3906 ppm
K^+	21 ppm
Ca^{2+}	79 ppm
Mg^{2+}	109 ppm
Cl^-	5244 ppm
CO_3^{2-}	411
SO42-	31 ppm
Total Organic Carbon (TOC)	999 ppm

TABLE.3. Characteristics of Berea Core

Mineral	Content
Quartz (SiO_2)	77.1%
Kaolinite ($Al_2Si_2O_5(OH)_4$)	5.3%
Montmorillonite ($CaO.2(Al,Mg)_2Si_4O_{10}(OH)_2.4H_2O$)	2.6%
Calcite ($CaCO_3$)	-
Calcium Silicate ($CaSiO_3$)	-
Albite, calcian, ordered ($(Na,Ca)Al(Si,Al)_3O_8$)	2.5%
$NaO.3(Al,Mg)_2Si_4O_{10}(OH)_2.4H_2O$	-
Muscovite ($(K,Na)Al_2(Si,Al)_4O_{10}(OH)_2$)	7.3%
Hydrotalcite ($Mg_6Al_2CO_3(OH)_{16}.4H_2O$)	-
Pumpellyte ($Ca_2FeAl_2(SiO_4)(Si_2O_7)(OH)_2H_2O$)	-

A. Surfactant Characterization

Surfactant used in this study is anionic extended surfactant (ethoxy carboxylate surfactant [CnH_{2n+1}-(EO)$_x$-COO$^-$]. It was analyzed by FTIR to determine functional groups.

B. Surfactant Performance Test

Performance of the surfactant with different EO group number are evaluated by testing IFT and CMC, phase behavior, salinity scan with wide range of monovalent (Na^+) and divalent (Ca^{2+}) concentrations, and thermal stability. The final test is core flooding to determine the incremental oil recovery.

i. CMC Measurements

This test was conducted to determine the minimum surfactant concentration to form micelle. The test is carried out with surfactant concentration of 0.5%, 1%, 1.5%, 2% and 4% w/w. Each solution is measured its IFT [10] with Tempino crude oil using Tensiometer TX 500D at 68° C with 6000 rpm. The IFT measurements were commenced immediately after injecting 2 μL of the oil into a spinning drop tube containing the surfactant formulation. The IFT values were obtained as a function of time. [2]

ii. Phase Behavior Test

This test was conducted to study the behavior of oil/mixture/brine mixture systems at the desired temperature. Surfactant solution in 1 % w/w brine is mixed with Tempino crude oil in test pipette with surfactant/oil ratio 1:1. The open-end of test pipette that contains surfactant solution and crude oil are flame sealed before it is put in an oven at reservoir temperature (68°C) for 15 minutes. Then, pipette is pulled out from oven and shaken for 5 minutes. It is again placed into the oven at 68°C and observed for 24 hours and 48 hours by recording the formation of middle phase micro emulsion.

iii. Salinity Scan

During salinity scan, a specific concentration of surfactant in a different salinity of brine is measured the IFT with reservoir oil. Variation of salinity is generated using NaCl solution with concentration of 500 ppm, 1000 ppm, 5000 ppm, 10000 ppm, 20000 ppm, and 30000 ppm to look at the effect of monovalent ion Na^+. Another variation of salinity is generated using CaCl2 solution with concentration of 500 ppm, 1000 ppm, 5000 ppm, and 10000 ppm to observe the effect of divalent ion Ca^{2+}.

iv. Thermal Stability

Thermal stability for 1% w/w surfactant solution is carried out by keeping solution in oven at temperature of 68°C and measure the IFT every week for 3 months. The test is performed only when surfactants show a low IFT during salinity scan and thermal stability test.

C. Core Flooding

The core flooding system was set vertically to obtain oil recovery after injecting surfactant into the core. The syringe pump with 50 ml pump volume was used to inject the fluids (brine, oil, and surfactants). A nitrogen pump was used to maintain the confining over burden pressure inside the core holder. To establish the required reservoir temperature condition, the core holder was covered by heating mantel which is connected to a temperature controller. The effluent fluids were collected in a small 5 ml tube and the amount of the recovered oil was measured. Water flood was carried out with flow rate 0.3 cc/minute, recording emerging oil from core until no oil was produced. Surfactant flooding was carried out with flow rate 0.3 cc/minute until 7 PV. The large PV injected is intentional to observe overall performance of each surfactant. For field implementation, it concerns only data until 1.5-2.0 PV injected surfactant. Produced oil at each PV was recorded.

Results and Discussion

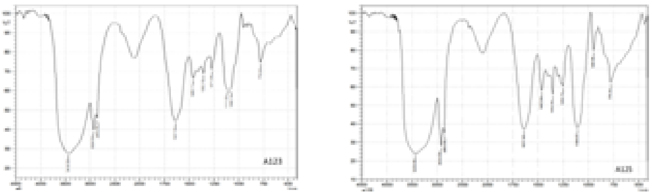
A. Surfactant Characterization

In this study, we have examined 4 samples of surfactants (Table 4).

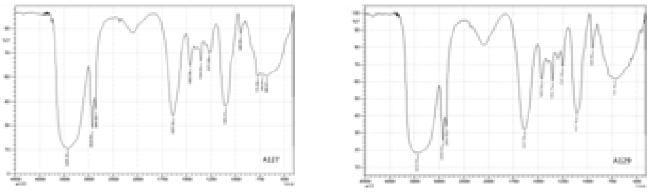
TABLE.4. Samples of Surfactant

Code	Extended Surfactant	No EO	% active	MW (g/mol)
A123	$C_{12}H_{25}$-EO_3-OCH_2-COOH	3	50	376.53
A125	$C_{12}H_{25}$-EO_5-OCH_2-COOH	5	50	464.33
A127	$C_{12}H_{25}$-EO_7-OCH_2-COOH	7	50	552.69
A129	$C_{12}H_{25}$-EO_9-OCH_2-COOH	9	50	640.41

A Fourier Transform Infra-red (FT-IR) analysis was performed in this study. FT-IR is used to determine the existence of functional group in a surfactant or any other chemical compound. Based on the structural analysis, the anionic extended surfactant has a unique peak on the FT-IR spectrum. The FT-IR spectroscopy test of this surfactant in the range of 4000-500 cm^{-1} showed a strong absorption band at 3434-3440 cm^{-1} indicating the stretching vibration of O-H in carboxylate group, respectively. The IR band at 1637 cm^{-1} indicates the stretching vibration of C=O in carboxylate group, respectively. The IR band at 1109 cm^{-1} is characteristic of the C-O-C stretching mode of ethylene oxide group. The disappeared of broad band around 600-800 cm^{-1} that occurs because of the difference in the amount of EO as intermediate polar at the molecular structure of surfactant. The strong absorption band at 2854-2925 cm^{-1} at the FT-IR spectra was due to the-CH3 and-CH2-vibration from the hydrophobic part of the surfactants [11].



(a) A123 (b) A125



(c) A127 (d) A129

Fig.2. FTIR Anionic Extended Surfactant Samples

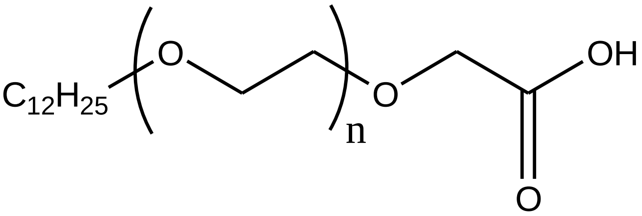


Fig.3. Structure of anionic extended surfactant with n = 3, 5, 7, 9

B. Surfactant Performance

Critical Micelle Concentration or CMC is a minimum concentration of a surfactant to form micelle at which a lowest interfacial tension (IFT) value is attained in oil-water system. Increasing of surfactant concentration after the CMC is reached, the interfacial tension in oil-water system remains the same or it often increases significantly. At concentration greater than CMC value, the excess surfactant do not occupy the interface, therefore they do not improve the IFT. Instead, it forms micelle aggregates as shown in the Figure 4 below that taken from Spinning Drop Tensiometer.

CMC is used as a reference to determine the lowest concentration of surfactant that compatible with the fluid and it is also as a recommended surfactant concentration applied in the EOR application in the field.

a b

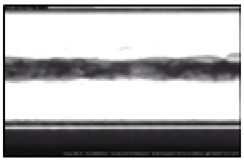

c

Fig.4. Display of Oil-Surfactant Solution during Spinning Drop Measurements (a) before CMC, (b) at CMC, (c) after CMC

The addition of EO group in between hydrophilic and hydrophobic group can increase the ability of conventional surfactant to lower the interfacial tension in a lower concentration. With the addition of EO groups, the polarity difference between the hydrophilic and hydrophobic group will be smoothed, so the interaction of water and oil at the interface will be much longer and also the formation of micro emulsions can be easily done. But this addition of EO groups also need to be exercised to obtain the optimum one to be compatible with the fluids sample. As for the oil sample from Tempino Field that only has an EACN number around 8, and salinity of 8670 ppm, the optimum EO group number is 5-7. It is seen in Figure 5.

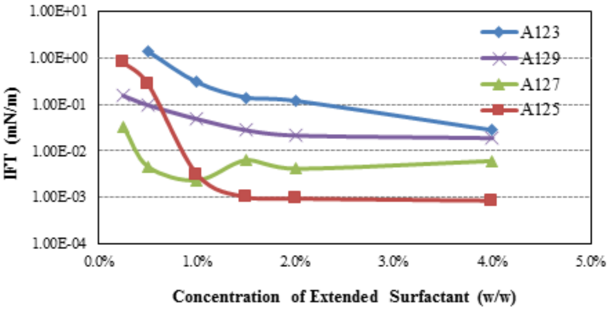


Fig.5. Plot to Estimate CMC of Surfactants

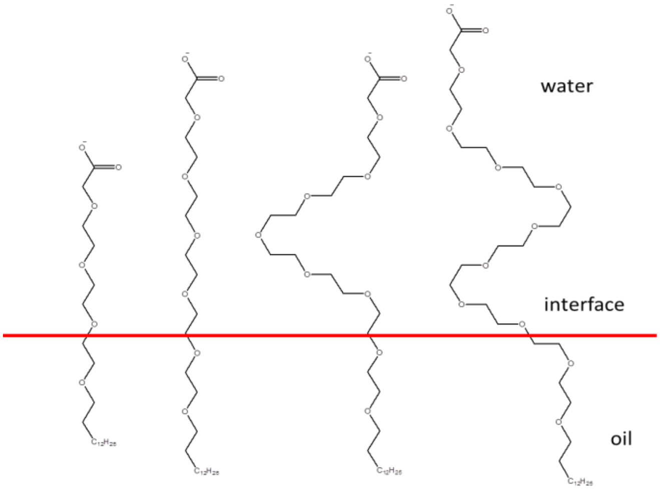
As we can see on Figure 5, at surfactant concentration between 0.25%-4% (w/w), the surfactant A123 and A129 cannot lower the interfacial tension below 0.01 mN/m. It can be explained on an illustration at Figure 6 below.

Surfactant A-123 cannot lower the interfacial tension below 0.01 mN/m because the interaction between hydrophobic groups with oil and hydrophilic groups with water are not equal [2]. So the surfactant will interact with the oil more than the water. Although the surfactant was inserted by EO groups to increase the interaction of hydrophilic group with the water, it is still not enough to balance the interaction between hydrophobic groups with oil (Figure 6a). The same results are also given by the surfactant A-129 (Figure 6d). The addition of EO groups more than 7 will increase the interaction between the hydrophilic groups with water. As a result, the interaction between the hydrophobic groups with oil becomes weaker and an imbalance energy of both interactions. Another important thing to be highlighted is the natural behavior of polymer that can fold when the chain has much number of monomer (Figure 6). This natural behavior of EO polymer will lower the interaction of the surfactant on the interface.

Both surfactant A-125 and A-127 can lower the interfacial tension below 0.01 mN/m, it is because the interaction between hydrophobic groups with oil and hydrophilic groups with water are equal [2]. But as it can be seen on Figure 5, that the surfactant A-127 has a higher interfacial tension value than surfactant A-125 when the surfactant concentration is higher than 1% (w/w) because the EO number added to the A-127 higher than A-125. At surfactant A-127, the amount of EO number added requires a larger space at the interface of oil and water than A-125 (Figure 6b and 6c) so with the same surface area, the surfactant A-127 requires a less concentration to fill the surface of the oil and water interface compared to surfactant A-125.

The surfactants that have been determined its CMC values are tested for the phase behavior test and salinity scan. A phase behavior test in oil-water system is an important parameter to determine the compatibility of surfactant for the application of EOR. A phase behavior of surfactant is dependent upon types and concentrations, reservoir temperature, co-solvent, and salinity of brine.

The phase behavior test is done by mixing oil and surfactant solution (at CMC value) in a test tube with ratio 1:1, respectively and the tube tip is closed by a flame sealed method. The sealed test tube is kept in an oven with reservoir temperature (68 ^{o}C) and the observations of micro emulsion were made at 24 hours, 48 hours, 7 days and 14 days.



(a) (b) (c) (d)

Fig.6. Interaction of Surfactant with Water and Oil on Interface; (a) A123, (b) A125, (c) A127, and (d) A129

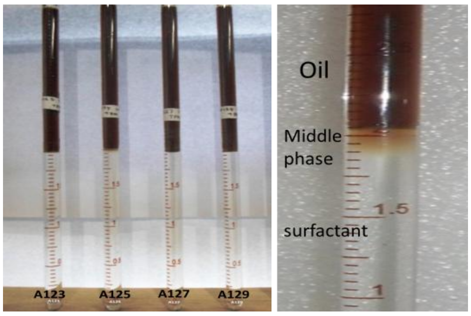


Fig.7. Phase Behavior of Anionic Extended Surfactant

In oil-surfactant-brine system, it can form 3 phases (brine phase, micro emulsion and oil phase) or it is known as Winsor Type III wherein the micro emulsion is in the middle phase. The phase behavior result shown in this study is at 48 hours of observation time because at that time was considered sufficient to represent the stability of the micro emulsion. Results are all four surfactants have shown a middle phase of micro emulsion. Summary of IFT and phase behavior is given in Table 5.

TABLE.5. Summary of IFT and Phase Behavior Tests

Surfac-tant	CMC	IFT at CMC	Aqueous Stability	Phase Behavior	Viscosity of Emulsion
A123	>4%	1.89E-2	One Phase	Have Middle Phase	Not Viscous
A125	1.5%	1.01E-3	One Phase	Have Middle Phase	Not Viscous
A127	1.0%	2.33E-3	One Phase	Have Middle Phase	Not Viscous
A129	2.0%	2.15E-2	One Phase	Have Middle Phase	Not Viscous

After the phase behavior test, salinity scans were conducted to determine the tolerance of brine salinity changes. It can be seen in Figures 8 and 9 that IFT value of each surfactant tends to stable against changes in brine salinity with monovalent Na^+ and divalent Ca^{2+} ion. This is because of the intermediate polar group owned by the surfactants. This intermediate polar group affects the strength of the interaction of surfactants with oil or brine. An ethylene oxide group, which is the intermediate polar group, has an ability to increase the interaction between oil and water.

Another parameter to analyze the surfactant compatibility with the reservoir is thermal stability test. The thermal stability test was conducted for three months by measuring the interfacial tension of surfactants every week after it kept in oven at reservoir temperature (68 °C). Figure 10 shows the thermal stability results for each surfactant (A125 and A127).

It can be seen at Figure 10 that surfactant A127 with 1% (w/w) of concentration gave better thermal stability for the three months period of test. However, we can say that both surfactant types are quite stable and resistant to heat whereas the tendency of IFT remains below 0.01 mN/m. This is because of the existence of ethylene oxide groups as a transition smoother between hydrophobic and hydrophilic groups so that the surface energy balance is maintained.

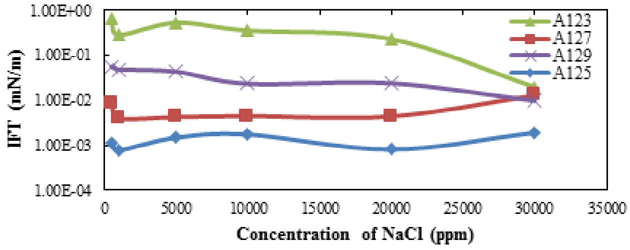


Fig.8. Salinity Scan with NaCl

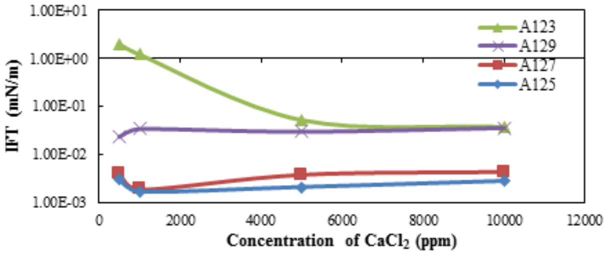


Fig.9. Salinity Scan with $CaCl_2$

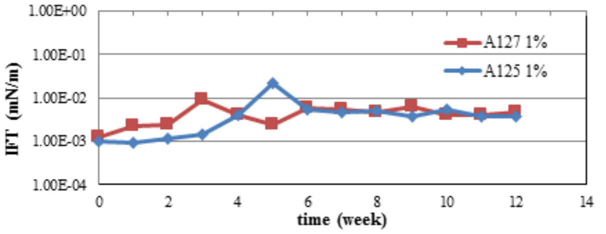


Fig.10. Thermal Stability Anionic extended Surfactant

C. Core Flooding

The surfactant samples that gave good performance in phase behavior, salinity scan, and thermal stability were tested in core flood tests. In this study, the surfactant samples, A125 and A127 with IFT values 9.4×10^{-4} mN/m and 4.2×10^{-3} mN/m respectively (concentration 2% w/w), were tested for core flooding using a Berea core. Both surfactants showed good aqueous stability and have middle phase (Winsor type III). The permeability of Berea cores are 238.2 mD and 254.8 mD. The porosity of the Berea cores are 23.25% and 23.42%. The temperature during the core flooding experiment was 68 °C. Table 6 below display detailed core properties and summary of core flood tests.

TABLE.6. Summary of Core Flood Results

Parameter	Core 1	Core 2
Surfactant	A125	A127
Concentration	2%	2%
Porosity	23.25%	23.42%
Permeability	238.2 mD	254.8 mD
Pore Volume	3.21 ml	3.49 ml
Initial Water Saturation	0.44	0.40
Initial Oil Saturation	0.54	0.60
Initial Oil-in-Place	1.80 ml	2.10 ml
Waterflood		
Cumulative Oil Produced	1.03 ml	1.15 ml
Recovery Factor	57.2%	54.8%
Residual Oil Saturation	0.24	0.27
Surfactant Flood		
Cumulative Oil Produced	0.70 ml	0.85 ml
Recovery Factor	38.9%	40.5%
Residual Oil Saturation	0.02	0.03
Total Flood		
Cumulative Oil Produced	1.73 ml	2.0 ml
Recovery Factor	96.1%	95.2%

First, core was saturated by brine. Then oil was injected to displace water until no more water was produced. To preserve the oil saturation, the treated core is aged in oil for about 7 days at reservoir temperature. For oil recovery evaluation, the saturated core was injected by brine (water flooding) for about 4 PV, at which no more oil were produced. Recovery factor were calculated by dividing cumulative oil produced by known initial oil in place and expressed in percentage. The average oil recovery was 56% (Table 6), which is a normal oil recovery by water flooding in sandstones with permeability around 250 mD.

This is followed by injecting continuous surfactant solution for a total of 7 PV (pore volume). The oil recovered during this stage was also recorded. As shown in Table 6 and Figure 11, the incremental oil recovery by the two surfactants (A125 and A127) are quite high. Further examination, the incremental oil recovery by surfactant A127 (40%) is almost similar than the incremental oil recovery by surfactant A125 (39%). However, as seen in Figure 11, the surfactant A127 injection produces oil faster than the surfactant A125 does. The differences may be explained that adsorption of surfactant by rock surfaces is expected to occur in both cases, meaning that effective surfactant concentration interacting with oil and water is less than initially injected. Thus it reduces the ability of surfactant to provide low IFT value especially for A125 whose IFT is greater than 0.01 mN/m for concentration less than about 0.9%. On the other hand, surfactant A127 can still provide IFT lower than 0.01 mN/m at lower concentration down to 0.3% (Fig. 5).

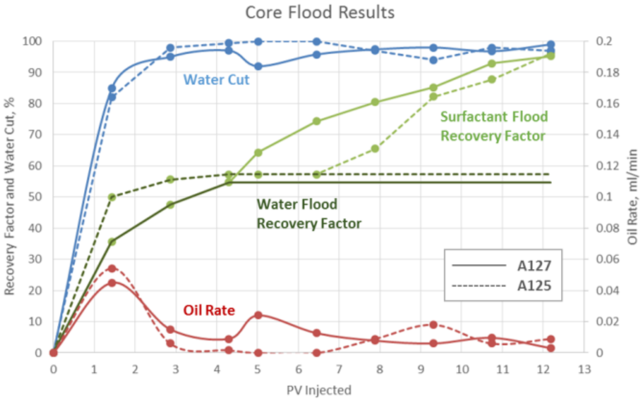


Fig.11. Core Flood Results

Conclusion

In this study AES formulation is variation intermediate polar (EO group number of 3, 5, 7, and 9) between Carboxylate (hydrophilic) and hydrophobic chain of C11-C13. Ethylene Oxide (EO) Group, as spacer between the hydrophilic head and hydrophobic tail, reduce the IFT between brine and oil at Tempino Field. EO groups in the surfactant structure affects critical micelle concentration (CMC) and interfacial tension between oil and water. The optimum number of EO groups must be exercised and for Tempino light oil, EO number range between 5 and 7 is the optimum one. Lower and higher number than this range create a condition of imbalance energy between interactions hydrophilic head with water and hydrophobic tail with oil.

Further observations indicate that AES with relatively low chain in the tail works for very light oil. It shows to have wide salinity tolerance with either monovalent ion Na^+ or divalent ion Ca^{2+} and it is stable at reservoir temperature of 68 ^oC. Core flooding of AES A127 in Berea core with Tempino fluids at reservoir temperature yield a promising initial result with total oil recovery of 95% (incremental oil recovery of 40% after water flood).

References

[1] D. W. Green, and G. P. Willhite, Enhanced Oil Recovery, Vol. 6, Richardson Texas, pp. 239-245, 1998.

[2] A. Witthayapanyanona, E. J. Acosta, J. H. Harwella, and D. A. Sabatini, “Formulation of Ultralow Interfacial Tension Systems Using Extended Surfactants,” Journal of Surfactants and Detergents, 9(4), pp. 333-336, 2006.

[3] J. J. Sheng, Modern Enhanced Oil Recovery: Theory and Practice, Elsevier Inc, pp. 239-335, 2011.

[4] M. Miñana-Pereza, A. Graciaa, J. Lachaise, and J-L. Salager, “Solubilization of Polar Oils with Extended Surfactant,” Colloids Surfaces A: Physicochem. Eng. Aspects, 100, pp. 217-224, 1995.

[5] S. Solairaj, New Method of Predicting Optimum Surfactant Structure for EOR, Master Thesis, Petroleum Engineering, University of Texas, Austin, 2011.

[6] A. Ferna´ndez, C. Scorzza., A. Usubillaga, and J. Salager, “Synthesis of New Extended Surfactant Containing A Carboxylate or Sulfate Polar Group,” Journal of Surfactants and Detergents 8, pp. 187-191, 2005.

[7] A. M. Forgiarini, C. Scorzza, J. Vela´squez, F. Vejar, E. Zambrano, and J. Salager, “Influence of The Mixed Propoxy/Ethoxy Spacer Arrangement Order and of The Ionic Head Group Nature on The Adsorption And Aggregation of Extended Surfactants,” Journal Of Surfactants and Detergents 13, pp.451-458, 2010.

[8] N. Arpornpong, A. Charoensaeng, D. A. Sabatini, and S. Khaodhiar, “Ethoxy Carboxylate Extended Surfactant: Micellar, Adsorption and Adsolubilization Properties,” Journal of Surfactants and Detergents 13, pp. 305-31, 2010.

[9] J. Lu, C. Britton, S. Solairaj, P. J. Liyanage, D. H. Kim, S. Adkins, W. Gayani, P. Arachchilage, U. Weerasooriya, and G. A. Pope, “Novel large-Hydrophobe Alkoxy Carboxylate Surfactant for Ehanced Oil Recovaery,” SPE Journal, pp. 1-9, 2014.

[10] M. J. Rosen, Surfactants and Interfacial Phenomena, Wiley Interscience, pp. 84-86, 1978

[11] R. M. Silverstein, F. X. Webster, and D. J. Kiemle, Spectrometric Identification of Organic Compounds, 7th ed., John Wiley & Sons, Inc., pp. 72-101, 2005