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Evaluation and research on performance of a blend surfactant system of alkyl polyglycoside in carbonate reservoir

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ABSTRACT

As a green and efficient surfactant, alkyl polyglycoside (APG) has been applied in many industrial areas due to its green and environment friendly characteristics, which is in accordance with the world-wide sustainable development trend. Up to now, the relative studies were limited in sand reservoirs. In this paper, the performance of APG and the flooding efficiency in carbonate core were experimentally studied.

The interfacial tension between water and oil could be effectively reduced to an ultra-low level by APG, and to 2.3×10^{-3} mN/m by the APG+$NaHCO_3$ system. For the APG+base composite system, the rock interface wettability could be improved and the surface property was transformed from hydrophilicity to lipophilicity. A new system of 0.5%APG+0.5%$NaHCO_3$ was selected to test its ability for the improvement of oil recovery. The oil recovery could be increased about 6.4–7.1% by this binary compound system.

1. Introduction

G oilfield of Kuwait has abundant carbonate rock resources, and some oilfields suffered natural depletion problem during the waterflood stage. After secondary oil extraction stage, water content is rapidly increased and oil recovery is reduced. More than half of the oil is still under the oilfield. Hence, the tertiary oil extraction methods should be applied to enhance oil recovery (Lahann and Campbell, 1980; Nancollas and Sawada, 1982; Zaitoun et al., 2003; Liu et al., 2004). In order to realize the sustainable development and to reduce environmental pollution and destruction during the oil exploration procedure, the green and environment friendly surfactant APG should be put into application.

In this paper, the interfacial tension, interface wettability, and oil displacement efficiency of the APG were analyzed in order to find the best composition of binary compound system (Wang et al., 2005; Rezaei Gomari and Hamouda, 2006; Rezaei Gomari et al., 2006).

2. Experimental materials and methods

The moisture retardant RS-2 and RS-3, petroleum sulfonate ORS41 and T701, heavy alkylbenzene sulfonate LH-1 and LH-2, as well as nonionic surfactant APG and PNP were used in the experiments.

RS-2 and RS-3 were modified by quaternary ammonium salt cationic surfactants. They were stable in aqueous alkali and have moisture retard capability.

As a kind of industrial petroleum sulfonate, ORS41 has good performance but is expensive, whose main components are a variety of mixture of alkyl benzene sulfonate. The content of the single alkyl benzene sulfonate is 18% in the composite and that of bi-alkyl benzene sulfonate is 16%.

Produced from barium petroleum sulfonate by Yumen refining company, T701 is a common surfactant, whose effective component is more than 98%. The moisture is less than 0.3% and mechanical impurity is less than 0.2%.

LH-1 and LH-2 are heavy alkylbenzene sulfonates, which are the new types of surfactants with high temperature resistance, high salinity and high oil condensate performance.

PNP is a type of frequently-used phosphate ester anionic surfactant with strong emulsifying ability for tertiary oil recovery, whose effective component is more than 98%.

As a newly completely biodegradable, non-toxic, and no-skin irritants nonionic surfactant, APG has been widely applied in many areas, such as detergent, food, and cosmetic industries. The production as well as understanding of APG are still in early stages and the application of APG is up to now just limited in sandstone reservoir.

The oil samples for laboratory experiments are collected from G oilfield, and the characteristic of crude oil is shown in Table 1. Natural carbonate cores are obtained from G oilfield of Kuwait by drilling. The NaOH and $NaHCO_3$ are used as base. The formation

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Nomenclature

API	API gravity
CMC	Critical Micelle Concentration, mol/L
γ_l	the lowest interfacial tension, mN/m
γ_b	the balanced interfacial tension, mN/m
θ_A	advancing angle, deg
θ_R	advancing angle, deg
θ_c	advancing angle, deg
K	permeability, 10^{-3} μm
φ	matrix porosity, %

water and injected water were simulated by laboratory water with the mineral composition shown in Tables 2 and 3.

The interfacial tensions of different systems are measured by the springing drop method on an interfacial tensiometer TEXAS500. Rheometer Brookfield DV-III Ultra is used to measure the viscosity of the oil and solutions. The wettability of carbonate core is measured by dynamic contact angle method and Washburn method on dynamic contact angle analyzer DCA-322 and Washburn tube.

3. Experiment 1: measurement of interfacial tension between surfactant and oil

3.1. Experimental procedure

The different kinds of surfactants and injected water were mixed to prepare solutions with the mass concentration of 0.5% at room temperature (25–33 °C), and the PH values of solutions are about 7 to 8.5. The surfactant solution was injected into the glass tube of interfacial tensiometer, and then a drop of oil was injected into surfactant solution by needle tubing. The interfacial tension was measured under the condition of 45 °C and 3000 r/min. The interfacial tension points at different times were recorded for 24 h to get the lowest and stable values. Before the interfacial tension get stable, the values were recorded once in a minute, and when the values become nearly stable, the time interval will extend to once in 60 min.

3.2. Results and discussions

3.2.1. The reduction ability for the interfacial tension

The lowest and stable interfacial tension between surfactant systems with 0.5% mass concentration and oil are shown in Table 4.

From the table it can be seen that all the surfactant systems with mass concentration of 0.5% have a low interfacial tension level, but the abilities for interfacial tension reduction are quite different. APG and RS-3 have the strongest abilities for interfacial tension reduction, while that of the two kind petroleum sulfonates are relatively weaker.

The results of dynamic interfacial tension between surfactant solutions and simulated oil are shown in Fig. 1. APG, PNP and moisture retardant were selected as representatives.

The transformation discipline of dynamic interfacial tension shown in Fig. 1 demonstrates that interfacial tension between solutions and oil varies with time. After reaching the minimum value, the interfacial tension was in a stable state without dramatic variation. As the lowest interfacial tension can be only kept within short time, the stable interfacial tension instead of the lowest one was chosen to evaluate the ability for interfacial tension reduction between water and oil.

3.2.2. The efficiency of the interfacial tension reduction

From measured abilities for the interfacial tension reduction, it can be seen that APG and RS-3 can reduce the interfacial tension to a relatively low level. The interfacial tension efficiencies of APG and RS-3 solutions with different concentrations are shown in Table 5.

As the mass concentration of surfactant solution increases from 0.1% to 0.6%, interfacial tension between water and oil increases firstly and then decreases a little. Hence, it is unrealistic to get a lower interfacial tension from the surfactant solution with higher mass concentration. To a certain extent, the surfactant solution could efficiently work to reach the lowest interfacial tension.

Table 2
The mineral composition of simulated formation water, (mg/L).

Na^+	SO_4^{2-}	Cl^-	HCO_3^-	Mg^{2+}	Ca^{2+}	Salinity
2033.9	19.41	2659.5	1039.9	29.5	136.2	6048.4

Table 3
The mineral composition of simulated injected water,(mg/L).

HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	Salinity	PH	Water type
350	8.86	11.5	64.1	21.9	28.3	485	7.64	$NaHCO_3^-$

Table 4
Interfacial tension between Surfactant systems and oil.

Surfactant	Mass concentration (%)	γ_l (mN/m)	γ_b (mN/m)
ORS41	0.5	7.89×10^{-3}	9.1×10^{-3}
T701	0.5	6.24×10^{-3}	9.8×10^{-3}
LH-1 (C16–18)	0.5	4.95×10^{-3}	8.25×10^{-3}
LH-2 (C14–16)	0.5	4.37×10^{-3}	7.88×10^{-3}
PNP	0.5	1.53×10^{-3}	2.75×10^{-3}
APG	0.5	1.1×10^{-3}	2.16×10^{-3}
RS-2	0.5	1.78×10^{-3}	2.95×10^{-3}
RS-3	0.5	1.41×10^{-3}	2.26×10^{-3}

Table 1
The characteristics of crude oil.

API	Density at 20 °C (kg/m^3)	Viscosity at 45 °C (mpa S)	Freezing point (°C)	Moisture (%)	Paraffin content (%)	Colloid (%)	Asphaltene (%)
28.17	878.5	8.7	< -20	0.04	1.38	10.65	2.17