Surfactant solutions for low-permeable polimictic reservoir flooding

A N Kuznetsova, M K Rogachev, A S Sukhih

Saint-Petersburg Mining University, 2, 21st line V.O., Saint Petersburg, 199106, Russia

E-mail: kuznetsova_an@hotmail.com

Abstract. The paper presents the results of the study and development of new surfactants for flooding of low-permeable polimictic reservoirs. The developed composition allows considering the influence of reservoir rocks on a clay bond (to ensure clay-swelling inhibition), and on oil displacement (to reduce the interfacial tension within the oil-water-rock system).

1. Introduction

Polimictic reservoirs of Western Siberia representing low-permeable rocks with high clay content ensure the extension of petroleum reserves in the Russian Federation [1]. Oil production from such reservoirs is extremely difficult since traditional flooding does not meet the requirements of efficiency and profitability of their development.

The traditional flooding of polimictic reservoirs increases the volume of argillaceous cement several times and considerably reduces the permeability of oil reservoirs. Therefore, there is a need to develop new compositions that improve the properties of water injected into the formation thus increasing the oil production efficiency.

2. Materials and methods

Natural core samples from the fields of Western Siberia. EASYDROP surface (interfacial) tension measurement device. The Zhigach-Yarov device to measure the clay-swelling ratio. DTS-430 machine and MS-535 saturator (Coretest Systems Corporation) was used for core grinding and preparation. High pressure pump, confining pressure pump, and Hassler type core holder were used for filtration.

3. The study of oil recovery factor using a new surfactant

However, the choice of a surfactant (from a variety of known reagents) for the flooding system (formation pressure maintenance system) of a specific field is a difficult task. Until now there is no unified criteria allowing confirming the efficiency and scope of application of either reagent.

According to some researchers [2], an efficient surfactant shall satisfy the following requirements: ability to dissolve in formation water, to reduce interfacial tension within the ‘water-oil’ phase, to have minimal adsorption, to fully maintain its activity upon contact with fluids and surfaces of the borehole equipment, to prevent clay swelling, and to be available and ecologically safe.

The above makes it possible to conclude that to increase the flooding efficiency of low-permeable argillaceous reservoirs there is a need to add two types of surfactants: nonionic and cation-active surfactants into the injected water, which are able to reduce the interfacial tension within the ‘oil-gas-
water-rock’ system and prevent the hydration of clay minerals.

The reagent under the code name NG-2 belonging to hydroxyethylated amines was chosen as nonionic surfactant and the KATAPAV reagent produced in Russia under TS 2482-003-04706205-2004 [3] representing alkyldimethylbenzylammonium chloride was chosen as cation-active surfactant for the given study. If the reagents for surfactant composition in these systems are properly selected, this may lead to synergism, i.e. to the improvement of mixture properties in comparison with the properties of its components. It is of primary importance to reduce the critical micelle concentration (CMC) in low-permeable polymeric sandstones, and hence, the ‘surfactant-oil’ interfacial tension alongside with the reduction of clay minerals hydration.

The interfacial tension for both surfactant components and for the mixture in general was determined and the obtained data were compared with some surfactants mostly known and widely used in petroleum industry to estimate the efficiency of obtained surfactant mixture. The interfacial tension was determined via the EASYDROP surface (interfacial) tension measurement device (droplet shape analysis system).

Figure 1 shows the diagrams of experimental dependences of ‘distilled water-kerosene’ interfacial tension on mass concentration of reagents (surfactants) in water.

The diagrams confirm that with the increase in surfactant concentration the interfacial tension decreases. At the same time it turned out that for NG-2 reagent the CMC is 20 times lower than for KATAPAV (0.1% and 2%), but, at the same time, KATAPAV reduces the interfacial tension more. The NG-2 (nonionic) and KATAPAV (cation-active) reagents demonstrated synergetic properties in the mixture: their joint CMC was 2 times lower than that for NG-2 (0.05% and 0.1%), and the interfacial tension, when the reagents were added, was lower than when the components of the mixture were added separately (7 and 3.8 times respectively, in comparison with NG-2 and KATAPAV).

Nonionic surfactant may reduce the hydrophobic properties of cation-active surfactant, therefore the Zhigach-Yarov device was used to define the clay-swelling ratio [4] (Fig. 2). It was found that the addition of nonionic surfactant to cation-active surfactant strengthens the hydrophobic properties of the latter one. As a result, the composition leads to swelling of clay minerals in a reservoir by 0.2%, whereas the initial pure cation-active surfactant increases a clay volume by 2%.

![Figure 1. Dependence of ‘distilled water-kerosene’ interfacial tension on mass concentration of reagents in water](image-url)
A number of tests was carried out in the Laboratory of Enhanced Oil Recovery of Saint Petersburg Mining University to study the filtration properties of the chosen surfactant composition.

The study was conducted on the filtration unit, which schematic diagram is given below (Fig. 3).

During the study of the influence of surfactant composition on the displacement factor and filtration properties of productive samples, the prepared core samples were placed in a core holder for confining pressure of a real productive reservoir. The filtration velocity was set to 0.5 cm³/min. The fluids were injected in equal volumes. Six various filtration tests accompanied by pumping of surfactant solution and formation water through a core sample were made. Besides, the filtration test with surfactant pumping followed by sampling of pumped fluid every 2nd pore volume.

The natural rock samples of the Priobskoye Field with the following average parameters were used in filtration tests: length – 6 cm, diameter – 3 cm, absolute porosity – 19%, absolute permeability – 0.02 µm². The density of fluid saturating a core sample made 0.842 g/cm³.

Figure 4 shows the dependence of pressure gradients on cumulative flow and type of fluid obtained as a result of filtration tests. The diagram of pressure gradient dependence on time (Fig. 4) shows an obvious difference in pressure gradients depending on the type of injected fluid. These data make it...
possible to conclude that a surfactant solution efficiently reduces the ‘water-oil’ interfacial tension, which provides for injection at lower pressure.

The study resulted in dependences of oil displacement efficiency on type of injected fluid, which are given below (Fig. 5). The histogram shows that the injection of surfactant solution gave higher oil displacement efficiency than that for the injection of formation water.

**Figure 4.** Time dependence of pressure gradient of formation water or developed surfactant composition

**Figure 5.** Efficiency of oil displacement from rock sample while injecting formation water or developed surfactant

Besides, the surfactant adsorption was defined during the filtration tests, which included periodic (upon injection of every 2nd pore volume) sampling of water at the output of a core holder and assessment of residual surfactant concentration in it. Figure 6 shows the diagram of surfactant
adsorption dependence on pore surface on the injected volume.

It is known that polymictic reservoirs have high specific surface (up to 0.5-1.2 m²/g) and bigger adsorption activity in comparison with carbonates and quartz sandstones. According to studies, the surfactant adsorption is 5-6 times higher for polymictic reservoirs [5] than the adsorption for quartz sandstones, and thus reaches 1.2-5.5 mg/g of rock or 15-60 kg/m³ of porous medium. On average, the nonionic surfactant adsorption on pore surface makes \( (2-3) \times 10^{-6} \) kg/m². Figure 6 shows that the adsorption of the developed surfactant mixture on pore surface of a rock sample makes on average \( 1.88 \times 10^{-6} \) kg/m², which is less than the average adsorption of similar reservoirs.

![Figure 6. Dependence of adsorption of the developed surfactant mixture on pore surface on the volume of injected solution](image)

4. Conclusions
The surfactant composition, representing water solution of two surfactants: nonionic and cation-active ones, is developed for injection into low-permeable polymictic reservoirs for enhanced oil recovery.

The results of the study showed that the developed surfactant composition is different from its analogs in terms of smaller adsorption on pore surface reservoir rocks, higher efficiency to reduce the ‘oil-water’ interfacial tension and hydration of clay minerals, ability to reduce injection pressure into a reservoir and to increase oil displacement efficiency, which makes it possible to recommend the developed surfactant composition for industrial application during flooding of low-permeable polymictic reservoirs.

References
[1] The state report on conditions and use of mineral resources of Russia in 2014.
[2] Petrov N A, Izmukhambetov B S, Agzamov F A, Nogayev N A 2004 Cation-active surfactants as effective inhibitors for technological processes of oil industry (SPb.: Nedra)
[3] KATAPAV reagent (Cation-active surfactants), Retrieved from: http://niipav.ru/alkildimetilbenzilammoniy-hlorid-s12--s14-50-voda
[4] Bakirov A U 1987 Chemical methods in oil production, Institute of Organic Chemistry (USSR Academy of Sciences, Ufa Petroleum Institute: Nauka)
[5] Surguchev M L 1985 Secondary and tertiary methods of enhanced oil recovery (M.: Nedra)