

Dynamic modeling of surfactant flooding in low permeable argillaceous reservoirs

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Abstract. This article reveals the current state and problems of the Russian oil production sector. Physicochemical enhanced oil recovery methods are proposed as a solution. The investigation of surfactant treatment efficiency and their integrated effect on oil and reservoir rock is conducted as well as its applicability analysis for low permeable poly-mineral reservoir. The results of dynamic modeling of oil displacement by the developed surfactant composition in a low permeable reservoir are presented.

1. Introduction

World oil consumption is continuously growing. To meet the demand, the increase of the production is required. Russia is one of the leaders in oil production. In order to sustain at least the same level and even more to enhance production, it is required both to put new fields and deposits into production, and to increase the oil recovery factor in existing ones. Nowadays, low permeable reservoirs (about 0.05 mm²) of Western Siberia are major suppliers for the Russian raw material base. Oil production from these reservoirs is extremely challenging, because traditional waterflooding cannot establish efficient and profitable development. In addition, hydrocarbon reservoirs of Western Siberia are clay-containing rocks (clay minerals content is about 20%).

Oil and gas reservoirs are characterized by the chemical equilibrium state between the formation water and the clay minerals, which are pore-filling cement. When ion balance in the "water - clay minerals" system changes, the key feature of clay minerals initiates, which is their capacity for ion exchange. The process is driven by the mineral composition of clays and their specific properties, as well as the chemical composition of the injected water. That is exactly why the proper choice of injection water is one of the most important task in oil field development.

The article investigates ways to solve the mentioned problem along with dynamic modelling results.

2. Materials and methods

Core samples collected from upper-Jurassic hydrocarbon reservoirs in Western Siberia, with a fine grain size less than 0.16 mm.

Clay fraction swelling was quantitatively evaluated by the volumetric method. A volume of liquid absorbed by a milled core sample can be determined by the increase of the core sample volume, which is measured on Zhigach-Yarov device. This device consists of perforated cylinder with a piston connected to measuring system. The cylinder contains a diaphragm that comprises a layer of clay stacked in between of two paper filters. Then, this system is submerged into the examined solution. The measurements of thickness are taken with fluorescent microscope Labomed-2L and are conducted until thickening stabilisation that corresponds to the ultimate clay swelling.

Interfacial tension was determined on EASYDROP ((KRUSS GmbH) droplet shape analysis system) surface/interfacial tension measurement device. Lithofacies model was designed in Roxar RMS software package. Dynamic model simulation was conducted in Schlumberger Eclipse software.



3. The study of oil displacement efficiency by surfactant

Waterflooding is a well-known traditional worldwide method of oil recovery. Nonetheless, the conventional waterflooding is ineffective under conditions of low permeable poly-mineral reservoirs.

One of the successful enhanced oil recovery techniques, which was proved by global experience, is surfactant addition into injection water in order to increase sweep efficiency.

Surfactant is injected as a part of an aqueous solution that allows reduction of interfacial tension on the phase boundaries in “oil-gas-water-rock” system that can provide the increase of oil recovery factor [1].

Selection of injection water is not a simple task. A widely known fact that clay swelling index is much lower for formation water than that for fresh water. This is accounted for higher salinity of formation water. Practically, formation water is the most suitable in terms of oil displacement.

Pattern flooding requires significant amount of water, whereas formation (mineralized) water reserve is limited. Thus, fresh and bottom water, as well as Cenomanian water in Western Siberia must be utilized. This fact results in swelling of the clay particles that was proved by a number of researches.

In case of fresh water injection, application of chemical agents, such as clay swelling inhibitors, should be taken into account.

Clay swelling inhibition can be achieved in different ways: reduction of the surface hydration due to cation exchange of the clay exchange complex by less water sensitive; clay mineral transformation and elimination of interplanar hydration; clay surface modification due to molecular absorption of bi- and trivalent metal hydroxides, as well as due to hydrophobization of clay mineral surface [2].

Cation-active surfactants have the highest rock hydrophobization capability. However, these chemicals demonstrate poor efficiency regarding interfacial tension reduction, which is essential for low permeable reservoirs.

The maximum interfacial tension reduction can be achieved by usage of anion-active surfactants. But they react with minerals dissolved in formation water and add hydrophilic properties to surface. Furthermore, it is not recommended to use them along with cation-active surfactants.

Nonionic surfactants generally do not react with salts dissolved in formation water, and therefore do not decrease their own surface activity.

In the laboratory of “Enhanced oil recovery” of Saint Petersburg mining university a new surfactant composition, which is a mixture of cation-active and nonionic surfactants, was designed. The composition efficiently decreases “oil-water” interfacial tension by a factor of 16,5. It also works at less concentrations in comparison with traditionally used nonionic surfactants, such as OP-10 (Blue line) and initial nonionic surfactant NG-2 (Green line) (Fig. 1).

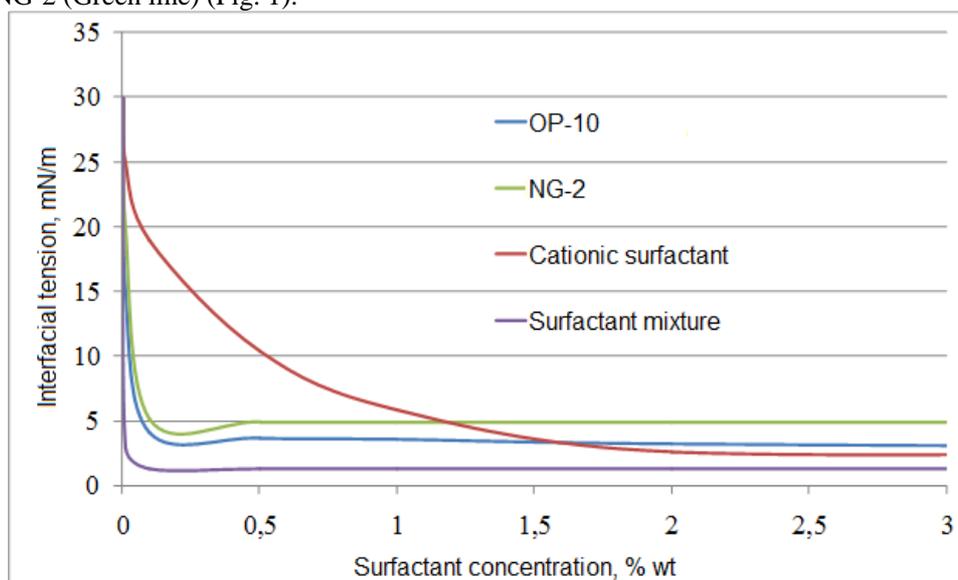


Figure 1. “Distilled water/kerosene” interfacial tension versus chemical agent concentration in water.

Nonionic surfactants addition can cause descent of hydrophobic properties of cation-active surfactants.

Therefore, clay swelling estimation should be conducted all over again. It turned out that additive of nonionic surfactant intensifies the hydrophobic properties of the cation-active surfactant, as well as decreases interfacial tension even more. As a result, the composition leads to swell clay minerals in

reservoir by 0.2%, whereas the initial pure cation-active surfactant increases a clay volume by 2%. This fact was also confirmed by a microscope survey.

Photographs (Figure 2) represent that clay particles affected by surfactant composition have a significantly smaller size than those affected by low salinity (fresh) water.

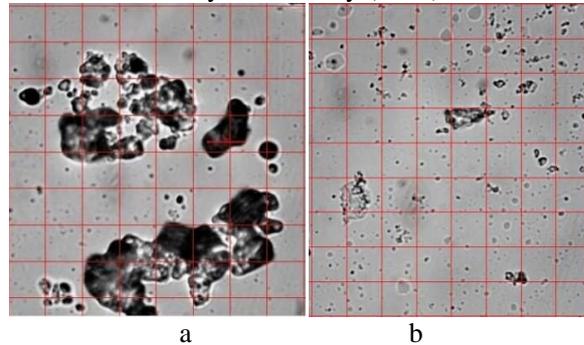


Figure 2. Photographs of clay particles after interaction with a) - freshwater, b) – designed surfactant.

In order to confirm the efficiency of this technique, dynamic simulation was conducted. Initially, the lithofacies model was elaborated. The grid size was 1400x1400m. The model design considered grain size distribution and structural features of oil field, such as lenticular beds and layered heterogeneity. Subsequently, porosity and permeability distributions were applied into each lithofacie group. After that, upscaling was conducted on structure and reservoir properties.

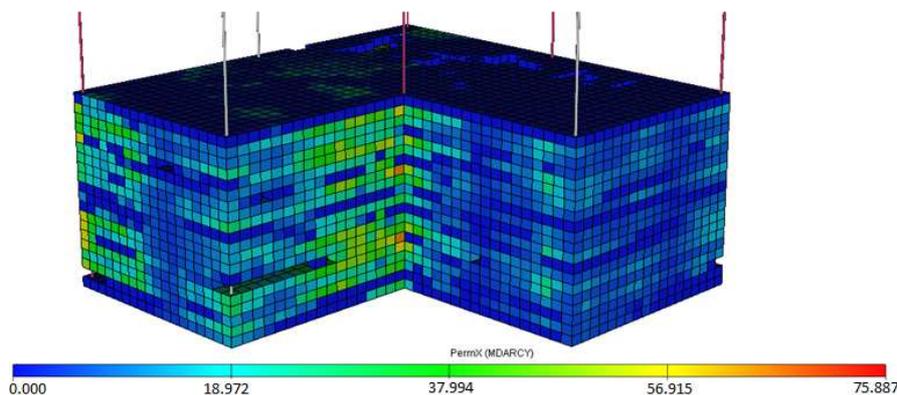


Figure 3. Permeability distribution of the dynamic model

Then, upscaled porperm properties were involved into the dynamic model. Subsequently, the surfactant model was simulated in Schlumberger Eclipse.

Reservoir and fluid averaged properties of upper-Jurassic hydrocarbon reservoirs in Western Siberia were used for initial data:

- Formation volume factor – $2.16 \text{ m}^3/\text{m}^3$
- Gas to oil ratio – $405.7 \text{ m}^3/\text{m}^3$
- Bubble point pressure - 28.9 MPa
- Oil viscosity at reservoir conditions – 0.3 cP
- Oil density at surface conditions – $772 \text{ kg}/\text{m}^3$
- Initial reservoir pressure - 41.3 MPa
- Initial reservoir temperature – 102 deg. C.

The following development system was applied, since it is commonly used for this kind of oil reservoirs.

- Inverted 9 spot well pattern;
- Minimal bottom hole production well pressure – 10 MPa;
- Target liquid production rate – $100 \text{ m}^3/\text{day}$;
- Voidage replacement ratio – 0.9;
- Maximum injection pressure – 46 MPa.

When water cut reaches 98%, the well shuts. Simulation stops when all production wells are shut. Surfactant concentration in the injection water is 0.01%.

The results revealed that surfactant composition notably decrease residual oil saturation, regardless the fact that the displacement front propagation remained unaffected. The ultimate difference in recovery factor amounted 2.3% and total oil recovery increased by 40.91 thousand m³ (Fig. 5).

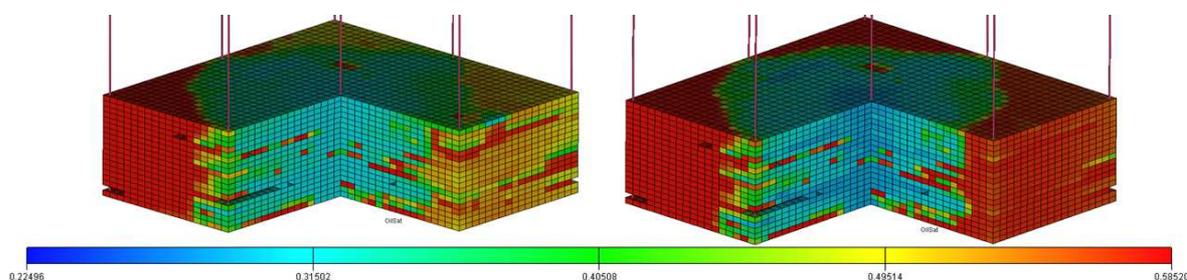


Figure 4. Oilsaturation distribution after 10 years of production. On the left – conventional waterflooding. On the right – surfactant flooding.

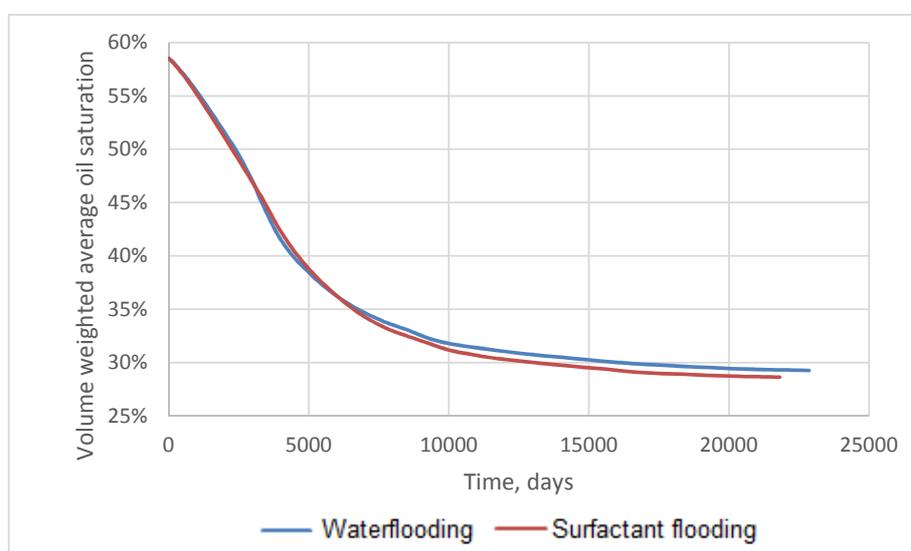


Figure 5. Volume weighted average oil saturation vs production time.

Conclusion

Based on the results of cation-active and nonionic surfactants research, as well as observation of their properties combination, the new surfactant solution was developed. This composition declared itself as a substance that is not only able to wash residual oil out the rock surface but also able to efficiently inhibit the clay swelling process.

Dynamic simulation results show that flooding in low permeable argillaceous reservoirs with the application of developed surfactant can increase oil recovery factor by 2.3%

References

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