

Finally, results are obtained. The figure (Fig.4) demonstrates a cross-plot where the correlation between predicted and true values of oil rate after HF is presented for tested dataset ($R^2 = 0.86$). Obviously, the regression model has a high prediction ability. Additionally, the model has low aleatoric uncertainty if the predicted value lies in the range from 5 to 50 and from 200 to 300. It means that forecast of low and high oil rates looks better than middle values.

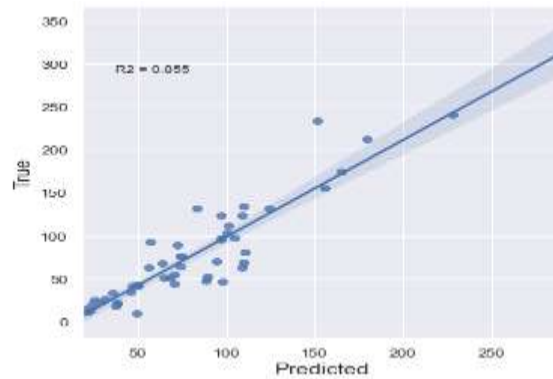


Fig. 4. Cross plot of predicted and true values

The following conclusion is made as a result of this study:

- The regression model for flow rate prediction was created by CatBoostRegressor algorithm;
- Input parameters allow to reach the high predictive ability of the model;
- Performance of model is sufficient: RMSE (test) = 0.86;
- Based on the trained model the computational time for the forecast is less than 1 minute;
- Applicability of proposed solution can be translated into routine reservoir engineer tasks.

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SURFACTANT TYPES AND CLASSIFICATION IN CHEMICAL ENHANCED OIL RECOVERY (CEOR)

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For the first time, the use of surfactants as an additive in oil reservoir flooding was used in the USA in the 40s of the 20th centuries. According to the nature of hydrophilic head groups, surfactants are majorly divided into four classes: anionic, cationic, zwitterionic, and nonionic surfactants (Fig. 1). Anionic surfactant is the most commonly used type, containing sulfate ($-O-SO_3^-$), sulfonate (SO_3^-), or carboxylate ($-COO^-$) groups, though usually in association with an alkaline metal (Na^+ or K^+) cation. The sulfate surfactant has a better tolerance to salinity for both monovalent and divalent cations, but can be easily decomposed at temperature higher than 60 °C. On the other hand, surfactants containing sulfonate groups are tolerated to high temperature, but sensitive to high salinity and easily precipitate at high divalent cation concentrations. The most commonly used surfactants for CEOR are sulfonate surfactants, which were produced either by direct sulfonation of aromatic groups in refinery streams or crude oils, or by organic synthesis of alkyl/aryl sulfonates. Petroleum sulfonate, synthetic alkyl/aryl sulfonate, internal olefin sulfonate (IOS), alpha olefin sulfonate (AOS), and alkoxy sulfonates have been evaluated for CEOR applications. Equilibrium adsorption for the alkyl aryl sulfonate surfactant was 3.5 mg/m², whereas its ethoxylated counterpart demonstrated lower adsorption of 0.8 mg/m² on calcite. Under water-wet conditions, changing the surface redox potential from an oxidized to a reduced state decreased the C14–16 AOS adsorption level by 40%, to ~0.3 mg/g on Berea sandstone cores [1, 2]. At a concentration of 3000 ppm of IOS, increasing the pH from 8.24 to 9.57 decreased surfactant adsorption from 0.760 to 0.161 meq/100 g of rock. Adsorption of C15–18 IOS onto two pure minerals (calcite and quartz) are about the same ~1.1 mg/g, and the adsorption capacity of shales depends on the mineral composition, ranging from 7.0 to 1.7 mg/g. Typically, cationic surfactants are quaternary ammonium compounds (QAC), with the positive charge on the N atom. Nonetheless, cationic surfactants are more expensive than anionic surfactants. Zwitterionic surfactant contains

both anionic and cationic surface charges, such as carboxyl and sulfonate betaines. Nonionic surfactant bears no apparent ionic charge, consisting of non-dissociable functional groups such as alcohols, phenols, ethers, esters, or amides. When opposite charges are present among surfactant and rock surface, surfactant adsorption tends to be higher. Similar behavior is also observed for amphoteric surfactants, which have a greater adsorption on kaolinite surface than anionic surfactant because of the strong electrostatic interactions. The nonionic surfactants adsorption on clay minerals was found to be much higher than anionic surfactants. In a commercial surfactant system, it generally contains surfactant mixtures with a variety of hydrophobic and polar groups. Interactions among surfactant mixtures can result in remarkable interfacial effects owing to changes in surfactant adsorption and also in the charge density of rock surfaces. In terms of anionic-nonionic surfactant blends, the presence of nonionic surfactant decreased adsorption of anionic surfactant on positively charged surfaces, but the adsorption of nonionic surfactant was enhanced. Similarly, the amounts of both nonionic surfactants adsorbed on shale or sandstone surfaces were reduced in the presence of anionic surfactant. On the other hand, the amount of either anionic surfactant or nonionic surfactant adsorption can be minimized on clay minerals when they were mixed with each other. Results showed that the synergistic effect for the coadsorption of cationic-nonionic surfactant mixtures induced wettability alteration of rock surfaces. The underlying mechanism for the adsorption of cationic-nonionic surfactant mixture was thought to be more or less the same for the anionic-nonionic surfactant mixture: hydrophobic interactions and the reduction of the electrostatic repulsions. Because of the risk of precipitation or formulation instability, the adsorption behavior of cationic-anionic surfactant mixtures was seldomly investigated, and more focus was put on their micellar and interfacial properties [1]. The added chemical groups greatly affect surfactant adsorption, such as propoxy (PO, C₃H₆O) and ethylene oxide (EO, C₂H₄O) groups. It was found that surfactant adsorption on kaolinite clay declined with the increase of the number of PO groups. This is because increasing PO groups make surfactants more hydrophobic and the stronger hydrophobic interactions relatively lessen the interactions between polar heads of the surfactants and the specific sites on the kaolinite clay surfaces. Increasing the EO to hydrocarbon ratio resulted in a substantial decrease in the adsorption of poly(ethylene glycol) monoalkyl ethers on silicas. A lower adsorption was observed on calcite for ethoxylated alkyl aryl sulfonate surfactant compared to its non EO counterpart. Moreover, by incorporating EO units into the surfactant molecule, high solubilization of oil and brine phases were achieved due to the hydrogen bonding of EO and water. Unlike SDS and SDBS systems, the EO groups may bind Ca²⁺ and the interaction between Ca²⁺ and -O-SO₃⁻ group decreases, consequently, the anionic surfactant would not easily precipitate by Ca²⁺, i.e., the Ca²⁺ tolerance of anionic surfactants is improved by the introduction of EO groups. A nonyl phenol with 5.1 EO groups has the same hydrophilicity as a dodecylphenol with 8.3 EO groups, but the second one produces twice as much solubilization of octane and water, whose hydrophilicity can be varied continuously by changing the average EO groups. It was also observed that more the number of EO groups in the anionic surfactant, the higher was the aqueous stability at higher salinities. The influence of the number of EO and PO groups on phase behavior of Guerbet alcohol sulfates have been investigated to select optimal surfactant structures for cosurfactant-free microemulsion systems. Moreover, compared to its linear counterpart, the branched structure of phosphate ester surfactants is beneficial to improve the adsorption performance of the gas-liquid interface, but not to the adsorption of the solid-liquid interface [1]. The position of the branching of sulfonate group has a measurable effect on the surfactant adsorption on the alumina surface. Increasing percent of PO and increasing degree of hydrophobe branching of the surfactants leads to increase surfactant adsorption. Surfactant concentration is the most crucial factor to determine the adsorption of the surfactant and adsorption isotherms. At low surfactant concentration below the CMC, surfactant adsorbs as monomers on the mineral surfaces. The adsorption is due to electrostatic interactions for ionic surfactants and hydrogen bonding for nonionic surfactants. As surfactant concentration increases, lateral (hydrophobic) interactions are significant for later surfactant adsorption and surface aggregation takes place. When reaching the CMC, adsorption achieves a plateau and further increasing surfactant concentration gives no influence on adsorption. However, too high surfactant concentration may cause the building of undesirable pressure gradients by the end effect, against the direction of flow. Recently, many researchers proved that adding nanoparticles (NPs) to surfactant foam show an enhancement in the stability of foam, due to the characteristics of the NPs, their performance is not affected by conditions such as high temperature and the presence of oil or salt. In addition, they are difficult to maintain when moving in porous media, so the rock permeability remains virtually unchanged. In addition, its uptake by the reservoir rocks is negligible, and amplifiers are cheap as they can be obtained from various inexpensive sources [3].

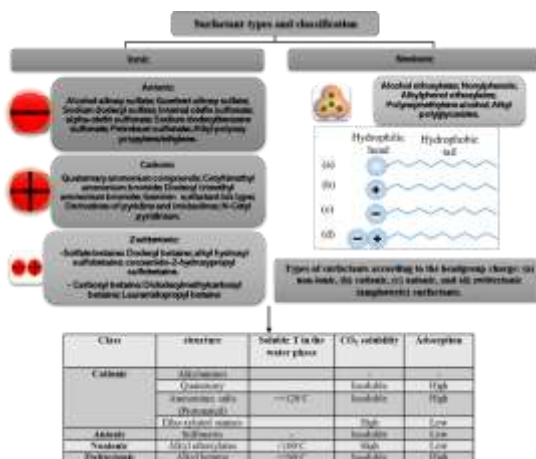


Fig. 1. Surfactant types and classification

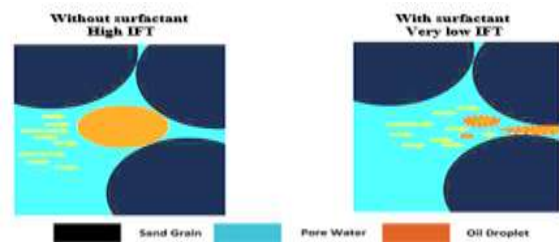


Fig. 2. mechanism of surfactant for CEOR [2]

The main mechanism in oil recovery processes using surfactants is to reduce the surface tension at the interface between the displacing and displaced liquids to very low values, at which capillary-retained oil becomes mobile (see Fig.2). Over time, the films between the foam bubbles become thinner due to the liquid draining, the bubbles burst, the foam breaks down and, finally, instead of the foam, one liquid phase remains - a solution of the foaming agent in water or other liquid.

Conclusion

Main factors influence surfactant adsorption, including (i) surfactant characteristics. Types of anionic, cationic, zwitterionic, and nonionic surfactants with different head groups, such as sulfonate and sulfate groups. Surfactant mixtures, surfactant structures with various functional groups, linear chain or branched chain, and surfactant concentrations; (ii) solution chemistry, i.e., solution pH, ionic composition with monovalent and divalent cations, hardness and salinity; (iii) rock mineralogy referred to sandstones, carbonates, and unconventional shales; (iv) and reservoir temperature. In an effort to mitigate surfactant adsorption, various additives and chemical formulations have been proposed with the addition of alkalis (strong alkalis, weak alkalis, and organic alkalis), polymers, nanoparticles, co- solvents, ionic liquids as well as implementing with salinity gradient and low salinity water flooding strategies. Finally, current trends and future challenges in alkalis, sacrificial agents, nanofluids injections, at high salinity and high temperature conditions for surfactant based EOR are outlined, which significantly improve our knowledge in designing and optimizing CEOR with reduced surfactant loss.

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**TELLURIDES IN THE ORES OF THE ABYZ GOLD-PYRITE DEPOSIT
(CENTRAL KAZAKHSTAN)**

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The Abyz birthplace is located at the production site of Central Kazakhstan in the Karaganda region, 30 km west of the Kentyube mine. The geological structure includes devonian volcanogenic-sedimentary deposits intruded by intrusive and subvolcanic formations of medium-basic composition. According to previous works [1], two types of ores are widespread at the deposit: solid and disseminated.

The ores of the Abyz deposit are difficult to enrich. Their technological persistence is conditioned by close mineral intergrowth of copper and zinc, with pyrite and rock-forming minerals, a variety of textural and structural features and a complex composition. The average content of gold in ores is 6.6 g/t, silver - 64.6 g/t.

In the course of scientific work using the Tescan Vega 2 SBU device with a thermionic tungsten cathode, a large number of tellurides were discovered, namely: calaverite, petzite, hessite, altaite, chenguodaite, racligite and tellurobismuthite.

Gold is present in mineral form, the predominant amount, which is associated with electrum, is less common in the form of native. About 16% of gold is represented by tellurides (Table 1).

Table

Gold mineralization in ores of the Abyz deposit

Mineral form of gold	Percentage, %
Electrum AgAu	60 %
Native gold Au	24 %
Calaverite AuTe ₂	12 %
Petzite Ag ₃ AuTe ₂	4 %

The more common gold telluride in ores in terms of its chemical composition (Au = 40-43 %, Te = 57-60 %) is represented by calaverite AuTe₂. The detected inclusions of oval grains do not exceed 1.5 microns in size. The surface image (Fig. 1) shows that the grains are “overlaid” on pyrite, that is, they belong to a later stage. The rare mineral petzite Ag₃AuTe₂ (Au=25-26 %, Te=32-33 %, Ag=41-42 %) was also found in ores in the form of irregular inclusions with a dimension of about 1.45 microns (Fig. 2).

In the process of studying ores, silver tellurides in addition to gold tellurides were identified. With their chemical composition they are represented by hessite Ag₂Te (Ag=62.84 %, Te=37.16 %). The mineral was found as isometric grains, concentrated mainly in pyrite (Fig. 3) and chalcopyrite. Their dimension does not exceed 2.5 microns.

In the course of the work, in addition to the tellurides described above, altaite, chenguodaite, raclidite, and tellurobismuthite were also found.