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Numerical approach for enhanced oil recovery with surfactant flooding

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ABSTRACT

The remained oil in the reservoir after conventional water-flooding processes, forms a dispersed phase in the form of oil drops which is trapped by capillary forces and is almost about 70% of the original oil in the place (OOIP). To reduce oil residual saturation in laboratory experiments and field projects, surfactant flooding is effective via decreasing the interfacial tension mobility ratio between oil and water phases. Estimation of the role of design variables, like chemical concentrations, partition coefficient and injection rate in different performance quantities, considering a heterogeneous and multiphase oil reservoir is a critical stage for optimal design. Increasing demand for oil production from water-flooded reservoirs has caused an increasing interest in surfactant-polymer (SP) and alkali-surfactant-polymer (ASP). Modeling minimizes the risk of high cost of chemicals by improving our insight of process. In the present paper, a surfactant compositional flood model for a three-component (water, petroleum and surfactant), two phase (aqueous and oleic) system is studied. A homogeneous, two-dimensional, isothermal reservoir with no free gas or alkali is assumed. The governing equations are in three categories: the continuity equations for the transport of each component, Darcy's equation for the transport of each phase and other auxiliary equations. The equations are solved by finite-differences using a procedure implicit in pressure and explicit in saturation. The validation of the model is achieved through comparing the modeling results with CMG simulators and Buckley–Leverett theory. The results of modeling showed good agreement with CMG results, and the comparison with Buckley–Leverett theory is explained according to different assumptions. After validation of the model, in order to investigate sensitivity analysis, the effects of system variables (partition coefficient, surface tension, oil viscosity and surface injection concentration) and performance variable (cumulative oil recovery) are studied. Finally, the comparison of oil recovery between water-flooding and surfactant-flooding was done. The results showed higher oil recovery with changes in capillary number when the partition coefficient is greater than unity. Increasing oil viscosity resulted in decreasing the oil recovery by changing in fractional flow. Moreover, it was concluded that the oil recovery was enhanced by increasing surfactant injection concentration. The oil recovery was increased when surfactant was

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injected to the system and this result was obtained by comparing water-flooding and surfactant-flooding.

1. Introduction

The purpose of surfactant-flooding is decreasing the interfacial tension between oil phase and water phase, then oil can easily displace in porous media. Surfactant-flooding is a multicomponent-multiphase system, and can improve oil recovery by injecting a solution of surfactant. This method of EOR, recovers the residual oil saturation by reducing interfacial tension between oil and water phases. Surfactants in low concentration make better the desired oil recovery by decreasing the interfacial tension, alteration of wettability from oil-wet to water-wet, and increasing Capillary number [1,2]. The mechanism of surfactant flooding relates to structures of surfactants molecules which they typically composed of a strong hydrophilic (water loving) group, and a strong hydrophobic (water fearing) group. After injections, it goes to the interface of oil phase and water phase and by accumulating in the form of micelles reduces the interfacial tension between the phases. After the formation of microemulsion of oil and water, the trapped oil is mobilized and the oil recovery increases. Also, surfactant is adsorbed on the surface of the reservoir, and alters the wettability of the reservoir from oil wet to water wet [3,4]. Surfactant flooding can also recover a very high fraction of trapped oil at tertiary oil recovery, so the process should be designed in a cost effective way.

Experimental researches revealed loads of parameters which affect the recovery process. One of the difficulties in chemical-flooding modeling is the complexity of the parameters. Physical properties presented in the process are: interfacial tension between phases, relative permeability, phase saturations, partition coefficients, salinity, surfactant concentration, adsorption, phase viscosities and retention of surfactants [5,6]. Many researchers have been trying to apply different assumptions in order to simplify the complexity and relations among existing variables. Many authors studied the mechanism of chemical-flooding with different methods.

Paul et al. predicted a simplified model for estimating economical aspects of surfactant flooding. They considered the variations of capillary number, surfactant adsorption, wettability and permeability in their designation. Moreover, the effect of salinity which has an important role in oil recovery was ignored in Paul's model [7]. Wang et al. investigated a sensitivity analysis on surfactant flooding, and studied the effect of different parameters. They used the modified model of Pope and Nelson. In one study they considered the process at constant salinity and in another case, extended the work to variable salinity. They detected the effect of salinity, changes of surfactant concentration due to adsorption and initial value of injected surfactant on oil recovery [8]. Camilleri et al. designed the surfactant-polymer flooding process under isothermal, multicomponent and multiphase conditions in a porous media. They studied the effects of polymer viscosity, surfactant and polymer adsorption, and the dependency of saturations to capillary number and permeability. Finally, they validated their results against experimental data [9–11]. Han et al. studied the designation of chemical flooding with GPAS simulator. In Han's modeling the third equation of state was used for hydrocarbon phase behavior, and Hand's rule was used for surfactant/oil/water phase behavior. GPAS solves the modeling equations with fully implicit method. Han studied the phase behavior of surfactant/oil/water solution, interfacial tension, viscosities, adsorption and relative permeability [12]. One of the most famous simulators developed at The University of Texas at Austin is UTCHEM. UTCHEM has the capability of simulating 19 components and 4 phases and considering most physical properties. UTCHEM simulates chemical-flooding in implicit pressure and explicit concentration (IMPES) code. Delshad et al. presented a complete survey of this simulator in several papers [13]. Najafabadi et al. simulated the process of surfactant-polymer flooding with UTCHEM for three types of Winsor phase behavior. In their modeling not only the surfactant was partitioned into three phases, but also the polymer and salt were partitioned between the phases. They used the Hand's rule for phase behavior, and neglected the effect of pressure on surfactant solution phase behavior. Finally, they compared the achieved results of UTCHEM with GPAS [14].

This study intends to present the governing equations for surfactant flooding using the implicit-pressure, explicit composition and explicit-saturation method. The brief review of formulations will be given, then the validation against Buckley–Leverett theory and CMG Simulation will be displayed. Finally, the sensitivity analysis of some parameters will be presented in details.

2. Model assumptions

1 Two phases-an oil phase and a water phase-, three component-oil, water and surfactant-are considered.
2 Only the surfactant component is partitioned in two phases and the equilibrium component relation is given by:

$$K_c = y_{surf}^{water} \Big/ x_{surf}^{oil}$$

3 Dispersion is neglected.
4 Isothermal condition in reservoir.
5 Adsorption of surfactant is not considered.
6 No free gas and Alkali is present in the system.
7 The system is two dimensional with uniform properties.
8 The effect of salinity on phase behavior is neglected.
9 There are no chemical reactions.
10 Darcy's law applies to the flow of each phase.

2.1. Governing equations

The theory presented here, provides an understanding for the case of two phase and three components flow in a porous medium. Using the above assumptions, the compositional mathematical modeling based on Sabeti's [15–17] method is as follows: