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NUMERICAL ANALYSIS OF ALKALINE FLOODING IN RESERVOIRS USING ONE-DIMENSIONAL BUCKLEY-LEVERETT MODELS

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Abstract: Alkaline flooding, a chemical enhanced oil recovery (EOR) technique, uses alkaline agents to generate in situ surfactants that reduce interfacial tension between oil and water. This paper develops and simulates a one-dimensional (1-D) model for alkaline flooding using the BuckleyLeverett frontal advance theory to improve oil recovery from reservoirs. The model applies nonNewtonian fluid dynamics and porous media flow equations to simulate the effects of alkaline solutions in reservoir environments, demonstrating improved oil recovery efficiency.

Keywords: Alkaline flooding, enhanced oil recovery, Buckley-Leverett theory, non-Newtonian fluids, oil recovery simulation

1. INTRODUTION

The demand for crude oil continues to rise globally, driven by economic growth, industrialization, and transportation needs. However, conventional oil production techniques are limited in efficiency, recovering only a fraction of the oil in place. Typically, primary recovery methods recover 5% to 30% of the original oil in place (OOIP), while secondary methods such as water flooding can increase recovery to 30% to 50% (Greaser, 2010). Despite these efforts, a substantial portion of the oil remains trapped in the reservoir due to capillary forces, rock wettability, and high oil viscosity. To address this challenge, enhanced oil recovery (EOR) techniques have been developed. Among the chemical EOR methods, alkaline flooding has gained attention for its potential to improve recovery rates by altering the physicochemical properties of the oil-water interface. Alkaline chemicals such as sodium hydroxide (NaOH) or sodium carbonate (Na_2CO_3) react with the acidic components of crude oil to produce surfactant in situ, reducing IFT and promoting oil mobilization (Cooke et al., 1974). This paper aims to simulate a 1-D model of alkaline flooding, utilizing the Buckley-Leverett frontal advance theory to describe the displacement of oil by alkaline solutions in a porous medium. The focus is on understanding the mechanisms behind alkaline flooding, including IFT reduction, emulsification, and wettability alteration. Through this simulation, the study seeks to contribute to the growing body of research on EOR methods, providing a cost-effective approach for enhancing oil recovery from mature and complex reservoirs.

Alkaline flooding is one of the oldest chemical EOR methods, with its origins dating back to the mid-20th century. Early studies by Wedge (1952) and Doscher (1956) laid the foundation for using alkaline chemicals to enhance oil recovery. These studies demonstrated that alkaline agents could react with acidic components in crude oil, forming surfactants that reduce IFT and improve oil displacement. Over the years, numerous researchers have explored the effectiveness of alkaline flooding in various reservoir environments. Lake (1989) and Jennings et al. (1974) provided comprehensive insights into the role of alkaline flooding in altering wettability and enhancing oil recovery. They showed that alkaline chemicals could change the rock's wettability from oil-wet to water-wet, facilitating better oil displacement through improved relative permeability.

In more recent studies, Sheng (2010) and Liu et al. (2006) emphasized the importance of surfactant generation and emulsification in the alkaline flooding process. These studies highlighted that the in-situ generation of surfactants could significantly lower IFT, leading to improved oil mobilization in reservoirs with high oil viscosity or low permeability. The emulsification of oil also contributes to reducing the mobility of oil, ensuring more uniform displacement. However, alkaline flooding is not without its challenges. The process is sensitive to reservoir conditions such as salinity, temperature, and rock composition. For example, alkaline flooding is not recommended for carbonate reservoirs, as calcium ions can react with alkaline chemicals to form precipitates, which can clog pore spaces and damage the formation (Liu et al., 2006). Therefore, understanding the reservoir's geochemical properties is essential for the successful implementation of alkaline flooding.

2. Material and Method

The methodology adopted in this study involves the development of a 1-D simulation model based on the Buckley-Leverett frontal advance theory. The simulation aims to describe the behavior of alkaline solutions as they displace oil in a porous medium. The Buckley-Leverett theory is widely used in reservoir engineering to model two-phase fluid flow, particularly for predicting the performance of water and chemical flooding.

2.1. Buckley-Leverett Equation for Alkaline Flooding

The Buckley-Leverett frontal advance equation is a conservative equation used to model two phase flow in porous media. For alkaline flooding, the equation is modified to account for the presence of Non-Newtonian fluids, which exhibit shear-dependent viscosity. The general form of the Buckley-Leverett equation is given as ,The rate of change of water saturation with respect to time, plus the velocity of the fluid flow multiplied by the rate of change of the fractional flow of water with respect to position in the reservoir, equals zero.

This equation is modified to include the effects of alkaline concentration and the non-Newtonian nature of the fluid. The revised equation for alkaline flooding is expressed as follows: The rate of change of water saturation with respect to time, combined with the fluid velocity and the rate of change of the fractional flow of water, is balanced by the effects of the alkaline concentration. The fractional flow of water, in this case, is a function of both the water saturation and the concentration of the alkaline solution. Additionally, the non-Newtonian nature of the fluid, where the fluid's viscosity changes with shear rate and alkaline concentration, is taken into account.

This modification ensures a more accurate representation of the fluid behavior during the flooding process, as alkaline solutions can alter the fluid's properties, leading to varying flow characteristics. By incorporating these factors, the model becomes more aligned with real-world conditions during enhanced oil recovery processes that use alkaline flooding.

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The simulation assumes that alkaline solutions follow the power law for non-Newtonian fluids, where viscosity decreases with increasing shear rate. The effective viscosity of the alkaline solution in the porous medium is calculated based on the following relationship:

3. Results and Discussions

The simulation was conducted using reservoir data from a hypothetical field, referred to as "Field X." The following parameters were used in the model:

3.1 table 1 showing the reservoir parameters of Field-x

Wellbore radius (r_w)	0.25ft
Porosity (∅)	20%
Formation thickness (h)	100ft
Connate water saturation (S_{WC})	20%
Residual oil saturation (S_{wi})	20%
Oil fvf(B_o)	1.25bbl/stb
Water fvf(B_w)	1.02bbl/stb
Oil viscosity (μ_o)	2.0cp
Water viscosity (μ_w)	1.0cp
Total injection rate (i_w)	780bbl/day

The relative permeability, saturation of water and alkaline and alkaline cut was also included in the simulation, based on experimentally derived data from similar reservoir conditions. **3.2** table 2: showing the relative permeability, saturation of water and alkaline and alkaline cut.

k_{ro}	k_{rw}	S_{w+alk}	f_{w+alk}	$\frac{df_{w+alk}}{dS_{w+alk}}$
0.48	0.00	0.00	0.00	0
0.31	0.00	0.20	0.00	0
0.18	0.02	0.30	0.12	2.39
0.08	0.06	0.40	0.49	3.86
0.03	0.15	0.53	0.83	1.87
0.00	0.26	0.63	0.96	0.69
0.00	0.45	0.73	0.99	0.13

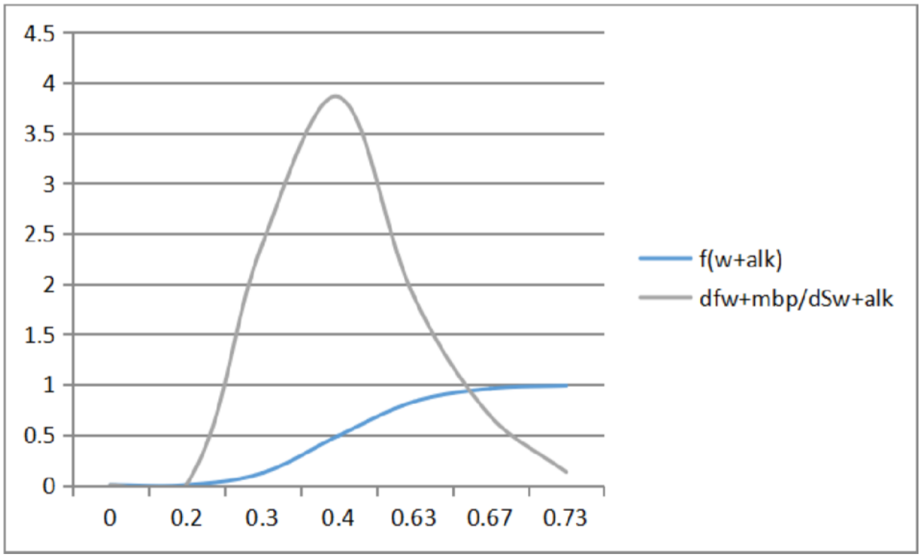

figure 3.1. Showing a graph of water plus alkaline cut against saturation of water plus alkaline.

The results of the 1-D simulation indicate that alkaline flooding significantly improves oil displacement efficiency compared to traditional water flooding. The reduction in IFT due to the In-situ generation of surfactants led to an increase in oil mobility, allowing previously trapped oil to be displaced from pore spaces. The Buckley-Leverett theory predicted the movement of the flood front, with the alkaline solution advancing through the reservoir more efficiently than water alone. The simulation showed that the addition of alkaline chemicals reduced the residual oil saturation from 20% to 10%, demonstrating the effectiveness of alkaline flooding in recovering additional oil. This aligns with findings from previous studies, which reported recovery factors ranging from 50% to 95% in laboratory experiments (Bryan and Kantzas, 2007).

The Non-Newtonian nature of alkaline solutions also played a crucial role in the simulation results. As the flow rate increased, the viscosity of the alkaline solution decreased, allowing for more efficient fluid movement through the porous medium. This behavior was particularly beneficial in regions of the reservoir with lower permeability, where traditional water flooding would have struggled to mobilize oil.

The simulation further revealed that the presence of non-Newtonian fluids improved sweep efficiency, ensuring that the injected fluid covered a larger area of the reservoir. This is consistent with findings from Mihcakan and Van Kirk (1986), who noted that non-Newtonian fluids are more effective in reducing viscous fingering and improving volumetric sweep efficiency.

4. CONCLUSION

This study successfully developed a 1-D simulation model for alkaline flooding, applying the Buckley-Leverett frontal advance theory to describe the displacement of oil in a porous medium. The results demonstrate that alkaline flooding can significantly enhance oil recovery by reducing IFT, altering wettability, and improving sweep efficiency. The use of non-Newtonian fluid equations further improves the model's accuracy, accounting for the unique behavior of alkaline solutions in reservoir conditions. While this study's findings suggest that alkaline flooding is a viable EOR technique for reservoirs, particularly those with high oil viscosity or low permeability, the study doesn't take into account the complexity of the reservoir. Future research should focus on extending the model to include more complex reservoirs and exploring the effects of combining alkaline flooding with other EOR methods, such as surfactant-polymer flooding.

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