Mechanisms of Low Salinity Water Flooding for Enhanced Oil Recovery: A Comprehensive Review

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Abstract: In the recent times, low salinity water flooding (LSWF) has been observed as a promising enhanced oil recovery (EOR) technique both in sandstone and carbonate reservoirs. It involves injection of low salinity water which alters the wettability and interfacial properties of the reservoir rock and crude oil, thus leading to improved oil recovery. This paper presents an overview of the current state of knowledge on the mechanisms of LSWF, gained from both experimental studies and field applications. The results obtained from laboratory analysis and field applications of LSWF have been critically reviewed showing a mixed response in sandstone and carbonate reservoirs. However, the efficacy of LSWF is dependent on various factors, like, reservoir properties, injection water composition and operating conditions. In this paper, a review of the various mechanisms like fines mobilization, wettability alteration, pH reversal, multicomponent ion exchange (MIE), mineral dissolution, micro-dispersion formation etc., affecting the improved oil recovery with LSWF in both sandstone and carbonate reservoirs have been highlighted. This review work can be helpful in proper designing of LSWF in view of the operating parameters and its successful implementation, through a better understanding of its mechanisms depending on different reservoir properties.

Keywords: Low Salinity Water Flooding (LSWF); Enhanced Oil Recovery (EOR); Wettability Alteration; Multicomponent Ion Exchange (MIE); Electrical Double Layer (EDL)

1. Introduction

Research on LSWF has gained significant momentum in recent years owing to its promising prospective to improve oil recovery beyond what is achievable with high-salinity brine injection. LSWF changes reservoir rock wettability, enhancing secondary and tertiary oil recovery. Although laboratory and field tests are encouraging, the specific oil displacement mechanisms in sandstone and carbonate reservoirs are controversial.

Bernard (1967) initially noticed enhanced oil recovery with low-salinity brine. Jadhunandan, Morrow, Yildiz, and Tang validated LSWF in the 1990s. Lab tests indicated better recovery in secondary and tertiary modes, but certain studies reported no tertiary recovery advantages. The mechanism was not known, but Nasralla et al. (2011) endorsed the improvement in recovery (up to 22%) to cation exchange, which lowered electrostatic attraction and changed rock wettability (Bernard et al., 1967) (Jadhunandan et al., 1995; G. Tang & Morrow, 1999; H. O. Yildiz & VALAT, 1999) (Patil et al., 2009; M. M. Sharma & Filoco, 2000; Shell et al., 2010; Skrettingland et al., 2011; Zhang et al., 2007) (Nasralla et al., 2011). Field trials of LSWF have been relatively few, highlighting the need for thorough evaluation before it can be adopted on a larger scale. Webb et al. (2003) provided the first field evidence of reduced residual oil. Studies in Alaska (McGuire et al., 2005) showed a 6–12% reduction in remaining oil saturation, while Syria's Omar field saw a 10–15% STOIIP increase (Vledder et al., 2010). The most notable success was in Alaska’s North Slope, where oil production doubled, and residual oil saturation dropped from 30% to 20% (Lager et al., 2008) (Webb et al., 2003) (Mcguire et al., 2005) (Vledder et al., 2010) (A Lager et al., 2008).

LSWF enhances oil recovery through various mechanisms, including fine particles migration within the reservoir, shifts in ion composition via multicomponent ionic exchange, expansion of the EDL, and changes in pH levels. This paper reviews LSWF fundamentals, experimental design, and field applications in sandstone as well as carbonate reservoirs (G. Tang & Morrow, 1999) (A Lager et al., 2008) (Ligthelm et al., 2009) (Austad et al., 2010).

A Brief History of LSWF

This review presents a chronological comparative study of the application of LSWF along with a detailed discussion of its underlying mechanisms in both sandstone and carbonate reservoirs. The mechanism(s) inferred to contributing the increase in oil recovery by LSWF technique are summarized in Table 1.

Table 1. A brief summary of previous studies on LSWF

Reference	Porous medium	Proposed mechanism	Remarks
(Bernard et al., 1967)	Sandstone	Wettability alteration	Oil recovery increases due to decrease in salinity of the reservoir.
(Jadhunaiidan 1990)	Sandstone	Wettability alteration	Increase in oil recovery by LSWF and lowest residual oil saturation due to intermediately wet systems.
(H. Yildiz & Morrow, 1996)	Sandstone	Wettability alteration	Wettability changes occur due to rock-brine interactions.
(G. Q. Tang et al., 1997)	Sandstone	Wettability alteration	A wettability change in the reservoir with transition toward a more water-wet system occurs when the temperature increases.
(G. Tang & Morrow, 1999)	Sandstone	Fines mobilization	To a certain degree, brine chemistry can be blamed for variations in oil recovery with salinity.
(Mcguire et al., 2005)	Sandstone	Saponification	LSWF is very effective at salinity levels of 5000 ppm TDS or less.
(Arnaud Lager et al., 2014)	Sandstone	Cation exchange	When a core is acidified, LSWF loses its effectiveness, which can be explained by cation exchange.
(Zhang et al., 2007)	Sandstone	Cation exchange Wettability alteration	LSWF produced little to no extra oil recovery in mixed-wet cores.
(Loahardjo et al., 2007)	Sandstone	Cation exchange Wettability alteration	Throughout multiple flood cycles, LSWF modifies core characteristics in various ways.
(Seccombe et al., 2008)	Carbonates	Multicomponent Ion exchange	A 40% LSWF is anticipated to be completely effective based on core flood investigations, numerical simulations, and geochemical modeling.
(Boussour et al., 2009)	Sandstone	Multicomponent ion exchange	Through a variety of methods, LSWF affects interactions between oil and rock. For example, organic chemicals adsorb onto the mineral surface, influencing wettability and oil recovery..
(Rezaeidoust et al., 2009)	Sandstone and Carbonates	Wettability alteration Multicomponent Ion Exchange	Salinity can increase water-wetness in carbonate reservoirs, particularly at high temperatures, increasing the effectiveness of oil recovery. The presence of clay minerals in sandstone reservoirs is linked to increased water-wetness.
(Austad et al., 2010)	Sandstone	Wettability alteration Cation Exchange	LSWF, especially in low water-wet circumstances, has demonstrated a notable increase in oil recovery of up to 75% in laboratory trials.
(Alotaibi et al., 2010)	Carbonates	Wettability alteration	Because aquifer water has a lower contact angle (TDS 5436 ppm) than formation water (TDS 54,000 pm), oil recovery is improved.
(Cissokho et al., 2010)	Sandstone	Cation exchange Temperature raise	Temperature affects oil recovery, which happens even in the absence of divalent ions in the low-salinity brine.
(Wang & Alvarado, 2016)	Sandstone	Interfacial effect.	Since low-salinity brine suppresses capillary hysteresis at low temperatures, the LSWF effect can still be present even when there is no change in wettability.

(Yousef et al., 2011)	Carbonates	wettability alteration	Dilution is essential for improving oil recovery.
(Nasralla et al., 2011)	Sandstone	Cation exchange Wettability alteration	When LSWF is used in the secondary mode, oil recovery increases; however, no further recovery is shown in the tertiary mode.
(Sandengen et al., 2011)	Sandstone	Wettability alteration Ion exchange	When LSWF changes wettability toward a more oil-wet system, it may result in a decrease in oil production.
(Fjelde et al., 2012)	Sandstone	Wettability alteration Cation exchange	With LSWF, oil production can continue for a long time.
(Romanuka et al., 2012)	Carbonates	Wettability alteration	Reducing the brine's ionic strength in carbonate reservoirs can improve oil recovery.
(Suijkerbuijk et al., 2013)	Sandstone	Wettability alteration Expansion of the double layer	LSWF changes the system's wettability to become more water-wet, however this process takes longer.
(Mahani, Keya, Berg, et al., 2015)	Carbonate	Wettability alteration	The wettability changes to a more water-wet state when the salinity drops.
(Mahani, Keya, & Berg, 2015)	Carbonate	Wettability alteration Mineral dissolution	The electrostatic interactions between the crude oil and the rock are what cause the low-salinity effect, which happens even when there is no mineral dissolution.
(Ouden et al., 2015)	Carbonate	Wettability alteration Mineral dissolution	LSWF works because calcite dissolution raises the salinity of the injected brines.
(Sandengen et al., 2016)	Sandstone	Osmosis	Osmosis, not changes in wettability, is the main cause of the increase in oil output.
(Fredriksen et al., 2016)	Sandstone and Carbonates	Osmotic pressure	There are several mechanisms at play since the low-salinity effect is not always seen in the same circumstances.
(Xie et al., 2018)	Carbonate	Increased pH Wettability alteration.	pH levels affect the contact angle and the wettability of the oil-rock-brine system, which in turn affects oil recovery.
(Nasralla et al., 2018)	Carbonate	Dilution of sea water	Compared to FW or SW, dilution of saltwater can significantly improve oil recovery.
(Chen, Xie, Pu, et al., 2018)	Carbonate	Multicomponent ion exchange pH increase	During LSWF, multicomponent ion exchange causes the pH to rise, particularly when basal-charged clays are present. This causes the system to become more water-wet.
(Chen, Xie, Sari, et al., 2018)	Carbonate	Wettability alteration Increased pH	The surface chemistry of oil-brine interfaces and wettability are fundamentally influenced by dilution, which causes an oil wet system at a lower pH.
(H. Sharma & Mohanty, 2017)	Carbonate	Wettability alteration Mineral dissolution	A key factor in determining the change in wettability is mineral dissolution.
(Alhammadi et al., 2018)	Carbonate	Wettability alteration Micro-dispersion formation	The creation of micro-dispersions, which are impacted by the interaction between brine molecules and polar components in crude oil, is the main factor driving further oil recovery.
(Saikia et al., 2018)	Carbonate	Wettability alteration	The interfacial energy between the rock surface and the aqueous brine solution, pH, and the isoelectric point of the rock surface all affect how wettable carbonate reservoirs are.

The processes of low-salinity EOR are controversial because of the complex and dynamic interactions between crude oil, rock surface and brines. Under reservoir conditions (pH ~5), clay minerals adsorb protonated and acidic parts of crude oil, along with divalent cations like Ca^{2+}. Injection of low salinity encourages Ca^{2+} desorption, increasing local pH and causing organic matter desorption, enhancing rock wettability and improving oil recovery (Romero et al., 2013). Adsorption characteristics depend on clay type (Romero et al., 2013).

Mohammed et al. (2015) created a 3D field-scale simulation demonstrating that multi-component ion exchange increases oil recovery by causing wettability alteration making the rock water-wet. Simulation showed LSWF performs better than high-salinity flooding, with a maximum recovery of 71% and 75% if performed early. Best ion concentrations were Ca^{2+} (450 ppm), Mg^{2+} (221 ppm), and Na^{+} (60 ppm).

Increased reservoir temperature also increased recovery, and the best candidates are high-temperature sandstone reservoirs for LSWF (M. Mohammed & Babadagli, 2015).

Principal controlling mechanisms of LSWF are mobilization of fines, alteration of wettability, temperature, pH, ion exchange, dissolution of minerals, and osmosis. This review covers suggested mechanisms and their strengths and limitations, contrasts secondary and tertiary LSWF, and emphasizes the significance of surface forces and interactions between rocks and fluids in wettability. Oil recovery mainly depends on the crude brine-oil-rock interaction, and clay type plays an important role. Maximum recovery requires optimal salinity to be determined in laboratories and sustained in fields (Mahmud et al., 2020) (Sheng, 2014).

Mechanisms of LSWF in Different Types of Reservoirs

Whether in sandstone or carbonate reservoirs, till date there is no clear consent on the dominant mechanisms behind LSWF, as multiple factors influence its effectiveness. The key mechanisms driving oil displacement in LSWF include fine particle migration, MIE, expansion of the EDL, and pH alterations (Andrews et al., 2023).

Fines migration

Fine-grain migration was first proposed in 1999 (Jadhunandan et al., 1995). The movement of fine particles from the rock surface can alter its wettability, making it more water-wet, as shown in Fig. 1. Additionally, these particles may block high-permeability channels, improving water sweep efficiency and enhancing oil recovery.

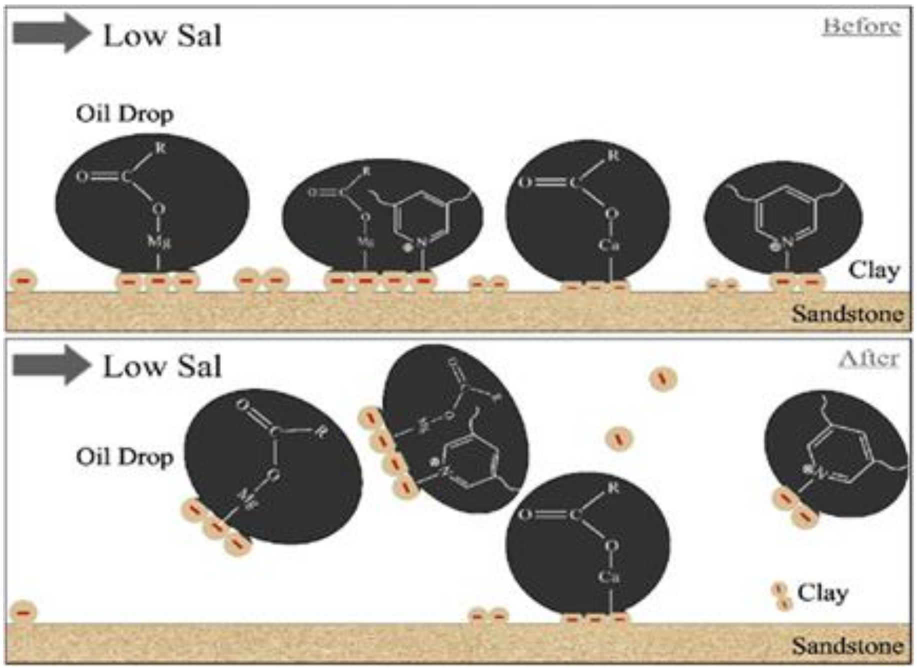

Figure 1. Effect of clay fine migration on recovery improvement by LSWF (Andrews et al., 2023)

MIE and EDL Expansion:

Calcium carbonate, which is positively charged in carbonate reservoirs, attracts negatively charged crude oil carboxyl groups and induces oil-wet conditions. Low-salinity water flood decreases surface charge and diminishes this attraction, thereby increasing oil recovery (Selem et al., 2022) (Soleimani et al., 2021).

In high-salinity reservoirs, a thin double layer immobilizes oil in between clay particles. Decreased salinity widens this layer, and sodium ions substitute divalent cations, enhancing water wettability and liberating immobilized oil (Brady & Krumhansl, 2012) (Zivar et al., 2022).

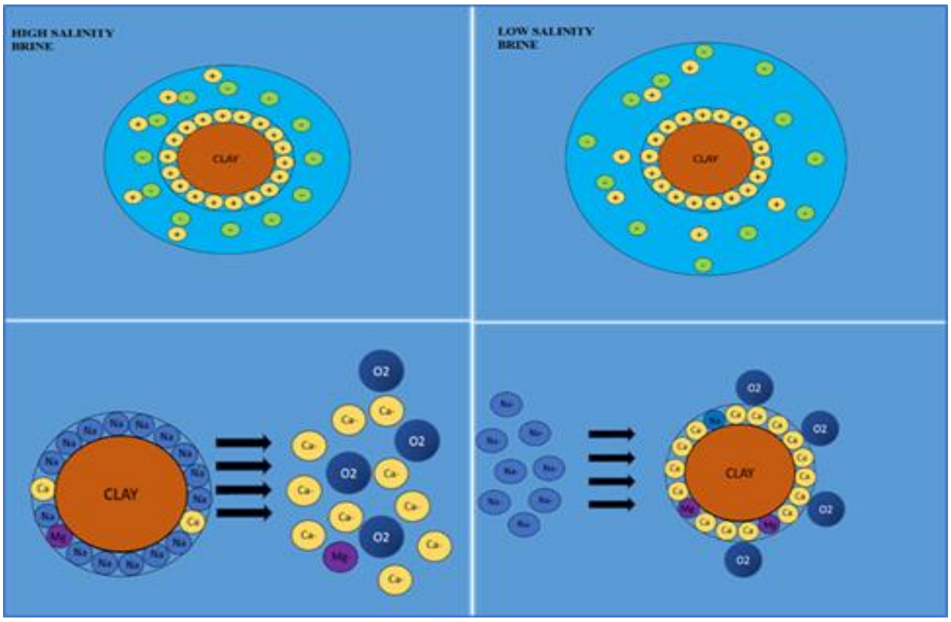

Figure 2. Effect of salinity on electrical double layer (Zivar et al., 2022)

pH effects

In sandstone reservoirs, an increase in local pH at the clay-water interface causes the desorption of organic matter from the clay surface, leading to improved water wettability and enhanced oil recovery (Hosseini et al., 2021).

Wettability alteration in Oil Reservoirs due to low salinity water

Studies show that diluting injection water, especially seawater, significantly alters wettability, reducing contact angle and improving permeability. Hosseini et al. examined various water types in an Iranian oil reservoir, finding that diluting seawater to 2000 ppm had the greatest effect, reducing contact angle by 100° and increasing recovery by 71%. Further analysis explored ion exchange by substituting sulfate with phosphate (Zivar et al., 2022) (Elakneswaran et al., 2021).

Impact of LSWF on Wettability Alteration by Capacitance Resistance Model

LSWF drastically changes reservoir rock wettability. The Capacitance Resistance Model (CRM) measures this by correlating injection and production data with fluid flow resistance. Zivar et al. (2022) examined wettability impacts on CRM's time constant through CMG-GEM simulations and core flooding data. Findings indicated that as wettability changes from oil-wet to mixed-wet and finally to water-wet, time constants rise, indicating enhanced recovery. Snosy et al. (2022) validated this trend, emphasizing CRM's suitability in evaluating wettability alteration (Zivar et al., 2022) (Snosy et al., 2022).

Impact of Modified Salinity Water Flooding in Oil Reservoirs

By precisely adjusting the salinity and ionic makeup of the injected water, Modified Salinity Water Flooding (MSWF) enhances oil recovery. Three models that connect fluid flow, hysteresis, and wettability variation in porous media were put forth by Hosseini et al. in 2021. Experimental results showed that MSW injection increased capillary and relative permeability hysteresis, modeled using Carlson and Killough methods. MATLAB-based simulations with Schlumberger ECLIPSE 100 analyzed salinity effects under varying water saturations. Wang & Alvarado (2016) found that low-salinity brine increases water wettability, leading to oil trapping. Muhammad et al. (2022) demonstrated that prolonged MSW injection in transition zones improves oil recovery and reduces water-cut (Hosseini et al., 2021) (Zhang et al., 2007) (Wang & Alvarado, 2016) (Muhammad et al., 2022).

Impact of Salinity and Kaolinite in LSWF of Sandstone Reservoirs

In sandstone reservoirs, the impact of kaolinite and salinity on LSWF is essential for improving oil recovery. LSWF shifts wettability to water-wet via altering ionic interactions and upsetting the EDL. Muhammad et al. (2022) modeled LSWF in the Sabah Basin with ECLIPSE 100 and Petrel, evaluating salinities between 100 and 500 ppm. The maximum oil recovery (17.78 MMSTB) at 100 ppm and 17.00 MMSTB at 500 ppm, which verifies that reduced salinity increases recovery. Indirect mobilization of oil was achieved by the composition of clays, while residual oil and irreducible water saturation were boosted by compaction (Muhammad et al., 2022) (Hosseini et al., 2021).

Impact of Surface Charge on Wettability Alteration of Oil Reservoirs

A key step in improving oil recovery is wettability change, which is greatly influenced by the charge on the rock surface. In oil-wet rocks, rock surfaces bearing positive charges tend to be attracted to negatively charged crude oil constituents. Elakneswaran et al. (2021) came up with a coupled model incorporating interface properties into solute transport to model low salinity water flooding in sandstone and carbonate reservoir rocks. With IPhreeqc, the model explained ionic transport, mineral dissolution/precipitation, two-phase flow and electro-kinetic properties. It effectively predicted pH, oil recovery, wettability index, and ionic profiles. The model was tested against PHREEQC and experimental data and was found to be effective in optimizing brine composition for oil recovery improvement (Elakneswaran et al., 2021) (Romero et al., 2013) (Elakneswaran et al., 2021).

Numerical Simulation studies in LSWF

Numerical simulations are vital in understanding the mechanisms of LSWF and maximizing oil recovery. Stephen et al. (2014) used Eclipse 100 to mimic floods with high and low salinity, and they found that higher Field Pressure (FPR) enhanced Field Oil Production Rate (FOPR) and Field Oil Efficiency (FOE). LSW resulted in reduced water cut and improved volumetric replacement, particularly in water-wet systems. Oil trapped in small pores within oil-wet systems reduces the Fluid Oil Efficiency (FOE). The primary process was identified as the change in wettability to a water-wet state. Additionally, LSW had the lowest fractional water cut (FWCT), which enhanced recovery in general (Arnaud Lager et al., 2014) (Brady & Krumhansl, 2012).

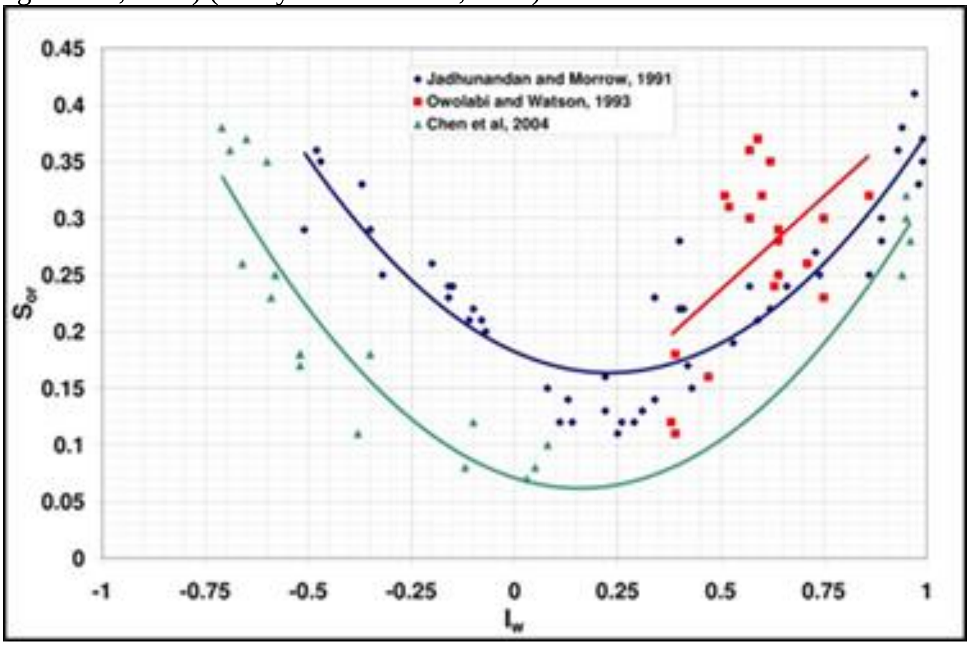

Figure 3. Effect of wettability on residual oil saturation (S_{or})

Impact of Injected Water Salinity and Ion Concentration on Oil Recovery

During Low Salinity Water Flooding (LSWF), the injected water's salinity and ion concentration are critical factors in oil recovery. The impact of iodide, sulfate, and salinity ions on carbonate reservoirs in tertiary recovery was examined by Snosy et al. in 2022. Crude oil (29 API) and Eocene carbonate cores (Egypt) experiments indicated up to 5% extra oil recovery. High sulfate brines enhanced recovery by 1.7–3.8% OOIP, while low sulfate brines had negligible effect (<1% OOIP). Potassium iodide (KI) injection following high sulfate brines contributed 1.7% OOIP recovery, but following low sulfate brines, the effect was small (<0.4% OOIP) (Snosy et al., 2022).

Low-salinity water (LSWI) injection improved oil recovery in Berea sandstones, especially in older cores, as shown by Alagic et al. (2011). Core tests indicated increased recovery with LSWI and LSWI with surfactants. Effluent analysis revealed Mg^{2+} retention in old cores, whereas Ca^{2+} was generated as a result of calcite dissolution. Unaged cores had greater fines migration, which could impact permeability. The study validated the effectiveness of LSWI in old reservoirs and emphasized surfactant advantages while reporting risks to permeability (Alagic et al., 2011) (Alagic et al., 2011).

Low-salinity water flooding lowers core permeability, which helps with mobility management, according to Zeinijahromi et al. (2011). They demonstrated that permeability decline increased sweep efficiency by postponing water breakthrough and lowering water cut using the Dietz model and a particle

detachment model. The study highlights the benefits of fines migration but stresses the need for careful design to balance permeability reduction and flow assurance.(Zeinijahromi et al., 2011).
Brady and Krumhansl (2021) demonstrated that a temperature-dependent surface complexation model influences petroleum adhesion on oil–water–kaolinite interfaces. Their research showed that while carboxylic acid groups were unaffected by the deprotonation of nitrogen bases, it did lower the pH at the oil-water interface as the temperature rose. Results indicated that low-salinity water flooding enhances oil-kaolinite adhesion, highlighting the need to balance flow assurance with permeability reduction when designing LSWFs (Soleimani et al., 2021).
Within the framework of Berea core flooding studies, Hadia et al. (2013) examined the impact of rock wettability on oil recovery. When wettability changed from water- to neutral-wet, observations showed increased oil recovery; however, when wettability changed to oil-wet, recovery was lost. The use of LSWF boosted recovery over the high salinity case, characterized by enhanced pressure drop and lesser permeability, emphasizing the involvement of wettability change in the effectiveness of LSWF (Hadia et al., 2013).
Romero et al. (2013) investigated water–rock interactions in Berea sandstone using single- and two-phase experiments. Low salinity water injection indicated comparable pressure and pH behavior in undamaged cores, incremental oil recovery in both undamaged and damaged cores, and favorable reservoir conditions for LSWF (Romero et al., 2013).
Aladasani et al. (2014) performed statistical analysis and simulation to evaluate LSWF recovery sensitivities in sandstone. There were strong correlations between chlorite content and residual oil saturation, while kaolinite and wettability index had smaller effects. Simulation indicated oil recovery as a function of initial wetting states, where capillary pressure controlled recovery in weak water-wet states and IFT reduction increased recovery in strong water-wet states. The complexity of predicting LSWF performance is highlighted in this study, as well as the importance of detailed reservoir characterization (Aladasani et al., 2014).
Sheng (2014) researched LSWF mechanisms, history, laboratory, and field observations, verifying its advantages and calling for more optimization in the oil industry (Sheng, 2014) .

Al-Shalabi et al. (2020) simulated LSWF and CO2 injection in carbonate cores. Using SWAG with low-salinity water maximized oil recovery while reducing the amount of injected solvent needed, resulting in the highest tertiary recovery factor and the lowest utilization factor. The work emphasizes the prospect of hybrid recovery techniques and the importance of accurate injection control (Mahmud et al., 2020) .
Kim and Lee (2017) used sand core samples to investigate how the type and content of clay affected the relative permeability in LSWF. Relative permeability curves depended on kaolinite content, and Honarpour's equation was extended to model permeability in kaolinite-rich reservoirs. The work forms a basis for explaining mineralogical influence on oil recovery (Kim & Lee, 2017).
Etemadi et al. (2022) constructed 2D models to investigate LSWF mechanisms in sandstone reservoirs. They found that the MIE approach more accurately depicted low salinity conditions, where wettability change was initiated by cation exchange. The study increases the realism of reservoir simulations (Muhammad et al., 2022).
Using silicon-wafer micromodels, Fredriksen et al. (2016) visualized pore-scale oil mobilization in LSWF, focusing on water transport via osmosis and diffusion. They observed that film extension through water-wetness and osmosis gradients enabled oil displacement. This paper offers fundamental microscopic findings for waterflooding design optimization (Fredriksen et al., 2016).
Injection Strategies of Smart Water
Smart Water injection optimizes oil recovery by altering brine chemistry to enhance rock wettability. In a high-temperature sandstone reservoir, Aghaeifar et al. (2018) discovered that low salinity brine functioned as Smart Water, producing 33.5% OOIP additional oil in secondary recovery and 11.8% in tertiary recovery. pH changes confirmed wettability shifts, highlighting the efficiency of early Smart Water implementation (Aghaeifar et al., 2018)(Selem et al., 2022).
Shaddel et al. (2014) investigated how fluid/rock and fluid/fluid interactions affected oil recovery, emphasizing the part surface chemistry plays in capillary pressure, wettability, and relative permeability (Gbadamosi et al., 2022). The experiments involved low-salinity water injection, core repair, and early formation brine flooding until a plateau of recovery. Seawater that had been diluted 10 and 100 times, as well as a variation that eliminated crude oil and divalent ions, served as the injection fluid. The results showed that the low-salinity water effect required altering the rock surfaces to a water-wetter state, but

that oil relative permeability and acid number were unrelated (Shaddel et al., 2014) (Gbadamosi et al., 2022).

Impact of Low Salinity Water Composition

Shabib-Asl et al. examined the Berea sandstone wettability alteration by employing brines with various ion contents (KCl, NaCl, $CaCl_2$, $MgCl_2$ and formation water) and salinity (500–6500 ppm, with formation water at 13,000 ppm). Thirty-one core slabs were saturated in formation water, aged in crude oil at 80°C and subsequently put into various brines. The wettability alteration was most affected by K^+ from 1120 to 62.230, with weaker impacts by Na^+, Ca^{2+}, and Mg^{2+}. This study highlights the significance of ionic content in LSWF, which may suggest that specific ions, such K^+, can improve wettability and oil recovery. This has significant ramifications for the best brine design for the use of enhanced oil recovery procedures (A. S. Mohammed et al., 2014).

Advances of a Microfluidic Method to study EOR by LSWF

Microfluidic techniques have become a valuable tool for studying improved oil recovery, particularly LSWF. These glass or silicon-based devices replicate reservoir pore structures, allowing real-time observation of brine-oil-rock interactions.

Important elements like injection rate, flood volume, micromodel structure, age, oil type, and brine composition were examined in a study by Saadat et al. (2020). The results showed that while low-salinity brine produced higher oil recovery than high-salinity brine, larger injection rates promoted emulsification. However, recovery was adversely affected by elements such as age, initial brine saturation, and the presence of divalent ions. This research successfully developed a reproducible microfluidic flooding process, demonstrating up to a 2% improvement in oil recovery at the tertiary stage.(Saadat et al., 2020) (Awad et al., 2020) (Saadat et al., 2020).

2. Conclusions, Critique and Recommendations

Numerous investigations of LSWF have been carried out by large oil companies and research institutes over the past 20 years. These studies include well-to-well pilot testing, SWCTTs, and laboratory core floods for tertiary recovery. According to all of the results, low salinity water injection increases oil recovery even in carbonate reservoirs by lowering water permeability and increasing oil relative permeability. The driving mechanisms of such changes in permeability vary depending on different conditions of the reservoir.

Low salinity water fractions are linked to greater hydrocarbon saturation in sandstone reservoirs, which make them good exploration targets and increase recovery rates. Lower water saturation indicates a higher proportion of hydrocarbons within the pore space, increasing the potential of the reservoir. LSWF helps to determine hydrocarbon-rich areas in carbonate reservoirs by affecting mineral dissolution and fluid flow and providing additional reservoir behavior insights.

A clear idea of LSWF in the reservoirs is needed to best optimize drilling and production plans. Of all mechanisms, wettability alteration proves to be paramount under all the conditions. It is also learned from studies that LSW efficiency is greatly governed by wettability. This means that LSW's mechanism of wettability alteration becomes more efficient when applied to water-wet formations than in the case of mixed-wet ones.

Future study on the fundamentals of how LSW alters wettability in carbonate reservoirs has a lot of potential. Field deployment of laboratory-scale data could enhance oil recovery techniques and maximize reservoir performance.

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CRediT authorship contribution statement

Prasenjit Talukdar: Conceptualization, Formal analysis, Supervision; Bondita Robidas: Writing - Review & Editing; Prasun Banik: Writing - Original Draft, Writing - Review & Editing; Bhaskar Jyoti Saikia: Formal analysis and Writing - Review & Editing; Ishan Baruah: Studying, Writing - Original Draft, Writing - Review & Editing; Irshad Akter: Writing - Original Draft, Writing - Review & Editing.

Declaration of competing interest

The authors state that none of the work described in this study could have been influenced by any known competing financial interests or personal relationships.

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